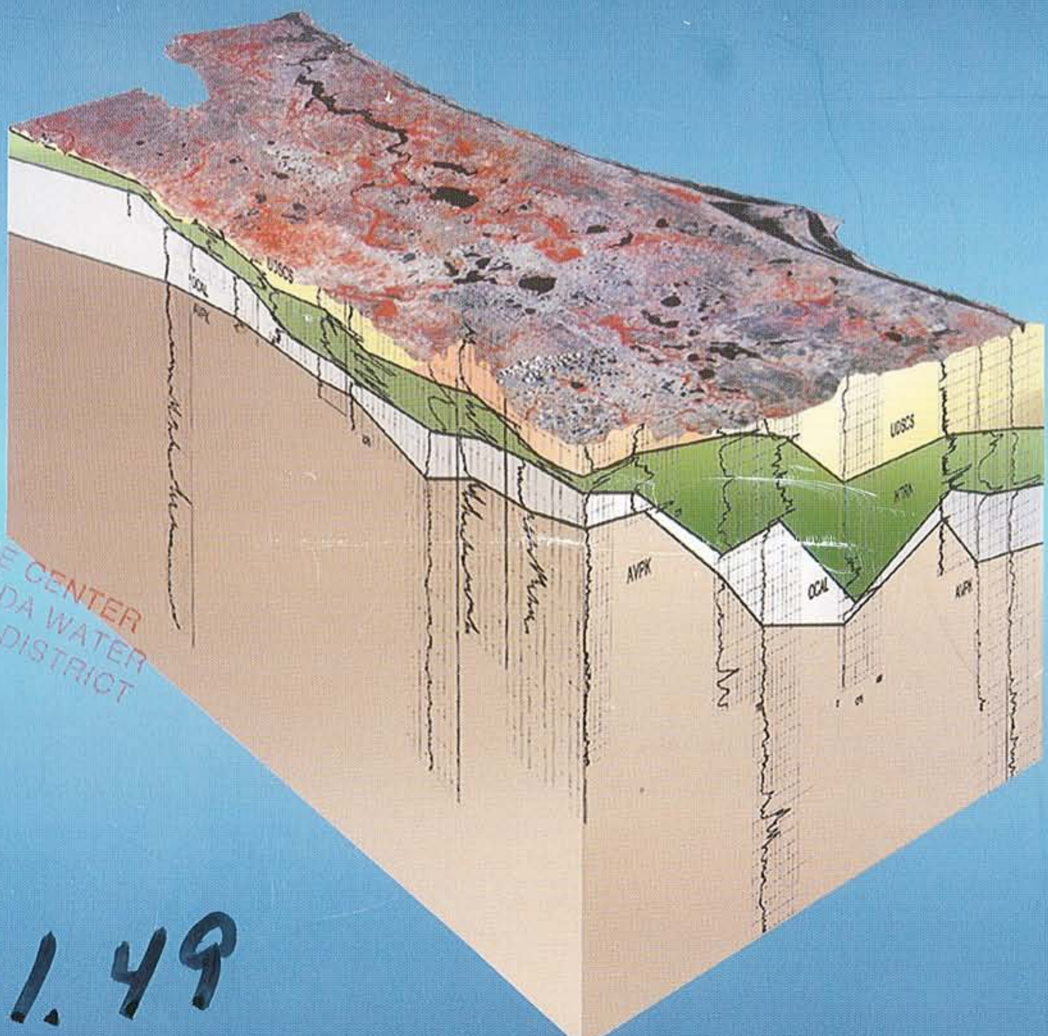
Guidebook to the Correlation of Geophysical Well Logs within the St. Johns River Water Management District



FLORIDA GEOLOGICAL SURVEY
SPECIAL PUBLICATION NO. 50

Published in cooperation with the
St. Johns River Water Management District

METRIC CONVERSION FACTORS

To eliminate duplication of parenthetical conversion of units in the text of reports, the Florida Geological Survey has adopted the practice of inserting a tabular listing of conversion factors. For readers who prefer metric units to the customary U.S. units used in this report, the following conversion factors are provided.

MULTIPLY	BY	TO OBTAIN
inches	25.4	millimeters
feet	0.3048	meters
miles	1.609	kilometers

ABBREVIATIONS USED IN THIS REPORT

FGS — Florida Geological Survey

SJRWMD — St. Johns River Water Management District

USGS — U.S. Geological Survey

MSL — Mean Sea Level: Sea Level refers to the National Geodetic Vertical Datum of 1929 — a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929." Mean sea level provides a consistent and corellatable datum for referencing elevations of geologic strata.

BLS — Below Land Surface, a depth expressed in feet in this report. Land surface, (or some point slightly above land surface) is the typical datum upon which well logs are based. Since land surface elevations vary considerably with topography, the depth below land surface at which a geologic marker lies does not provide a correlatable datum for constructing cross sections. Mean sea level provides the only constant statewide datum for such correlations.

To convert depths below land surface (BLS) to depths relative to mean sea level (MSL), subtract the depth BLS from the land surface elevation. *For example*: a very high gamma peak representing the top of the Hawthorn Group occurs on a log at 100 feet BLS. The land surface elevation at the well is 120 feet MSL. To find the elevation of the gamma peak relative to mean sea level, subtract 100 feet from 120 feet, which equals 20 feet, or 20 feet above mean sea level. If the depth to the top of the Hawthorn Group is greater than the depth to mean sea level, the resulting MSL value is negative, or below mean sea level.

Cover illustration compiled by Frank Rupert from U.S. Geological Survey false color satelite image (1989) and gamma log cross sections developed during this study. It is provided for illustrative purposes only, and no geospatial accuracy is implied or intended.

STATE OF FLORIDA

DEPARTMENT OF ENVIRONMENTAL PROTECTION
David B. Struhs, *Secretary*

DIVISION OF RESOURCE ASSESSMENT AND MANAGEMENT
Edwin J. Conklin, *Director*

FLORIDA GEOLOGICAL SURVEY
Walter Schmidt, *State Geologist and Chief*

SPECIAL PUBLICATION NO. 50

GUIDEBOOK TO THE CORRELATION OF GEOPHYSICAL WELL LOGS WITHIN THE ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

by

Jeff Davis, Richard Johnson, Don Boniol and Frank Rupert

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LETTER OF TRANSMITTAL

FLORIDA GEOLOGICAL SURVEY

Tallahassee, Florida
2001

Governor Jeb Bush
Tallahassee, Florida 32301

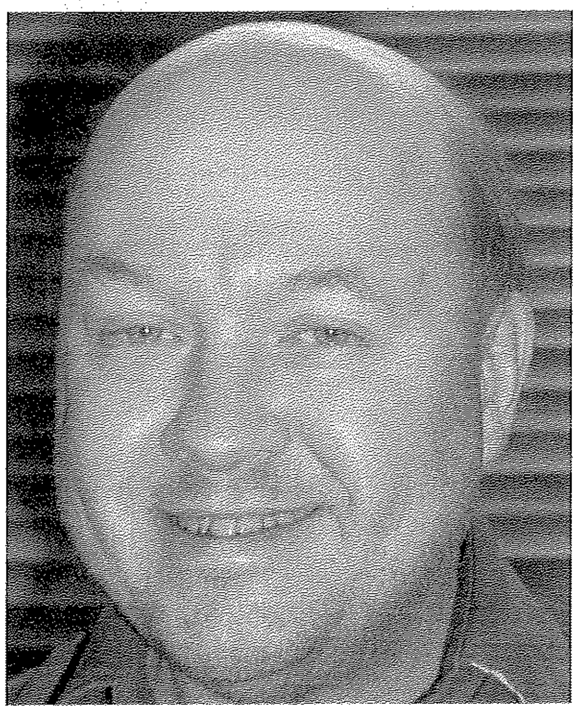
Dear Governor Bush:

The Florida Geological Survey, Division of Resource Assessment and Management, Department of Environmental Protection, is publishing as Special Publication No. 50, *Guidebook to the Correlation of Geophysical Well Logs Within the St. Johns River Water Management District*, prepared by Jeff Davis and Don Boniol of the St. Johns River Water Management District and Survey staff geologists Richard Johnson and Frank Rupert. The publication describes a correlation between geophysical well logs and geology within the St. Johns River Water Management District. This information will be useful for citizens such as water well drillers and environmentally conscious persons as well as municipal, county, state and federal agencies in interpreting the natural geological and hydrological environments of northeastern Florida.

Respectfully,

Walter Schmidt, Ph.D.
State Geologist and Chief
Florida Geological Survey

This work is dedicated to Richard Alan Johnson, 12/09/1949 – 5/27/2000,
coauthor, colleague, and friend.



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GUIDEBOOK TO THE CORRELATION OF GEOPHYSICAL WELL LOGS WITHIN THE ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

by

Jeff Davis, PG No. 844, Richard Johnson, Don Boniol and Frank Rupert

INTRODUCTION

The St. Johns River Water Management District (SJRWMD) maintains a database of over 2,500 wells that have geophysical logs in digital format. The Florida Geological Survey (FGS) also maintains a database of lithologic descriptions of wells throughout the State of Florida. Many of the lithologic logs have geologic contacts identified. Prior to this study, few of the SJRWMD geophysical logs had been correlated to the corresponding lithologic logs or to neighboring wells. It was apparent to geological staff at both agencies that such correlations, along with identification of distinct and recognizable log signatures for the different lithologic units, would serve as an extremely useful tool in subsurface hydrogeological investigations within the SJRWMD.

This guidebook identifies the correlation of geophysical well logs (natural gamma and electric logs) within the SJRWMD. The correlations were documented through a comprehensive review of existing well log data and literature. Typical natural gamma log signatures for geologic units in the SJRWMD have been recognized by Johnson (1984), Miller (1986), Scott (1988a), Duncan et al. (1994) and Green et al. (1995). Geophysical logs are presented in cross sections and individual figures to serve as *reference logs* for correlation purposes. These *reference logs* exhibit a characteristic log response that can be identified in other logs. Additionally there is sufficient lithologic data available to identify specific geologic units.

This study includes the geophysical log characterization and correlation for the entire SJRWMD and encompasses all the geological units commonly penetrated by water wells. The major geologic units considered in this report include the following Cenozoic strata: Paleocene Cedar Keys Formation; the Eocene Oldsmar Formation, Avon Park Formation, and Ocala Limestone; the Oligocene Suwannee Limestone; the Miocene Hawthorn Group; and the various Pliocene, Pleistocene, and Holocene formations. These units are discussed in detail in the Stratigraphy section.

Reference logs are identified to establish an objective standard for geophysical correlations of spatially separated well logs, much as a type section is used as a geologic formation reference. A *reference log well* has lithologies that exhibit characteristic geophysical log responses. Additionally, there is sufficient information to identify a number of formations in the well. Ideally, a *reference log* would have cores or cuttings described by a geologist and have a basic geophysical log suite consisting of natural gamma, normal electric and caliper logs.

Other wells may not have a lithologic description but do have a geophysical log which can be correlated to a *reference log*. Such a well log is designated as a *correlated log*. Since there is limited lithologic data, fewer geologic units may be identified in a *correlated log*. A database of *correlated logs* is currently being developed based on the *reference logs* identified in this report. Primarily, *reference logs* were used in the construction of a series of geological cross sections

(Appendix A). These cross sections provide a reference framework for correlation of logs from other sites throughout the SJRWMD. Appendix B presents a table with attributes of the *reference logs* that identify which lithologic log was used for geologic unit identification, geologic unit boundaries, location, and other pertinent information. The cross sections and tables do not include geologic contacts for the Pliocene, Pleistocene, and Holocene sediments. The log response to individual units within these post-Miocene sediments is too variable to identify consistently recognizable log signatures.

The guidebook is intended to be used as a field tool during drilling and logging operations, as well as to establish a documented basis (metadata), for the geologic units in the SJRWMD Geographic Information System data sets. It will also provide citizens and professionals with interpretations of geophysical log response (primarily natural gamma and electric normal resistivity) correlated with stratigraphy and lithology of the subsurface formations that can be applied to both well site planning and technical hydrological and geological research.

METHODS

A review of geophysical and lithologic data on file at SJRWMD and FGS identified 180 *reference logs*. Identification of wells with sufficient log data to be a *reference log* involved a review of geophysical and lithologic data on file at the SJRWMD and FGS data repositories. These data are accessed and displayed using GeoSys software (Arrington & Lindquist, 1987) and are available on the FGS website. The digital files for the geophysical data were obtained by real time acquisition using SJRWMD logging equipment or by digitization of existing analog files, logs in published literature (Appendix C), and logs that were provided by private well logging companies and other agents. The lithologic logs used for this report were chosen for completeness and reliability of description. Geophysical logs were used to determine the elevation of the geologic boundary. In some cases, both a lithologic log and geophysical log were not available for a well. In these cases a nearby well with a reliable lithologic log was used to confirm the geologic units.

Geophysical logs from eighteen reference wells were chosen to demonstrate typical log signatures throughout the SJRWMD. The location of these wells is shown in Figure 1. Variations in the absolute value of a natural gamma log response to a particular rock type will occur depending on borehole conditions, scaling units (counts per second [cps], American Petroleum Institute [API]), and probe design. To establish as much consistency as possible, the logs used to show typical signatures were first normalized by dividing each value by the maximum value in the log and multiplying by 100. In this way all logs plot on a 0 to 100, unitless scale. The gamma logs for these wells were then color coded to delineate relative gamma ray intensity based on a four interval system to provide consistency in descriptions. This system is similar to oilfield techniques of calculating a gamma ray index to identify a baseline value to end member lithologies (Dresser Atlas, 1975). While oilfield applications work best using the end members of sand to shale, a pure limestone to clay and phosphate range is more applicable to the SJRWMD.

Delineation of intensity zones is used to standardize and simplify descriptions of gamma ray response to various lithologies. The gamma intensity produced from pure limestone is herein described as *low intensity*. The gamma intensity produced from the clays and phosphates is described as *high intensity*. Between the *low intensity* and *high intensity* zones, *low moderate*

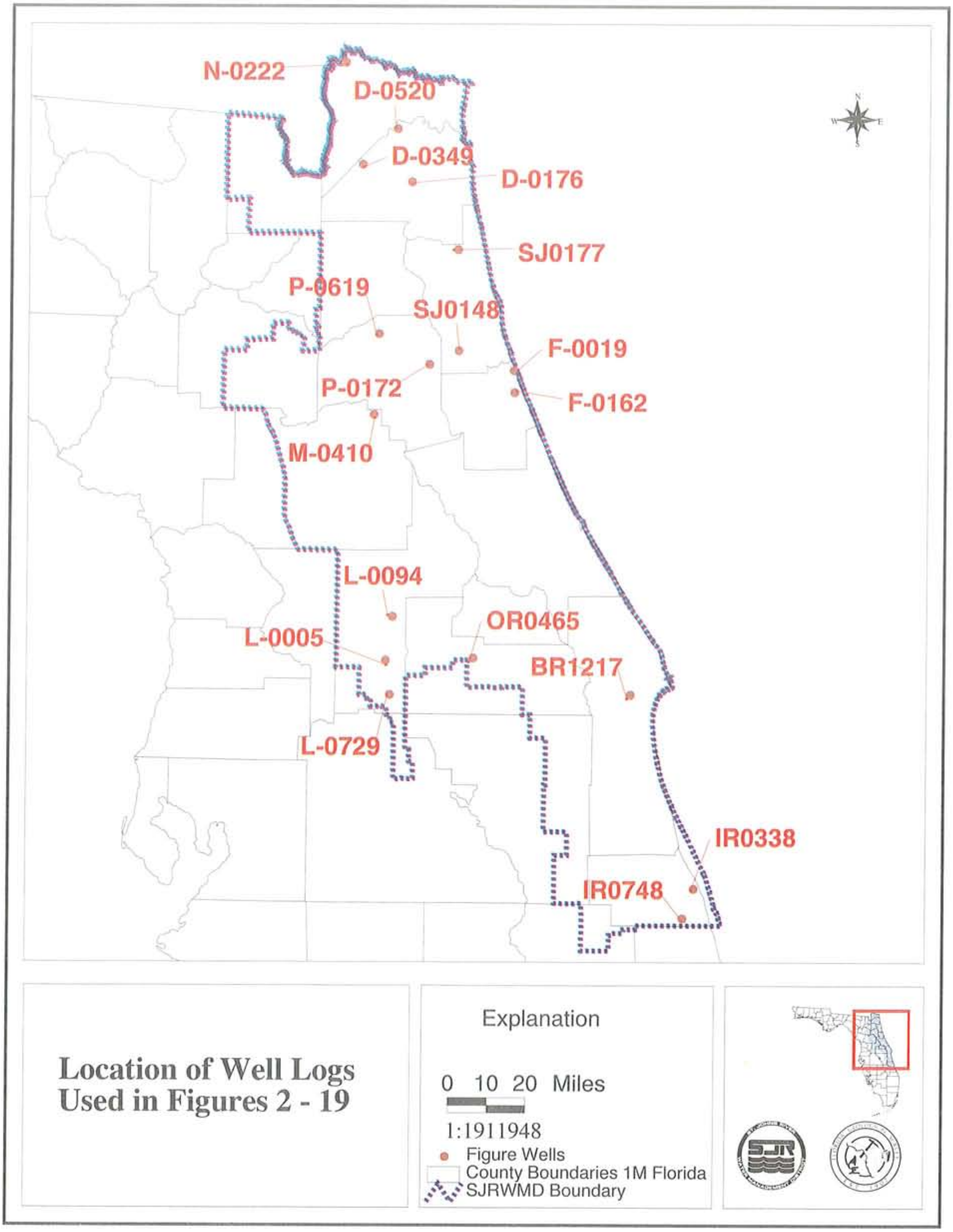

Figure 1. Locations of wells used in Figures 2 - 19.

intensity and *high moderate intensity* terms are used. The differentiation between *low moderate intensity* and *high moderate intensity* can help distinguish clean sands and dolostones from lithologies such as organics (peat, lignite) and dolostones that contain accessory minerals with higher radioactivity. Units containing anhydrite, glauconite, or chert may also be represented in these *moderate intensity* zones. Though the boundaries between geologic units often are marked by a recognizable change in gamma ray intensity, other factors should be considered when evaluating geologic unit boundaries.

Eocene carbonates show the lowest intensity gamma peaks of the Tertiary formations in Florida. A detailed description of these units is presented in the Stratigraphy section of this report. The *low intensity* baseline is defined by the maximum value of the lowest intensity zone within the Ocala Limestone. For example, the Ocala Limestone occurs in well BR1217 from a depth of 116 to 244 feet BLS (Figure 2). The gamma intensity is less than 7 for the entire Ocala Limestone section. In this case the *low intensity* baseline is drawn at 7 and all values less than seven are colored light blue. The high baseline is drawn on the mean value recorded in the Miocene Hawthorn Group, which occurs at a value of 30 in Figure 2. In this example, everything above a value of 30 is considered as *high intensity* and colored orange. The *low moderate intensity* zone is determined from the median value for the Eocene carbonate section. In Figure 2, the *low moderate intensity* zone extends from the *low intensity* baseline up to a line positioned at the median value of the underlying Eocene carbonate peaks (at a value of approximately 12). The *high moderate intensity* zone extends from this line up to the *high intensity* baseline and includes the highest peaks within the Eocene carbonate section.

In certain cases, the units within the Ocala Limestone range from *low intensity* to *high moderate intensity*. For the well L-0729 (Figure 3), only the zone from about 100 to 140 feet BLS is used to define the *low intensity* baseline. This log also contains peaks present in the Eocene section that are near the same magnitude as the peaks in the Miocene section. In this log the mean value is 26 for the Miocene section, and is used to define the *high moderate* to *high intensity* boundary. These intensity designations are used as a consistent method to describe gamma log intensity and assist with correlation between logs based on relative gamma ray intensity. These descriptive terms are used in this report for the gamma log cross sections that are presented in Appendix A but are not color coded.

Additional descriptive terms are used to describe a characteristic gamma response to lithologic changes within a specific interval. For strata where thin interbeds produce a series of high and low peaks within a short depth interval, the term "uneven" is used. An example of this can be seen in Figure 2, well BR1217 in the interval from 2,050 to 2,600 feet BLS and in Figure 13, well F-0162 in the interval from 300 to 400 feet BLS. A section of massive, pure carbonate limestone that produces an interval with a relatively flat profile such as seen in Figure 2 (well BR1217 from 1,500 to 1,550 feet BLS) and Figure 11 (well D-0176 from 510 to 650 feet BLS) is defined as "even" intensity. The logs shown in the following figures demonstrate this qualitative classification of gamma ray intensity from wells in different counties in the SJRWMD.

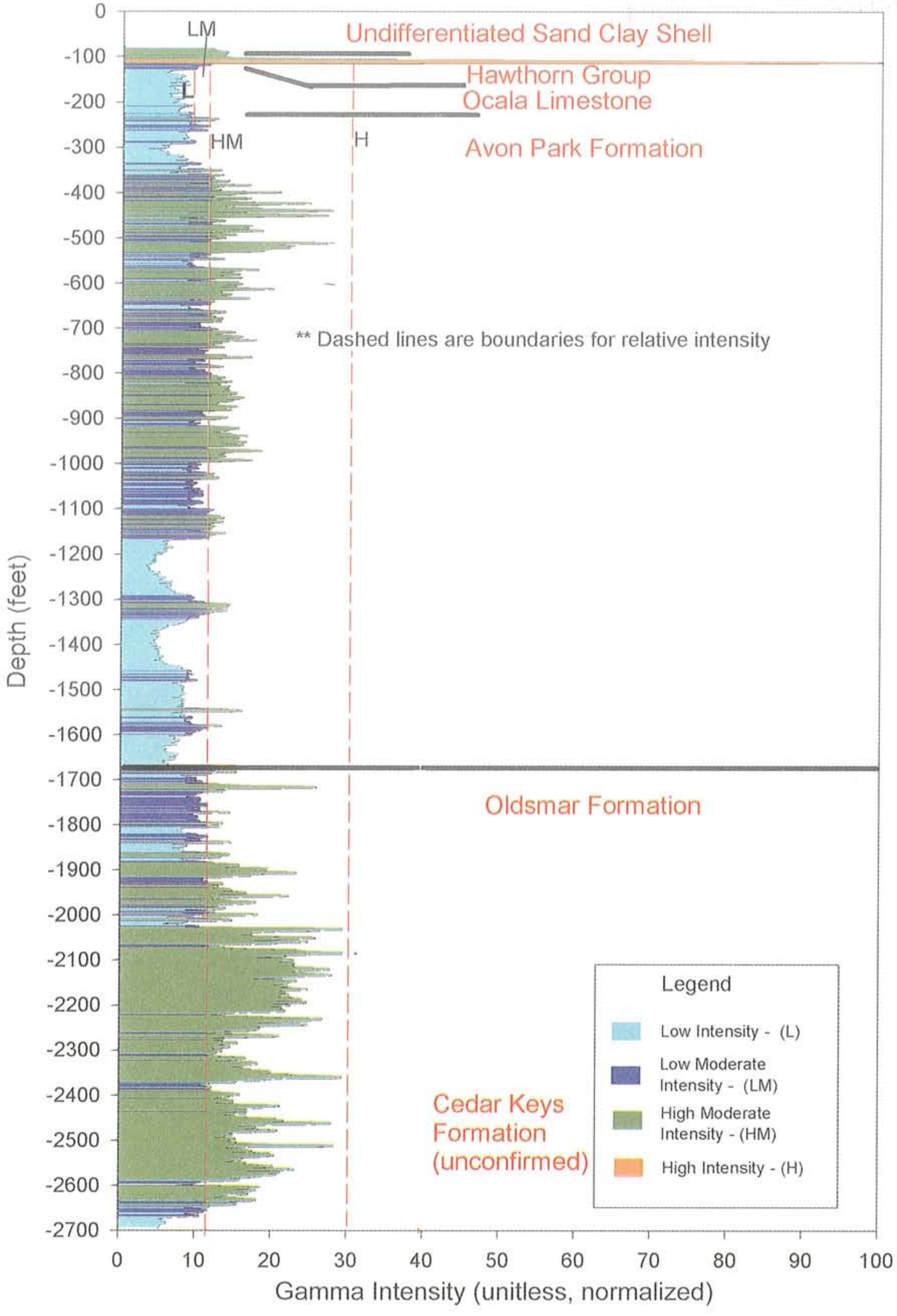

Figure 2. Gamma log of well BR1217, Brevard County.

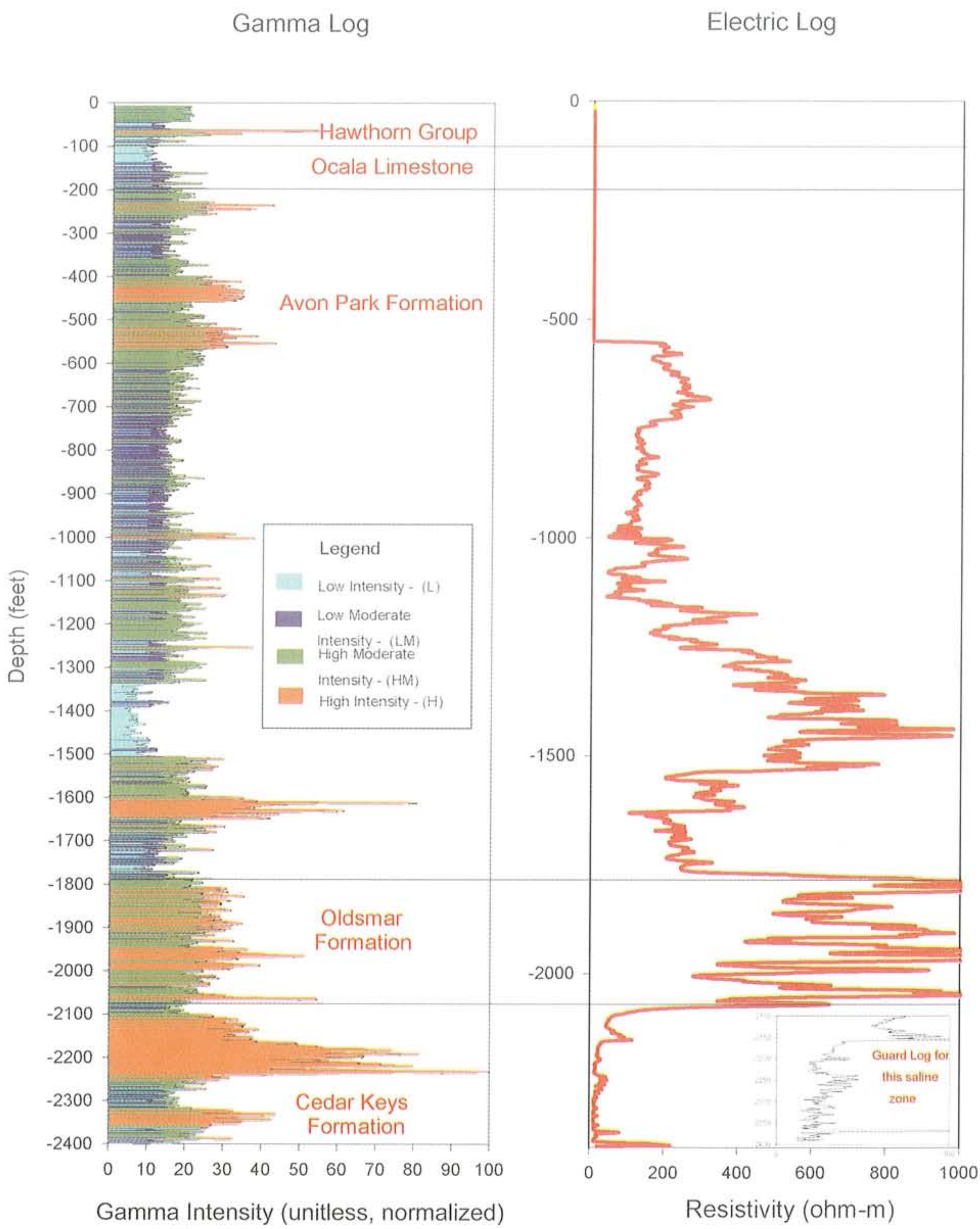

Figure 3. Gamma and Electric logs of well L-0729, Lake County.

GEOPHYSICAL WELL LOGS

Gamma Log

The *gamma log (natural gamma log)* records the naturally occurring gamma photon radioactive intensity in the sediment or rock composing the borehole wall. It is the most widely used nuclear log for groundwater applications (Keys, 1988). In peninsular Florida, this radioactivity predominantly results from inclusions of highly radioactive phosphate grains, from moderately radioactive clay-minerals, and from radioactive organic material or peat. Kwader (1982) discussed the effect on gamma log response from clay minerals and phosphates that are typical of the Hawthorn Group sediments found in Florida.

A gamma log can be run through both metal and plastic casing provided the borehole diameter is not excessive and a minimum thickness of cement grout is in place between the casing and the borehole wall. Additional "strings" of casing also reduce the sensitivity of the gamma log.

Electric Log

In this report the term "electric log" refers to any of the geophysical probes that measure potential differences due to the flow of electric current in and adjacent to a borehole. The predominant type of electric logs available that are most useful for log correlation within the SJRWMD are Single Point Resistance, Long (64") and Short (16") Normal electric logs. These logs are especially useful for identifying lithologic changes in carbonates where the rocks do not contain enough radioactive material to cause changes in the gamma log response. The electric logs can also be used to derive porosity within the sediment or rock surrounding the borehole. Penetration distance into the surrounding lithologic material varies with diameter of the borehole and the type of electric logging tool in use. The penetration is generally the same as the electrode spacing so that 16-inch normal resistivity probes penetrate approximately 16 inches into the borehole wall material.

Porous rocks provide electrical flow pathways through the ground water contained in their interconnected pores, and register as low resistivity on electric logs. Conversely, nonporous (massive) rocks resist electrical current flow, and register as high resistivity. Generally, in peninsular Florida, nonporous massive evaporites are recorded as high resistivity, and massive (nonporous) limestone and dolostone are recorded as moderate to high resistivity. Porous limestone and dolostone are recorded as low resistivity. Clay as well as peat are recorded as low resistivity, and pure quartz sand is recorded as moderate resistivity.

Most electric logs available for use in water wells in peninsular Florida can only be run in the uncased or openhole portion of boreholes. In general, small diameter (2-4 inch) wells yield the best and most accurate electric logs. This is because the logging probe samples a larger volume of rock or sediment in the borehole wall, rather than the fluid (usually water or drilling mud) filling the borehole. Neutron logs have been used in the cased portions of wells to obtain similar information as electric logs. These can be recorded in plastic or metal casing. However, since the probes use a nuclear source their usage is limited and logs are not readily available in the SJRWMD.

Other electric logs such as Focused Guard, Dual Induction and Fluid Resistivity are available for only a few wells and, therefore, have limited value for correlation purposes. Since the normal electric logs are greatly affected by the salinity of the fluid within both the borehole and the formation, the normal electric log responses discussed herein represent the formation resistivity as unaffected by high salinity fluids. The Focused Guard log can be used when the salinity is high.

The electric logs for wells L-0729 (Figure 3) and N-0222 (Figure 4) demonstrate several features that may be encountered in wells where saline water is encountered. Often, the salinity of the formation fluids increases dramatically in this environment and may cause a normal electric log to be attenuated or even flatten. This attenuation can be seen in the normal electric log for N-0222 at 1,300 feet BLS (Figure 4). The highly saline water has flattened the electric log so that no bedding can be distinguished below that point. The electric log would therefore be useless in identifying any formation boundaries below 1,300 feet. The focused guard log, however, shows many zones of high resistivity that could be used to identify the boundaries. In well L-0729 (Figure 3) elevated chlorides were encountered below 2,000 feet. The electric log shows a general decrease in resisitivity but there is still some bed resolution. A section of the guard log that was run on L-0729 shows more thin bed resolution and higher resistivity but no new high resisitivity beds are identified. This adds confidence to the formation picks that are determined from the electric logs.

STRATIGRAPHY

The Cenozoic stratigraphic column of the SJRWMD has been described in good detail by Miller (1986). In the northern portion of the District, the Cenozoic strata can be subdivided into two broad portions: a lower carbonate section, composed almost exclusively of limestone (calcium carbonate) and dolostone (calcium-magnesium carbonate), and an upper predominantly siliciclastic (quartz silt/sand/gravel and clay-mineral clay) section. The lower carbonate section also contains variable amounts of the evaporite minerals gypsum (hydrated calcium sulfate) and anhydrite (anhydrous calcium sulfate) toward its base. In the southern part of the SJRWMD carbonates comprise a significant portion of the Paleocene through Miocene strata, with siliciclastics comprising the Pliocene and younger part of the section.

Paleocene Series
Cedar Keys Formation

Cole (1944) proposed the name Cedar Keys Formation for cream to tan colored, carbonates underlying peninsular Florida. The Cedar Keys Formation is the oldest unit commonly penetrated by wells in the SJRWMD. It is composed of lower anhydrite and upper dolostone lithologic zones (modified from Chen, 1965). The top of this unit generally lies at elevations below -1500 feet MSL in the SJRWMD. The Cedar Keys Formation ranges from about 400 thick under the northern portion of the District, to 1200 feet or more under the southern portion (Chen, 1965; Miller, 1986). Water wells and monitor wells typically do not penetrate the entire Cedar Keys section.

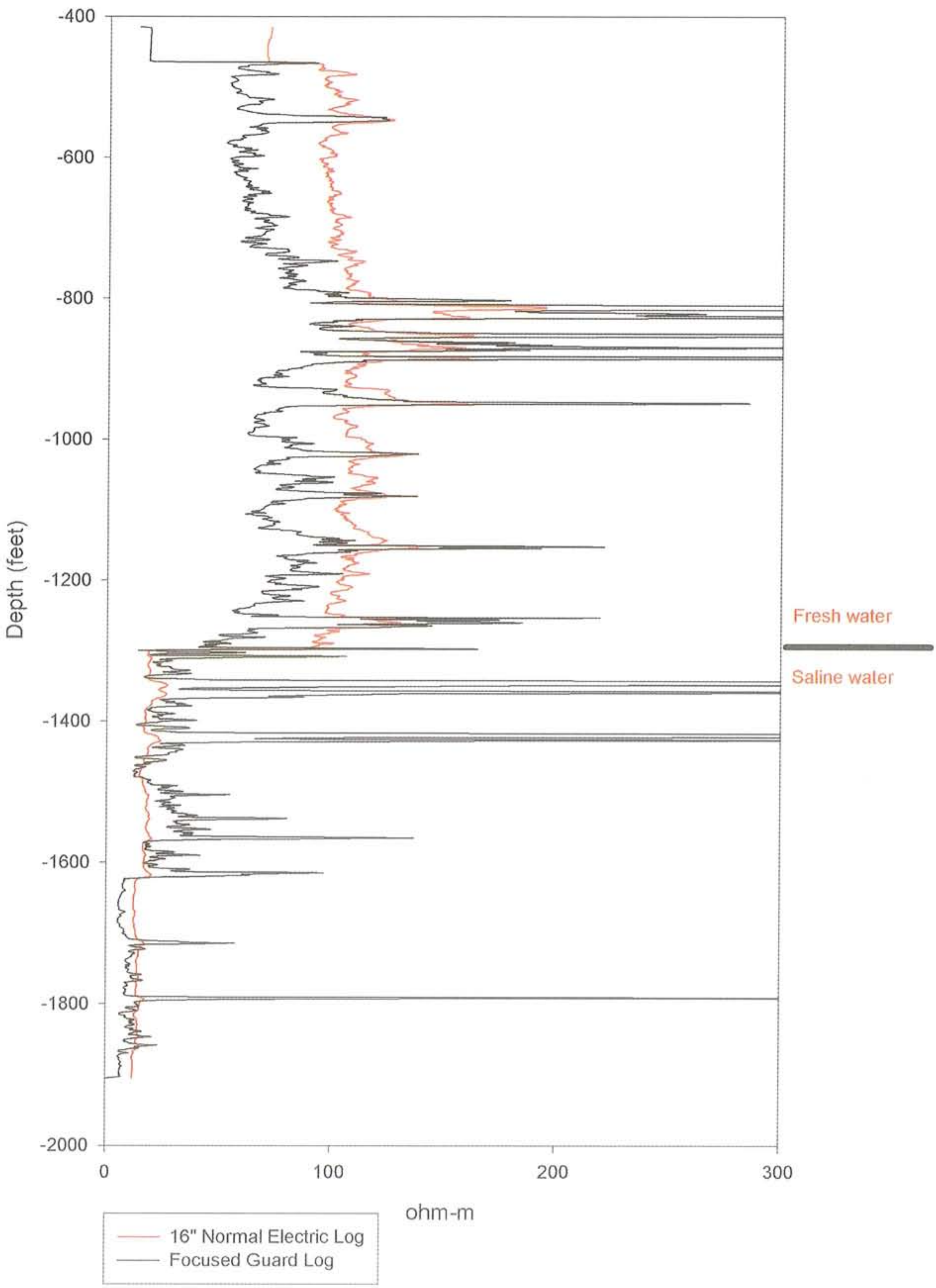

Figure 4. Electric and Focused Guard logs of well N-0222, Nassau County.

Lithostratigraphy

The lower anhydrite lithozone of the Cedar Keys Formation consists of interbedded gray, brown, or clear, massive anhydrite and gray to tan dolostone. The lower lithozone typically comprises up to two-thirds of the Cedar Keys thickness (Miller, 1986). Lower lithozone anhydrite characteristically occurs as sand-to-pebble-sized blebs surrounded by thin walls of dolostone; as discrete beds; as bands or laminae; as intergranular and foraminiferal moldic porosity fill in dolostone; and as rare discrete sand sized crystals in dolostone. White to clear gypsum may compose thin beds, bands, blebs, veins and porosity infillings in dolostone. Thin interbeds of gray to tan recrystallized dolostone also occur in the lower anhydrite lithozone.

The upper dolostone lithozone of the Cedar Keys Formation characteristically consists of gray to tan, relatively porous, finely recrystallized dolostone. Gypsiferous dolostone, containing white to clear gypsum, also occurs toward the base of the upper dolostone lithozone.

Gamma Logs

On gamma logs, the lower anhydrite lithozone is recorded as even, *high moderate intensity* dolostone peaks interspersed with *low* to *low moderate intensity* valleys representing anhydrite beds. Figure 2 illustrates the typical signature on a gamma log for the upper portion of the lower anhydrite lithozone of the Cedar Keys Formation. These logs are from an injection test well (BR1217, located in east-central Brevard County) that partially penetrates the Cedar Keys Formation. The top of the lower anhydrite lithozone can be identified by the presence of a discrete anhydrite bed centered at approximately 2,680 feet BLS that is recorded as a *low intensity* valley on the gamma log. Locally, the bedded anhydrite contains traces of very finely particulate peat that is radioactive. Therefore, slightly peaty anhydrite beds may not be as well-defined on gamma logs as pure anhydrite beds. However, the lower anhydrite lithozone of the Cedar Keys Formation is generally not easily identified on the gamma log; it is characteristically best defined on the electric log. The indistinct contact between the Cedar Keys Formation and the overlying Oldsmar Formation can be seen in Figure 2 at approximately 2,400 to 2,500 feet BLS.

A SJRWMD monitoring well (L-0729) was recently drilled in southern Lake County near Lake Louisa. This well penetrated the top of the Cedar Keys Formation at approximately 2,090 feet BLS. The gamma log shown in Figure 3 shows the *low moderate intensity* below 2,250 feet typical of the gypsum-rich dolostone that is found in the Cedar Keys Formation. The *high intensity* zone seen between 2,105 and 2,250 feet BLS is unusual, but may be due to the presence of clay and silt.

Because both the upper lithozone Cedar Keys Formation and the lower lithozone Oldsmar Formation consist of dolostone, their traces, as recorded on gamma logs, are quite similar. The uneven *low moderate* to *high moderate intensity* recorded at the contact between the Cedar Keys Formation and the Oldsmar Formation generally cannot be distinguished using gamma logs alone.

Electric Logs

The lower anhydrite lithozone of the Cedar Keys Formation is typically recorded on electric logs as a distinct series of thick, high resistivity (very low porosity) peaks representing discrete anhydrite beds, alternating with lower resistivity (higher porosity) dolostone intervals.

The upper dolostone lithozone of the Cedar Keys Formation is easily identified on most electric logs; the porous dolostone is characteristically recorded as a relatively flat, low resistivity (high porosity) line (Chen, 1965). This trace pattern contrasts sharply with that recorded from the overlying base of the Lower Eocene Oldsmar Formation, which consists of very hard recrystallized low porosity (high resistivity) dolostone. Figure 5 illustrates this trace pattern from an electric log obtained from a U.S. Geological Survey deep monitor well D-0349 located in western Duval County. The contact between low resistivity uppermost Cedar Keys Formation and high resistivity basal Oldsmar Formation occurs at about 1,975 feet BLS.

For well L-0729, a Focused Guard log was also run in the interval for the Cedar Keys Formation and is included in Figure 3 for comparison. Water quality samples from this zone indicated an increase in conductivity. The electric log is smoother and has somewhat lower values than the Focused guard log. The Focused guard log shows higher bed resolution but no new high resistivity zones are identified that would indicate the pore fluid was masking the response. Thus the low resistivity recorded for this zone is primarily caused by the formation materials. These two figures emphasize the advantages of electric logs over gamma logs for identifying the Cedar Keys Formation, however water quality should always be considered when evaluating the electric logs for this unit.

Lower Eocene Series
Oldsmar Formation

All Lower Eocene carbonate rocks underlying Florida are included in the Oldsmar Formation of Applin and Applin (1944). The Oldsmar Formation is subdivided into lower and upper lithozones (modified from Chen, 1965). The top of this unit typically occurs at elevations of -965 to -2,332 feet MSL in the SJRWMD. Within the SJRWMD, the thickness of the Oldsmar Formation generally ranges between 400 and 1,100 feet thick.

Lithostratigraphy

The lower lithozone of the Oldsmar Formation consists of very dark brown to dark gray, very hard and massive dolostone. Traces of glauconite, pyrite, peat and phosphate occur throughout the lower dolostone lithozone. The upper lithozone is composed of dolomitic, recrystallized, calcarenitic limestone and brown recrystallized dolostone. Near the top of the formation an impure carbonate section of highly variable thickness contains chert, peat, glauconite, pyrite, phosphate, clay, and granule to pebble sized quartz crystal masses. This section represents the "glauconitic zone" of Duncan et al. (1994) and the "silicic zone" of Johnson (1984). In Brevard County, Duncan et al. (1994) picked the upper contact of the Oldsmar Formation at the top of this impure carbonate section. Marking the top of the Oldsmar Formation, a relatively thin (0-60 feet) and somewhat discontinuous bed of white to light tan, pure, porous, foraminiferal calcarenitic lime-

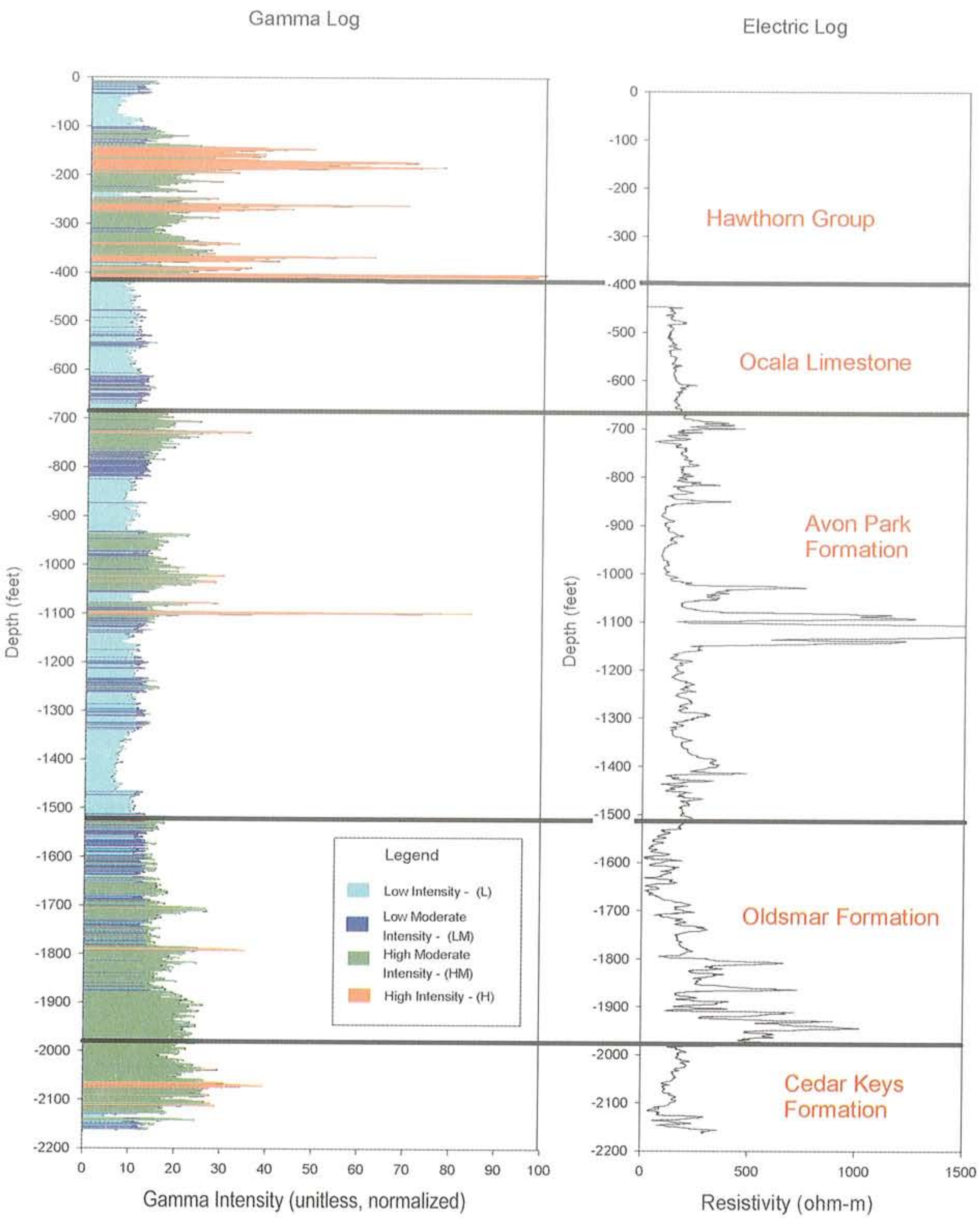

Figure 5. Gamma and Electric logs of well D-0349, Duval County.

stone occurs above the impure carbonate interval and directly below the brown, massive, crystalline dolostone occurring at the base of the overlying Avon Park Formation.

Gamma Logs

Because the lower lithozone of the Oldsmar Formation consists almost exclusively of dolostone, uneven *high moderate intensity*, with interspersed minor *low moderate intensity* peaks, is characteristically recorded on gamma logs. Therefore the lower lithozone Oldsmar cannot be distinguished from upper lithozone Cedar Keys Formation on the sole basis of the gamma log. The example shown in Figure 5 demonstrates the similarity in gamma response at the contact of the Oldsmar Formation and the underlying Cedar Keys Formation at 1,975 feet BLS. This gamma log was obtained from a deep test/observation well (D-0349) located in western Duval County.

The interval from 1,530 to 1,975 feet BLS in Figure 5 illustrates a typical gamma log response from the Oldsmar Formation. The interval shows a section of uneven *low moderate* to *high moderate intensity* from approximately 1,800 to 1,975 feet BLS, representing dolostone in the lower lithozone.

The upper lithozone is indicated by a series of predominantly uneven *low* to *low moderate intensity* limestone and dolostone peaks lying between 1,545 and 1,800 feet BLS. Interspersed *high moderate* to *high intensity* peaks likely reflect the moderately radioactive phosphate, clay, glauconite and peat content in the upper lithozone. The overall lower intensity of the upper lithozone contrasts with the higher intensity recorded below in the lower dolostone lithozone of the Oldsmar Formation.

Electric Logs

On electric logs, the lower dolostone lithozone of the Oldsmar Formation is characterized by a thick series of high resistivity peaks interspersed with very thin low resistivity valleys. This trace pattern contrasts greatly with the low, even resistivity typical of the subjacent upper dolostone lithozone Cedar Keys Formation. Figure 5 shows an electric log for well D-0349. It depicts the lower dolostone lithozone as a characteristically distinct series of high resistivity peaks between approximately 1,800 to 1,975 feet BLS.

The upper lithozone of the Oldsmar Formation (about 1,530 to 1,800 feet BLS on Figure 5) is recorded on electric logs as alternating higher resistivity peaks and lower resistivity valleys typical of alternating lower and higher porosity carbonate beds.

Middle Eocene Series
Avon Park Formation

Miller (1986) grouped the lithologically similar Avon Park Limestone and Lake City Limestone of Applin and Applin (1944) into a single unit, the Avon Park Formation. The Avon Park Formation comprises the Middle Eocene carbonates occurring under the SJRWMD. Within the SJRWMD the top of this unit typically occurs at elevations of -92 to -850 feet MSL. The thickness of the Avon Park Formation varies between 600 and 1550 feet.

Lithostratigraphy

The Avon Park Formation characteristically consists of dark brown to dark tan to dark gray, variably peaty recrystallized dolostone interbedded with white to tan, recrystallized foraminiferal limestone. Beds of tan to brown to gray, dolomitic limestone and dolostone also are common. Three dolostone lithozones are commonly present in this formation. A relatively continuous and massive dolostone, commonly occurs at the base of the Avon Park Formation. An upper dolostone lithozone, comprised of recrystallized dolostone with interbedded limestone, typically occurs within 50 to 200 feet of the upper contact. A less continuous middle dolostone lithozone may also be present, separated from the more continuous lower and upper dolostone lithozones by sections of limestone and dolomitic limestone.

The Avon Park Formation typically contains variable amounts of black to dark brown, finely particulate to fibrous, partially decomposed organic material or peat. The peat occurs very finely disseminated, or as sand to pebble sized blebs, as easily identifiable leaf or seagrass plant fossils, as laminations or stringers, and as discrete beds. Within the upper portion of the middle dolostone lithozone (if present) and at the base of the upper dolostone lithozone, two 5 to 15 feet thick discrete beds of peat (Chen, 1965) occur relatively continuously in the northern two-thirds of the SJRWMD (north of Brevard, eastern Osceola, and northeastern Okeechobee Counties). In the southern one-third of the district, the thick peat beds are locally replaced by intervals of peaty dolostone and recrystallized limestone. The lower dolostone lithozone of the Avon Park Formation may contain yellow to orange pyrite and green glauconite grains; the middle dolostone lithozone also locally contains glauconite, but commonly lacks the pyrite content. This typical lithology of the base of the lower dolostone lithozone of the Avon Park Formation (dark brown to dark gray, peaty, pyritiferous, glauconitic dolostone) differs markedly from the tan to white, pure, calcarenitic limestone bed occurring at the top of the underlying upper lithozone Oldsmar Formation.

At the top of the Avon Park Formation, the uppermost upper lithozone characteristically consists of brown to orange recrystallized dolostone interbedded with light to dark tan limestone. These lithologies are easily differentiated from the calcarenitic limestone typical of the overlying basal lower lithozone Ocala Limestone.

Gamma Logs

Due to the characteristic content of moderately radioactive dolostone and highly radioactive peat in the Avon Park Formation, the interval is typically recorded on gamma logs as uneven *low moderate* to *high moderate intensity*. Moderately radioactive glauconite increases gamma intensity recorded in the lower lithozone of the Avon Park Formation. Two discrete peat beds, one in the middle lithozone and the other at the base of the upper lithozone, are typically recorded as *high intensity* peaks or as a series of *high moderate intensity* peaks, where present. Figure 6 illustrates the gamma log obtained from a well (P-0619) in north-central Putnam County which clearly displays these two *high intensity* peaks. The stratigraphically lower peak is centered at approximately 660 feet BLS and the upper peak at about 540 feet BLS.

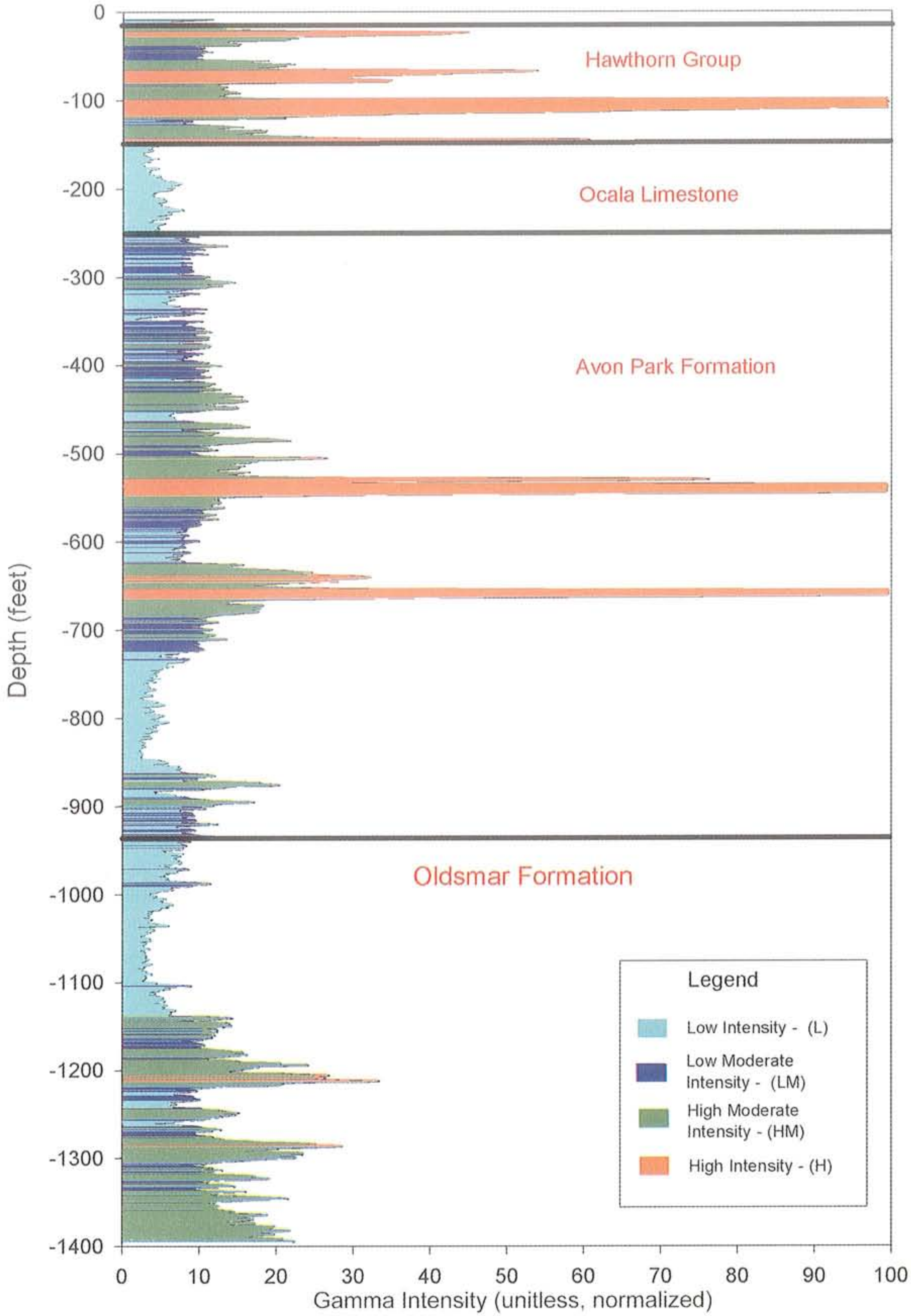

Figure 6. Gamma log of well P-0619, Putnam County.

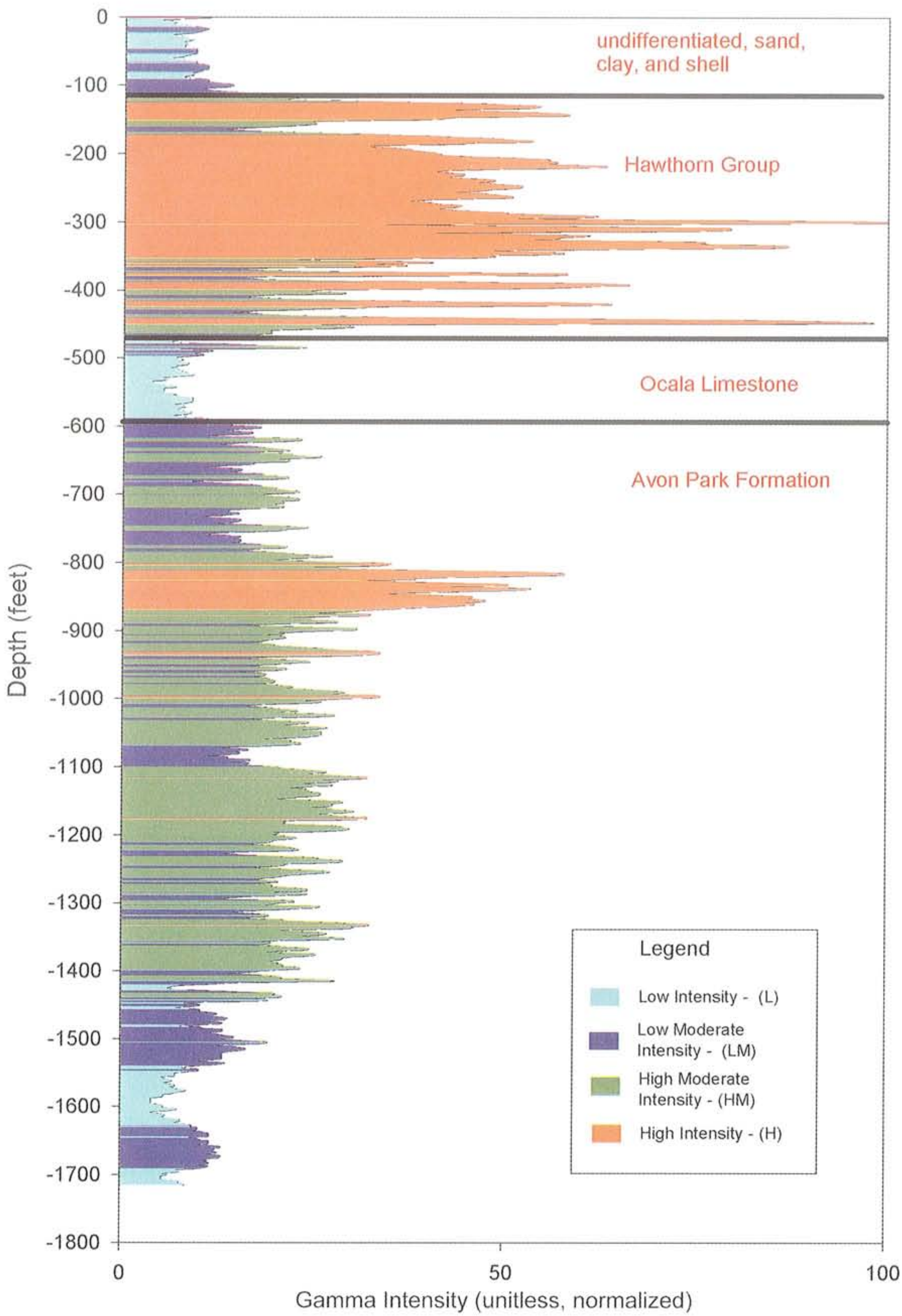

Figure 7. Gamma log of well IR0748, Indian River County.

Figure 7 illustrates a typical gamma log of the upper portion of the Avon Park Formation, obtained from a livestock supply well (IR0748) located in southeastern Indian River County. In IR0748, the Avon Park Formation-Ocala Limestone contact occurs at approximately 590 feet BLS. The *low intensity* of basal Ocala Limestone contrasts markedly with the uneven *low moderate* to *high moderate intensity* characteristic of the Avon Park Formation below. The Avon Park Formation also contains beds that produce *high intensisty* units such as those seen from 800 to 860 feet BLS in IR0748. These *high intensity* units may not be laterally extensive; however, they are helpful in identifying the presence of the Avon Park Formation. This contrasts with the even *low intensity* characteristic of the underlying calcarenite bed marking the top of the underlying Oldsmar Formation.

The top of the Avon Park Formation is characteristically recorded on gamma logs as an interval of *low moderate* or *high moderate intensity* peaks. This contrasts markedly with the lower intensity typically recorded in the overlying Ocala Limestone. This contrast between the top of the Avon Park Formation and the Ocala Limestone is demonstrated in Figure 6 where the contact in the gamma log for P-0619 is identified at a depth of 255 feet BLS. Figure 2 depicts the gamma log obtained from well BR1217 located in east-central Brevard County. Between approximately 225 to 300 feet BLS, the peaty uppermost upper lithozone Avon Park Formation is characteristically recorded as a series of very closely spaced *low moderate intensity* peaks. Above approximately 225 feet BLS, the Ocala Limestone is typically recorded as even *low intensity.*

In Alachua, Marion, and Lake Counties, the top of the Avon Park Formation locally contains clay in addition to peat; this results in an exceptionally distinct interval of *high moderate* to *high intensity* marking the formational top on the gamma log. Characteristic gamma log response for the Avon Park Formation-Ocala Limestone contact in these counties can be seen in the cross sections in Appendix A, in particular, well M-0060 in section T-T', wells A-0375 and M-0139 in section S-S', and wells L-0121 and L-0122 in section I-I'.

Figure 8 illustrates the gamma trace obtained from a public supply well (L-0005) in south-central Lake County in which the top of the Avon Park Formation contains clay. Below the even, *low* and *low moderate intensity* characteristically recorded in the Ocala Limestone (about 190 to 260 feet BLS), the uppermost upper zone Avon Park Formation is recorded as a series of *high intensity* peaks (about 260 to 325 feet BLS).

Electric Logs

On electric logs, the Avon Park Formation is characteristically recorded as alternating low to very low resistivity valleys (corresponding to moderate to high porosity limestone or dolostone, peaty carbonate, and/or discrete peat beds) and high to very high resistivity peaks (corresponding to hard and massive low porosity dolostone). The three (lower, middle and upper) dolostone lithozones are typically recorded as thick intervals containing abundant, closely spaced, moderate to high resistivity (low porosity) peaks separated by thin, sharp, low to very low resistivity valleys (which may represent fractures/joints or intercalations of peaty carbonate or discrete peat beds). This characteristic trace pattern is shown on Figure 9, an electric log from deep observation well OR0465 at Lake Ivanhoe in Orlando, Orange County. The lower dolostone lithozone extends from approximately 1,445 feet BLS to about 1,800 feet BLS, the middle dolostone litho-

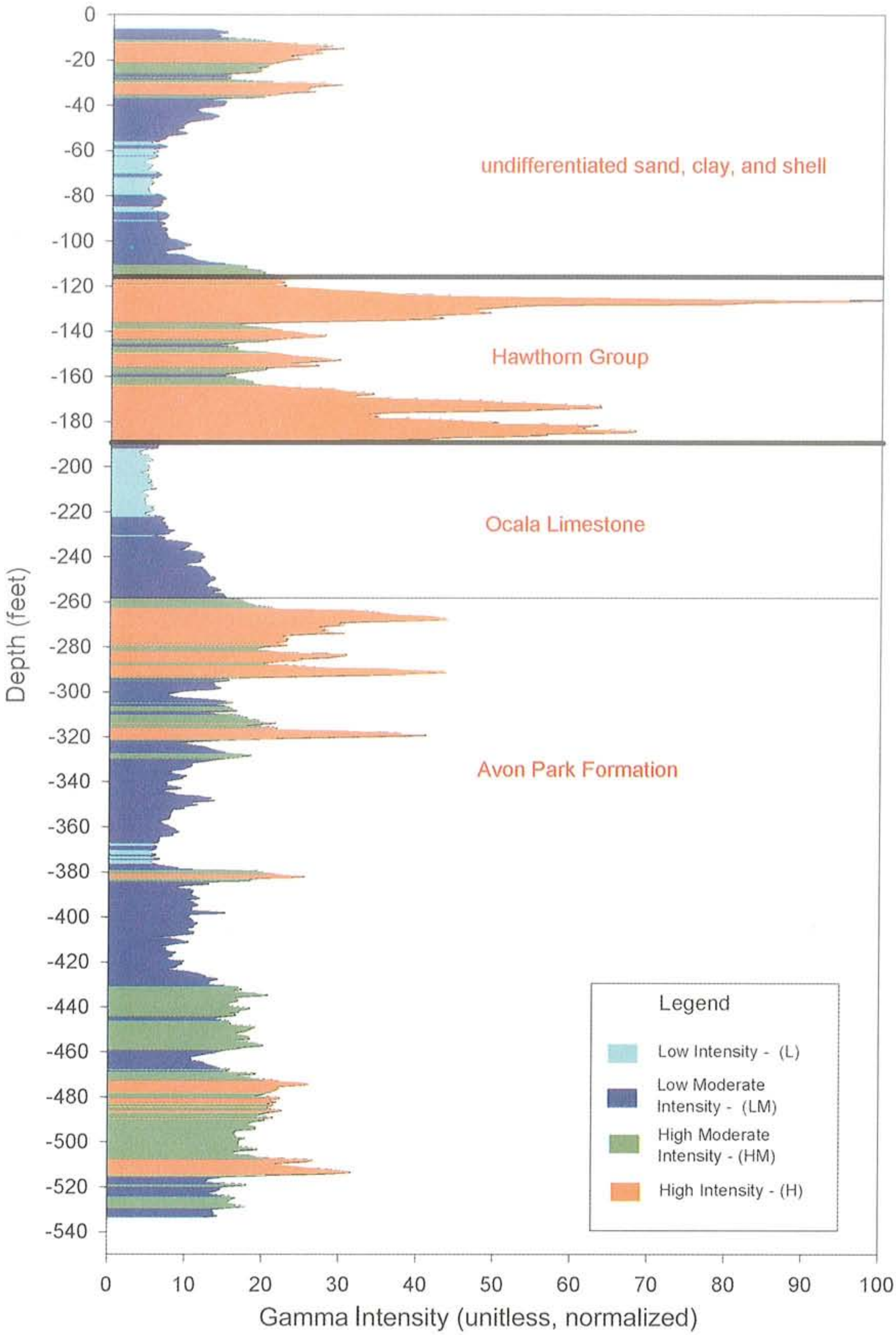

Figure 8. Gamma log of well L-0005, Lake County.

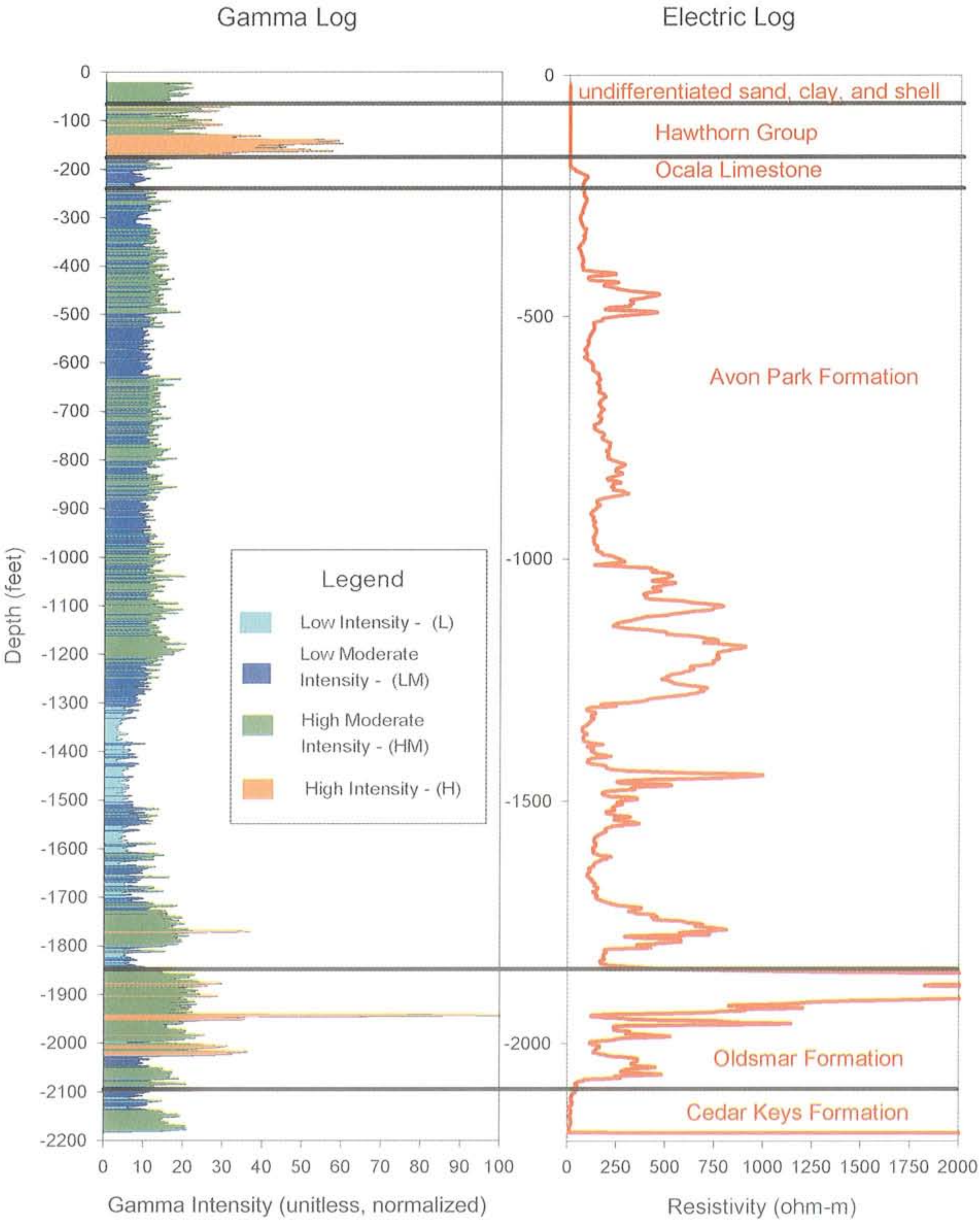

Figure 9. Gamma and Electric logs of well OR0465, Orange County.

zone includes from 1,000 feet BLS to about 1,300 feet BLS, and the upper dolostone lithozone extends from about 400 feet BLS to about 500 feet BLS. Since the upper lithozone of the Avon Park Formation contains peat and clay, it is characteristically recorded on electric logs as an interval of even, low resistivity or a series of thin, low resistivity peaks and valleys.

Figure 10 depicts the log response for the top of the Avon Park Formation as recorded on an electric log obtained from a SJRWMD observation well (P-0172) east-central Putnam County. The peaty uppermost Avon Park Formation is recorded as an even, low resistivity valley from approximately 245 to 265 feet BLS, with the basal Ocala Limestone high resistivity peak recorded just above. At 310 feet BLS the high resistivity peaks of the upper dolostone lithozone begins.

Variations in the resistivity response at the Avon Park – Ocala Limestone contact may make correlations using resistivity logs alone difficult. A combination of electric and gamma log may be the only way to recognize the contact. The upper dolostone lithozone is most easily recognized by the high resistivity peaks. Once this upper dolostone lithozone is identified, the gamma log for the interval above this zone can be reviewed for a decrease in gamma intensity.

Upper Eocene Series
Ocala Limestone

Dall and Harris (1892) first used the name Ocala Limestone for marine carbonate rocks exposed in quarries near Ocala, Marion County. It is found throughout most of Florida. The Ocala is subdivided into upper and lower units (after Applin and Applin, 1944; Scott, 1993). The top of the unit occurs at elevations between 80 feet MSL in western Alachua County and -660 feet MSL in St. Lucie County. It ranges in thickness from 0 feet, where it is absent on structural highs, to about 400 feet in Duval County.

Lithostratigraphy

The Ocala Limestone typically consists of white or tan, homogeneous, porous and permeable, thickly bedded, foraminiferal limestone containing abundant granule to pebble sized foraminifera, echinoids, mollusks, corals, and bryozoans. The Ocala Limestone characteristically consists of upper and lower lithozones (modified from Applin and Applin, 1944) which differ only slightly in average grain size and minor dolomite content.

The lower lithozone characteristically consists of white, tan, or light yellow, foraminiferal calcarenite and calcilutite, commonly with sparry calcite cement. Thick relatively soft intervals are interbedded with thinner, hard to very hard, finely recrystallized limestone with varying degrees of molluscan moldic porosity. Recrystallized dolomitic limestone beds occur discontinuously in the lower lithozone, as well as a basal section composed of very hard, molluscan to echinoid calciruditic limestone. The pure calcarenitic to calciruditic limestone lithologies typical of the lower lithozone Ocala Limestone contrast markedly with the clayey and/or peaty dolostone and limestone characteristic of the top of the underlying Avon Park Formation.

The upper lithozone of the Ocala Limestone is characteristically composed of white to light tan, thickly bedded, extremely fossiliferous, foraminiferal calciruditic limestone interbedded with

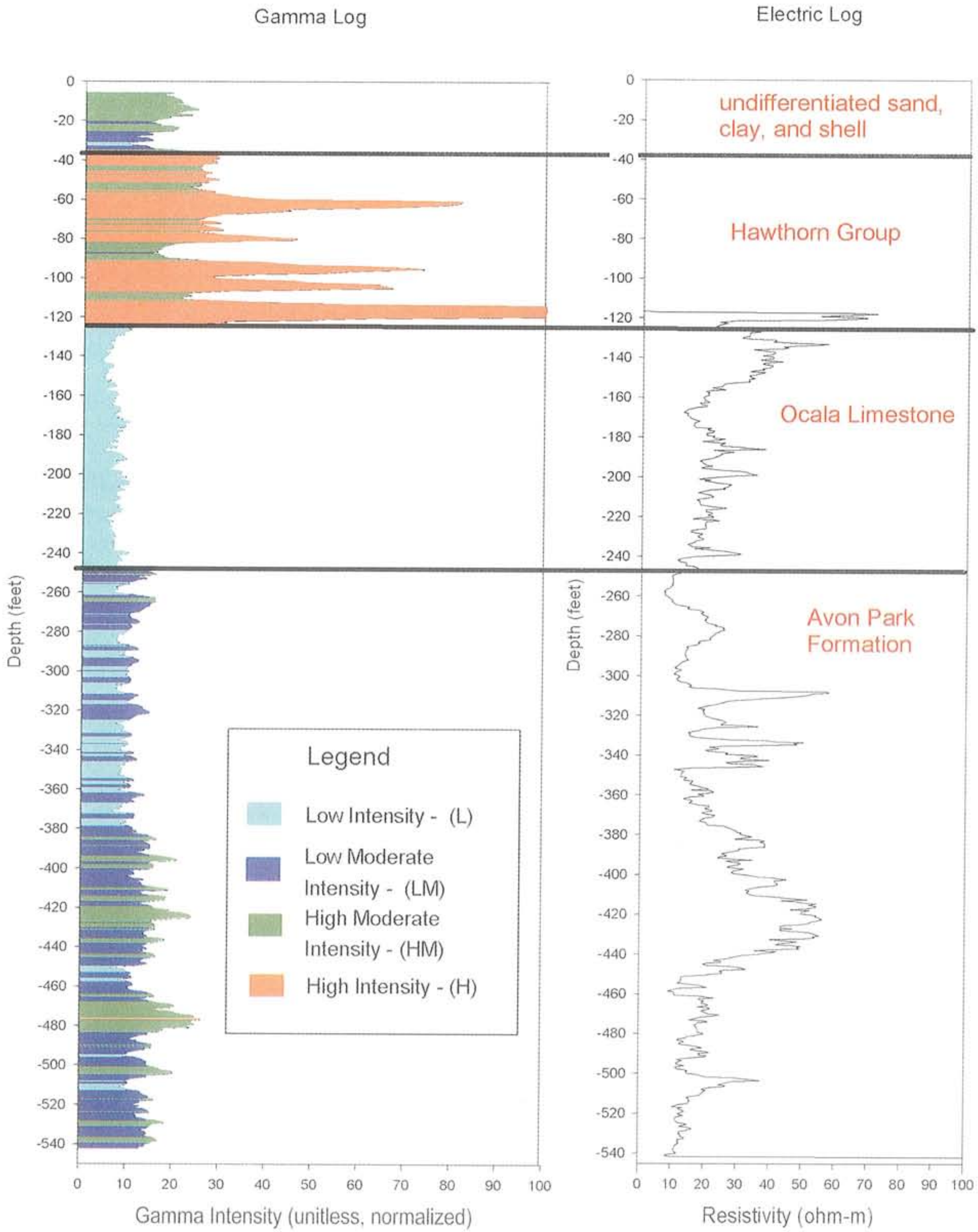

Figure 10. Gamma and Electric logs of well P-0172, Putnam County.

fossiliferous, foraminiferal calcarenitic limestone. Both types of limestone typically contain variable amounts of calcilutite cement; however, moderate to high intergranular porosity is nevertheless common. As in the lower lithozone, relatively thin (0.5-2 feet), very hard beds of molluscan, moldic, finely recrystallized limestone occur interbedded with the calcirudite and calcarenite.

The top of the pure foraminiferal calcirudite or calcarenite of the Ocala Limestone differs greatly from the phosphatic, predominantly siliciclastic lithology of the overlying Hawthorn Group. In eastern Indian River and southeastern Brevard Counties, Suwannee Limestone occurs above the Ocala Limestone. Again, the somewhat phosphatic, slightly peaty, variably dolomitic calcarenite of the Suwannee Limestone is easily differentiated from the pure calcirudite to calcarenite characteristic of upper lithozone Ocala Limestone.

Gamma Logs

The Ocala Limestone is easily identified on both gamma and electric logs. Because the Ocala Limestone is predominantly composed of very pure limestone, the interval is typically recorded on gamma logs as *low intensity*. The Ocala Limestone characteristically produces the lowest intensity recorded in the carbonate section of the Cenozoic stratigraphic column and is therefore used as a low baseline for the relative gamma intensity scale used in this report. The top of the Ocala Limestone is easily identified on most gamma logs. Over much of the SJRWMD, the base of the overlying Hawthorn Group is characteristically recorded as a *high intensity* peak just above the *low intensity* typical of the uppermost Ocala Limestone. This may be observed in Figure 10, well P-0172, at about 125 feet BLS. In many gamma logs, the entire Ocala Limestone section produces only *low intensity*. This is an indication that the upper lithozone and the lower lithozone may only differ slightly. Examples of Ocala Limestone gamma response that are primarily *low intensity* throughout can be seen in wells BR1217 (Figure 2), D-0349 (Figure 5), IR0748 (Figure 6), and IR0338 (Figure14). In some logs, a *low moderate intensity* zone is recorded on the top of the Ocala Limestone because the paleokarst has allowed clay and phosphate from the overlying formations to migrate downward and accumulate.

Other Ocala Limestone sections show both an upper and lower lithozone gamma log response. The gamma log for D-0176 (Figure 11) shows the characteristic upper lithozone gamma log response from 510 to 650 feet BLS. From 650 to 740 feet BLS the even *low moderate* and/or *high moderate intensity* typical of the lower lithozone in the interval can be seen. Other examples where both lithozones can be distinguished are shown in wells L-0005 (Figure 8), F-0162 (Figure 13), SJ0148 (Figure 15), D-0520 (Figure 17), and F-0019 (Figure 19). In most areas of the SJRWMD, the lower lithozone of the Ocala Limestone is recorded as slightly higher intensity due to the presence of dolomitic limestone beds. However, the gamma intensity recorded in this zone is generally lower than that recorded in the underlying upper lithozone Avon Park Formation.

The gamma log from well L-0094 (Figure 12), a water supply well located in Astatula, central Lake County, is an example of a log from the ridge areas where sand is mined. Note that the undifferentiated sand, clay and shell sediments at depths above 100 feet BLS have the lowest gamma intensity of the entire section. This is related to the very clean sands that occur above

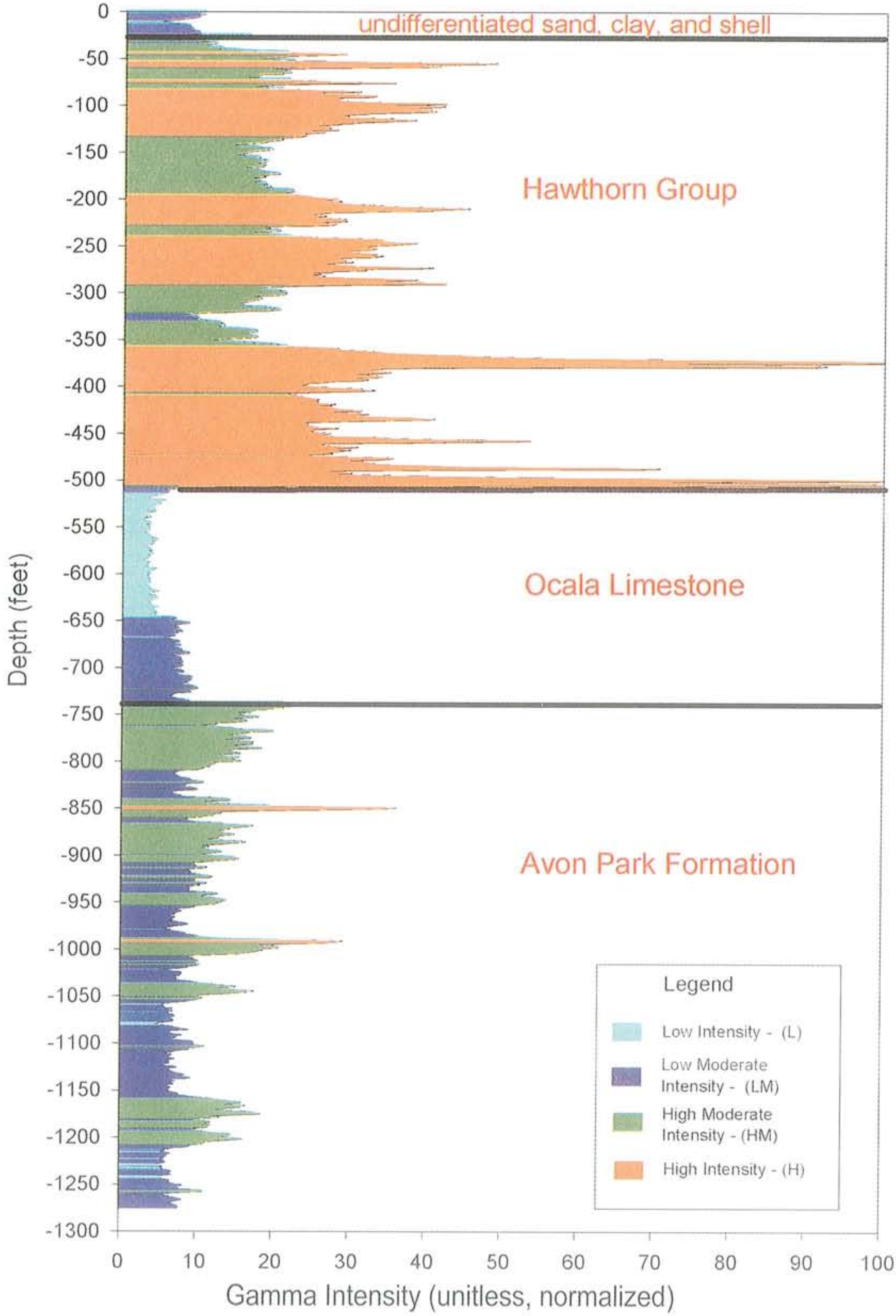

Figure 11. Gamma log of well D-0176, Duval County.

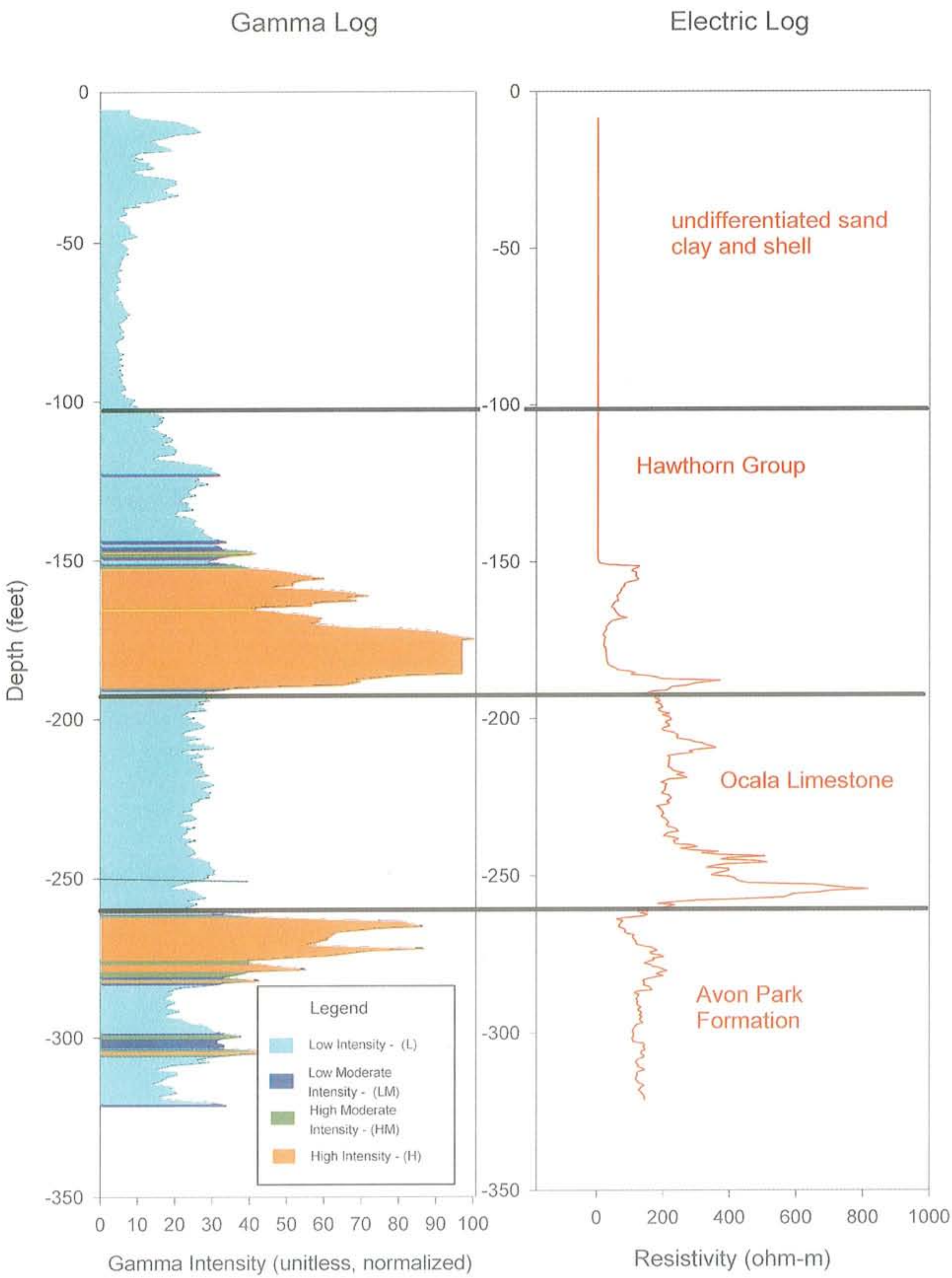

Figure 12. Gamma and Electric logs of well L-0094, Lake County.

the Hawthorn Group. Also in this log, the *low intensity* of the Ocala Limestone is higher than in wells in other counties (Figures 7-11).

Figure 13 shows the gamma log obtained from well F-0162 located in northeastern Flagler County. The top of the Ocala Limestone consists of characteristic even *low intensity* below the basal Hawthorn Group *high intensity* peak at approximately 145 feet BLS. Notice the transition zone of *low moderate intensity* from about 145 to 152 feet BLS, followed by *low intensity* to 200 feet BLS. This demonstrates the gamma response where clay and other minerals from the overlying Hawthorn Group have either filled lows in the paleokarst of the Ocala or have been deposited in the pore space thereby increasing the gamma intensity. Other examples of this effect can be seen in the gamma cross sections which are discussed later in this report.

In eastern Indian River and southeastern Brevard Counties, the Suwannee Limestone occurs above the Ocala Limestone. The base of the phosphatic, silty, and peaty Suwannee is typically recorded as *high moderate* gamma intensity, which contrasts with the *low intensity* recorded in the uppermost Ocala Limestone. Figure 14 illustrates the typical Suwannee Limestone/Ocala Limestone contact as recorded in a gamma log obtained from well IR0338 located in south-central Indian River County. The contact between the top of the Ocala Limestone at 380 feet BLS is characteristically recorded as relatively uneven *low intensity* lying directly below the *high moderate intensity* typical of the Suwannee Limestone in this area.

Electric Logs

On electric logs, the Ocala Limestone is highly variable but is most often recorded as a series of relatively thin, moderate to high resistivity peaks (corresponding to interbeds of hard, lower porosity limestone or dolomitic limestone) between broad, low resistivity valleys (representing porous limestone or moldic recrystallized limestone). Figure 12 depicts the electric log obtained from well L-0094. In this log, the Ocala Limestone recorded as uneven, higher resistivity peaks centered at 210 and 250 feet BLS. The Ocala is generally sandwiched between the low resistivity typical of the subjacent peaty to locally argillaceous Avon Park Formation (contact at approximately 255 feet BLS), and the very low resistivity typical of the overlying partially siliciclastic Hawthorn Group (contact at about 185 feet BLS). The base of the Ocala Limestone is often recorded as a relatively thick (10 to 15 feet) high resistivity, single or double peak marking the presence of the basal, very hard and recrystallized, low porosity, molluscan or echinoid limestone bed between approximately 245 to 255 feet BLS. This peak strongly contrasts with the broad low resistivity valley(s) characteristically marking the peaty top of the underlying Avon Park Formation below about 255 feet BLS.

The top of the Ocala Limestone is also typically recorded as a moderate to high resistivity peak on electric logs. This trace pattern may sharply contrast with the pattern recorded in the base of the Hawthorn Group, which, in portions of the SJRWMD, is recorded as a low resistivity valley (Figure 15, above approximately 185 feet BLS). The base of the Hawthorn Group here is locally composed of phosphatic, quartz sandy clay. In other areas (e.g., eastern Putnam and southern St. Johns Counties), basal Hawthorn Group (Penney Farms Formation) is composed of brown, very hard, very low porosity, crystalline dolostone, recorded as a very high resistivity peak, as illustrated in Figure 15. This electric log was obtained from an agricultural supply well

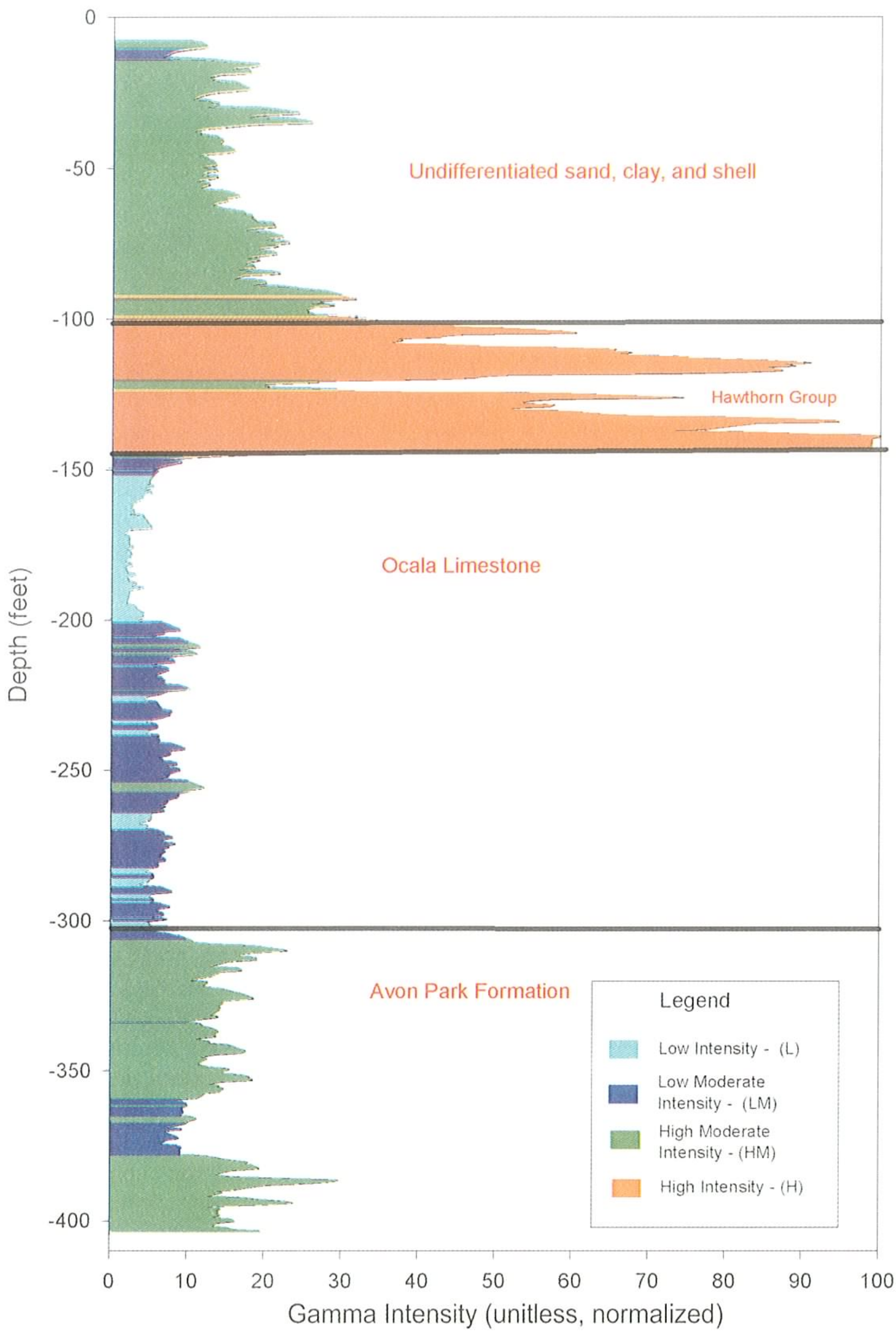

Figure 13. Gamma log of well F-0162, Flagler County.

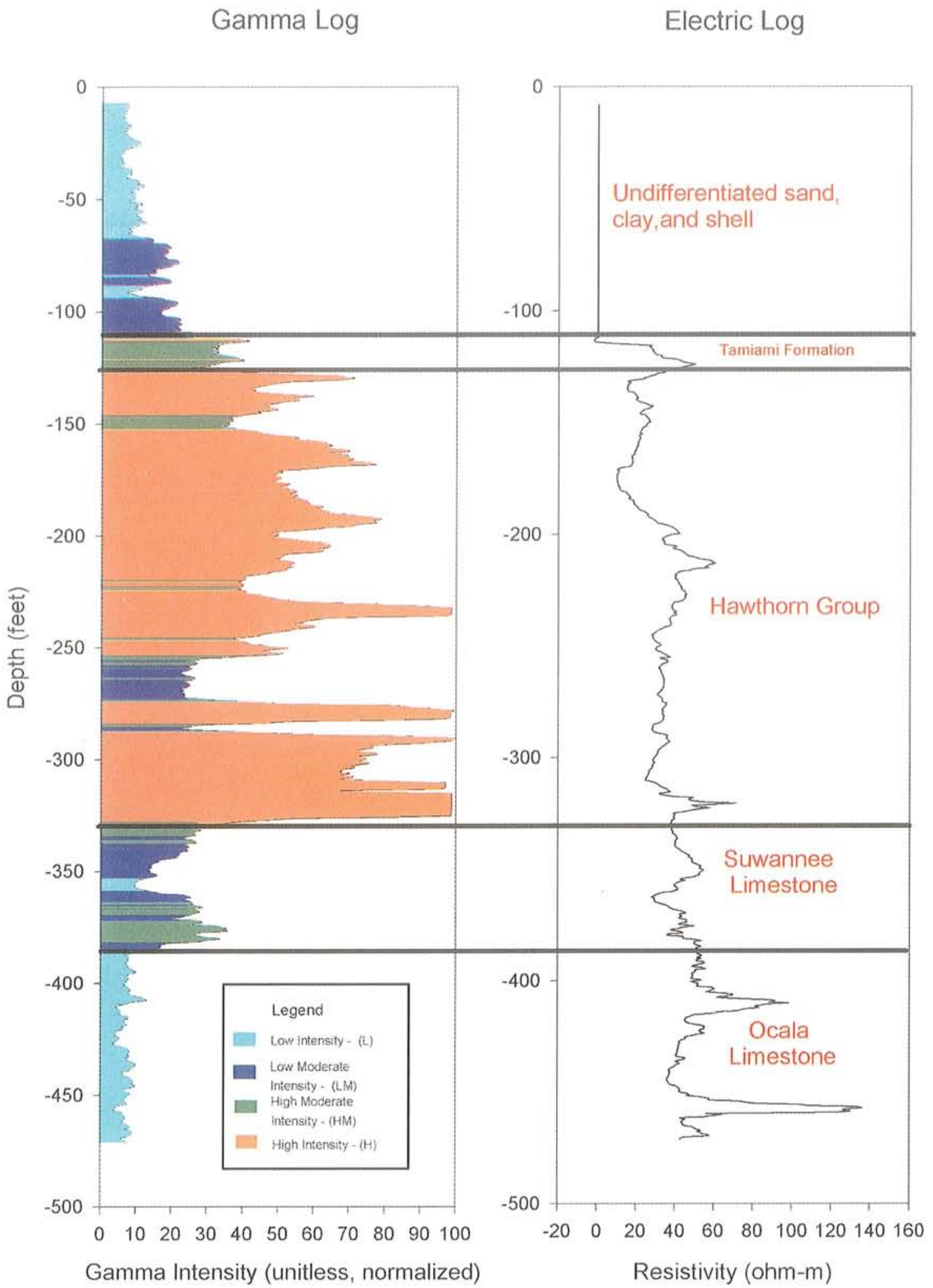

Figure 14. Gamma and Electric logs of well IR0338, Indian River County.

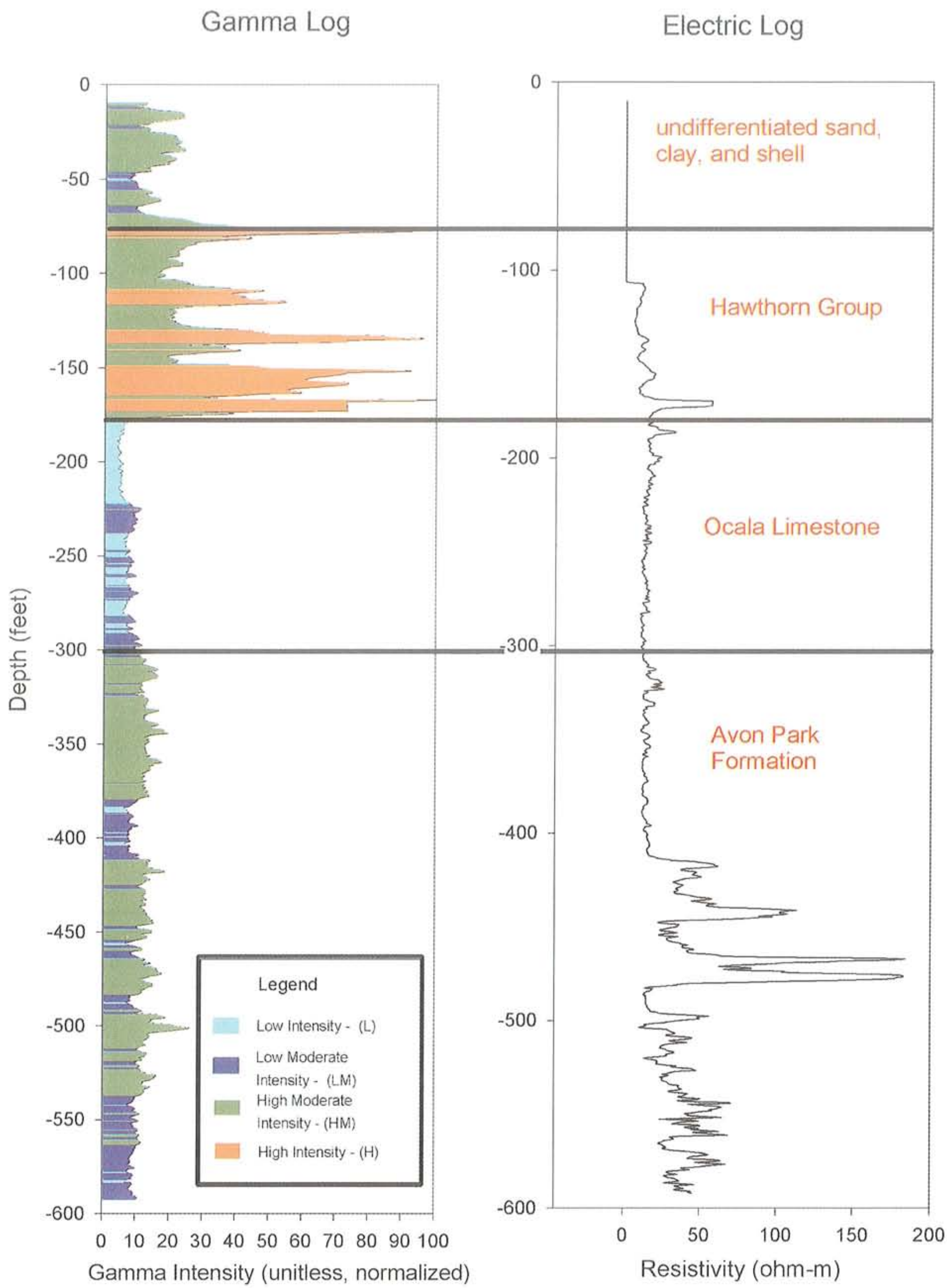

Figure 15. Gamma and Electric logs of well SJ0148, St. Johns County.

SJ0148 located in southwestern St. Johns County. The log records a very high peak at the base of the undifferentiated Hawthorn centered at about 175 feet BLS, representing the basal Hawthorn dolostone bed. The top of the Ocala Limestone is recorded as a relatively atypical decrease in resistivity. This log does, however, highlight the variability in electric log response since the entire section is an even pattern indicative of a massive carbonate with no differing interbedded lithology. For cases like this, and in general, it is necessary to use the gamma log in conjunction with the electric log in determining the top of the Ocala.

Where the Suwannee Limestone occurs above the Ocala Limestone (southeastern Brevard and eastern Indian River Counties), the contact, as recorded on electric logs, is typically not well-defined. Because both the Suwannee Limestone and the Ocala Limestone are generally composed of porous limestone, these formations are recorded similarly on electric logs. Locally in southeastern Indian River County, the basal Suwannee Limestone is significantly more porous than the thick beds of massive recrystallized very hard limestone at the top of uppermost Ocala Limestone. This produces a low resistivity zone on the log directly above the very high resistivity peak recorded at the top of the Ocala.

Oligocene Series
Suwannee Limestone

Cooke and Mansfield (1936) proposed the name Suwannee Limestone for limestone exposed along the Suwannee River, between the towns of Ellaville and White Springs, Suwannee and Hamilton Counties. Most older literature assigned the Oligocene carbonates in the SJRWMD, which locally are restricted to the southeastern portion of the District, to the Suwannee Limestone. Recent work by Brewster-Wingard et al. (1997) recognized that a large portion of these peninsular Florida Oligocene carbonates are actually Arcadia Formation, of the basal Hawthorn Group. For the purposes of this report the older convention of considering these sediments as Suwannee Limestone is used. In the SJRWMD the top of the unit typically occurs at elevations between -300 and -425 feet MSL.

Lithostratigraphy

The Suwannee Limestone consists of tan to brown, moderately to very porous, variably dolomitic, microfossiliferous calcarenitic limestone containing variable concentrations of silt sized phosphate grains and rare peat blebs. The interval is 60 feet or less in thickness over most of its extent and it thins to pinch out inland to the west. However, in extreme southeastern Indian River County, located approximately one mile south of Vero Beach, an anomalous maximum thickness of 288 feet occurs (Appendix A, gamma cross section HH-HH', well IR0930). The thickness of the formation below the southern one-half of the barrier island in Indian River County is also anomalous (150-200 feet).

Gamma Logs

On gamma logs from wells in this area, the Suwannee Limestone is characteristically recorded as uneven *low* to *high intensity.* The *low intensity* zones correlate with relatively pure nonphosphatic, nonpeaty intervals and *high moderate intensity* represents more dolomitic, phosphatic and peaty beds of carbonate. A typical Suwannee Limestone gamma trace is illustrated in Figure 14, obtained from a water supply well (IR0338) located in Vero Beach, southeastern Indian River County. The uneven *low moderate* to *high moderate intensity* from approximately 343 to 380 feet BLS contrasts with the *low intensity*, relatively even trace characteristically produced in the upper lithozone Ocala Limestone below approximately 380 feet BLS. The characteristic thick, *high intensity*, basal Hawthorn Group peak is centered at about 315 feet BLS directly above the lesser intensity typically associated with the uppermost Suwannee Limestone (below approximately 343 feet BLS). The basal Hawthorn Group invariably contains substantially higher concentrations of phosphate than the uppermost Suwannee Limestone. This produces an easily identified peak above the top of the Suwannee Limestone on gamma logs.

Electric Logs

The Suwannee Limestone is recorded on electric logs as a series of broad, low resistivity valleys interspersed with low, somewhat higher resistivity peaks. In general, the Suwannee Limestone cannot be differentiated from either the underlying Ocala Limestone or the lower dolostone lithozone of the overlying Hawthorn Group using only the electric log. At certain sites the top of the Ocala Limestone is easily identified on electric logs by a relatively thick (10 to 15 feet) extremely high resistivity peak, therefore the Suwannee Limestone can be identified by a decrease in resisitivity. Where basal Hawthorn Group consists of quartz sandy clay, a very low resistivity valley overlies the significantly higher resistivity recorded in the uppermost Suwannee Limestone.

Oligocene to Pliocene Series
Hawthorn Group

Dall and Harris (1892) first used the name Hawthorne beds for phosphatic sediments exposed near the town of Hawthorne, Alachua County. The unit has undergone considerable nomenclatural evolution through the years. It was first designated as a formation by Matson and Clapp (1909). Scott (1988a) raised the Hawthorn to group status, and recognized five formations of the group within the SJRWMD. The Coosawhatchie, Marks Head, and Penney Farms Formations occur in the northern portion of the SJRWMD. These units extend southward to the Lake County area, where the formations become indistinguishable in cores and are generally referred to as Hawthorn Group undifferentiated. In the southern portion of the SJRWMD, from the Polk-Osceola-Brevard County area southward, the Peace River and Arcadia Formations comprise the Hawthorn Group. Delineation of the individual formations is generally possible in cores. However, most of the well data is from cuttings in which it is generally not possible to differentiate formations within the Hawthorn Group. Additionally, identification of individual formations using gamma logs alone is difficult or not possible throughout most of the SJRWMD. Therefore, in this report, the unit is referred to as Hawthorn Group even if the individual formations can be distinguished in some wells.

Within the SJRWMD, the elevation of the top of the Hawthorn Group ranges from 150 feet MSL in central Alachua County, to approximately -175 feet MSL in south-central Duval County. The unit dips and thickens from the west-central part of the SJRWMD to the east-northeast into the trough of the Jacksonville Basin, and southward into the Okeechobee Basin. Thickness of the Hawthorn Group ranges from 0 feet in central Volusia County, where it is absent over the crest of the Sanford High, to approximately 500 feet in deeper subsuface basins.

Lithostratigraphy

The Hawthorn Group (Scott, 1988a) is an extremely heterogeneous mixture of both siliciclastic and carbonate lithofacies, divisible into lower and upper lithozones. Carbonate lithofacies predominate in the lower lithozone (Penny Farms and Arcadia Formations). However, relatively thin interbeds of siliciclastic material commonly occur in the lower lithozone. Lithologies characteristic of the lower lithozone of the Hawthorn Group include tan, brown, gray, and white, sandy, phosphatic dolostone and (relatively rare) limestone. Gray to brown chert locally occurs in the lower lithozone of the Hawthorn Group. The chert may be associated with white to light brown, slightly quartz sandy, variably phosphatic, recrystallized dolostone (representing the Arcadia Formation of Scott, 1988a) in the southern portions of the SJRWMD (Indian River, southern Brevard, southeastern Osceola and northeastern Okeechobee Counties). Quartz sand and phosphatic dolostone breccias and conglomerates also commonly occur within the lower lithozone of the Hawthorn Group.

Siliciclastic lithofacies predominate in the upper lithozone (Marks Head, Coosawhatchie, and Peace River Formations), although interbeds of carbonate also commonly occur in the upper siliciclastic lithozone. The upper lithozone contains olive-green, blue, and/or brown, phosphatic clay, quartz sand and dolosilt. The carbonate beds may have increased porosity due to mollusk molds. There are few macrofossils present in any of the units.

The predominant unifying lithologic character of the carbonate and siliciclastic lithofacies composing the Hawthorn Group is the presence of black, brown to amber, very fine sand to pebble sized phosphate grains in sufficient quantities to greatly affect gamma ray intensity. An exception to this is the Charlton Member of the Coosawhatchie Formation (Scott, 1988a) in northern SJRWMD (Duval County and portions of Baker, Clay and Nassau Counties). In this area, the Charlton Member marks the top of the Hawthorn Group, and consists predominantly of brown to dark gray, nonphosphatic to only sparsely phosphatic, molluscan to ostracod to foraminiferal moldic dolostone as well as green to blue clay. In the remainder of the SJRWMD, the top of the Hawthorn Group is characteristically composed of relatively phosphatic lithologies which are normally easily distinguishable from the nonphosphatic to sparsely phosphatic lithologies typical of overlying formations.

Gamma Logs

Because the Hawthorn Group characteristically contains variable, but relatively high, amounts of radioactive phosphate sand and gravel, the interval is typically recorded on gamma logs as a series of sharp to very broad, *high moderate* and *high intensity* units correlating with lower and higher concentrations of phosphate and/or clay. The gamma log is especially useful in picking the base of the Hawthorn Group. Within the SJRWMD, the basal Hawthorn Group typically displays a distinct *high intensity* peak on gamma logs. Where the Ocala Limestone occurs below the Hawthorn Group (most of the SJRWMD excluding southeastern Brevard and eastern Indian River Counties), the top of the Ocala is characteristically recorded as *low intensity* in sharp contrast to the *high intensity* typical of the basal Hawthorn. In eastern Indian River and southeastern Brevard Counties, the Suwannee Limestone occurs below the Hawthorn Group. Since the upper Suwannee Limestone may be recorded as a series of thin *high moderate intensity* peaks it may appear somewhat similar to the much thicker peak series recorded within the Hawthorn Group. Despite the similarities, gamma intensity characteristic of the Suwannee is invariably lower than the *high moderate* or *high intensity* typical of basal Hawthorn.

The gamma log pattern typical of the Hawthorn Group is illustrated on a gamma log (Figure 16) obtained from a FGS corehole (W-13751; Scott #2; SJ0177) located in northern St. Johns County. The pattern for the complete Hawthorn Group section occurs between 105 feet and 325 feet BLS in the log. The upper contact (105 feet BSL) is identified by an increase from *low* and *low moderate intensity* in the overlying surficial sediments to *high intensity* in the upper Hawthorn Group sediments. At the lower contact (325 feet BSL) a sharp contrast occurs where the *high intensity* of the basal Hawthorn Group overlies the *low intensity* units of the Ocala Limestone.

There are two lithologies that typically occur in the upper siliciclastic lithozone (Peace River Formation) of the Hawthorn Group in southern Brevard, southeastern Osceola, northeastern Okeechobee, and Indian River Counties. Thick sections of clay or homogeneous dolosilt are present and are recorded as predominately *high intensity* interbedded with *high moderate intensity* peaks. Figure 14 displays the gamma log obtained from a flowing well (IR0338) located in southeastern Indian River County which illustrates this typical trace pattern. The top of the Peace River Formation is characteristically marked by *high intensity* at approximately 128 feet BLS (contrasting with the *high moderate intensity* of the locally overlying Tamiami Formation). The remainder of the Peace River Formation is characteristically recorded as *high intensity* with interbedded *high moderate intensity* units downward to approximately 311 feet BLS, where the top of the Arcadia Formation of Scott (1988a) occurs. The Arcadia Formation (or lower dolostone lithozone) is recorded as a series of *high intensity* peaks. The base of the Arcadia Formation is represented by the basal Hawthorn Group *high intensity* peak centered at about 315 feet BLS, below which locally occurs the lower intensity typical of the Suwannee Limestone.

In Duval, Nassau, Clay and Baker Counties in the northern portion of the SJRWMD, where the nonphosphatic to sparsely phosphatic Charlton Member (of the Coosawhatchie Formation of Scott, 1988a) occurs at the top of the Hawthorn Group, the upper contact of the Hawthorn is not clearly defined by a *high intensity* phosphate peak on gamma logs. The Charlton Member may be recorded on gamma logs as *low moderate* to *high moderate intensity* depending upon the lithologic variations. A minimum of an electric log or (preferably) reliable well samples in some form are required for confirmation of the presence of the member. Figure 17 depicts the gamma log obtained from a public supply well (D-0520) located in northwestern Duval County. The base of the Hawthorn Group remains characteristically well-defined, represented by a *high intensity* peak centered at about 415 feet BLS; however, the uppermost portion, locally represented by the Charlton Member, is recorded as a thin interval of *high moderate intensity* between approximately 95-125 feet BLS.

Electric Logs

The Hawthorn Group is recorded as an extremely variable trace in a variety of different pat-

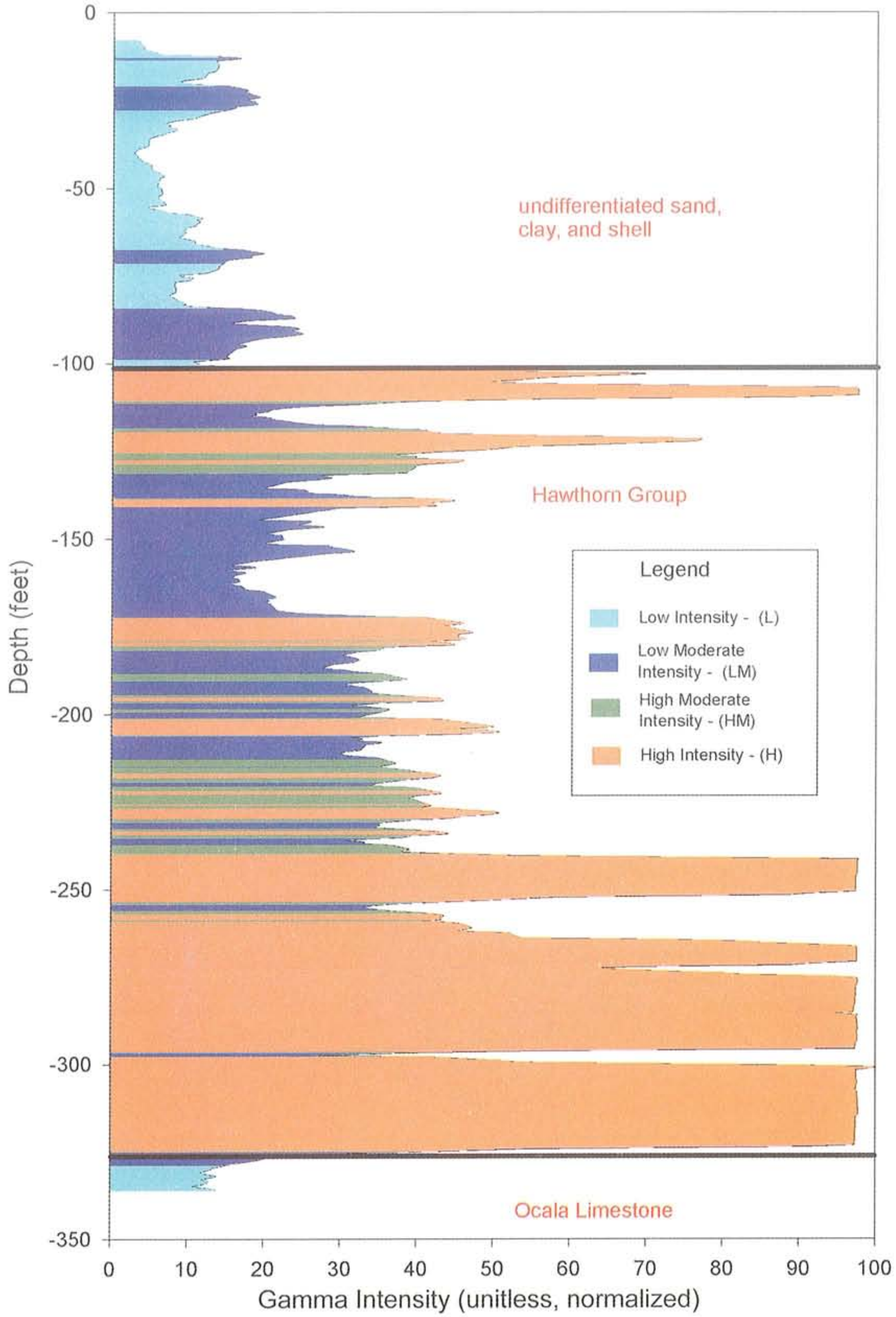

Figure 16. Gamma log of well SJ0177, St. Johns County.

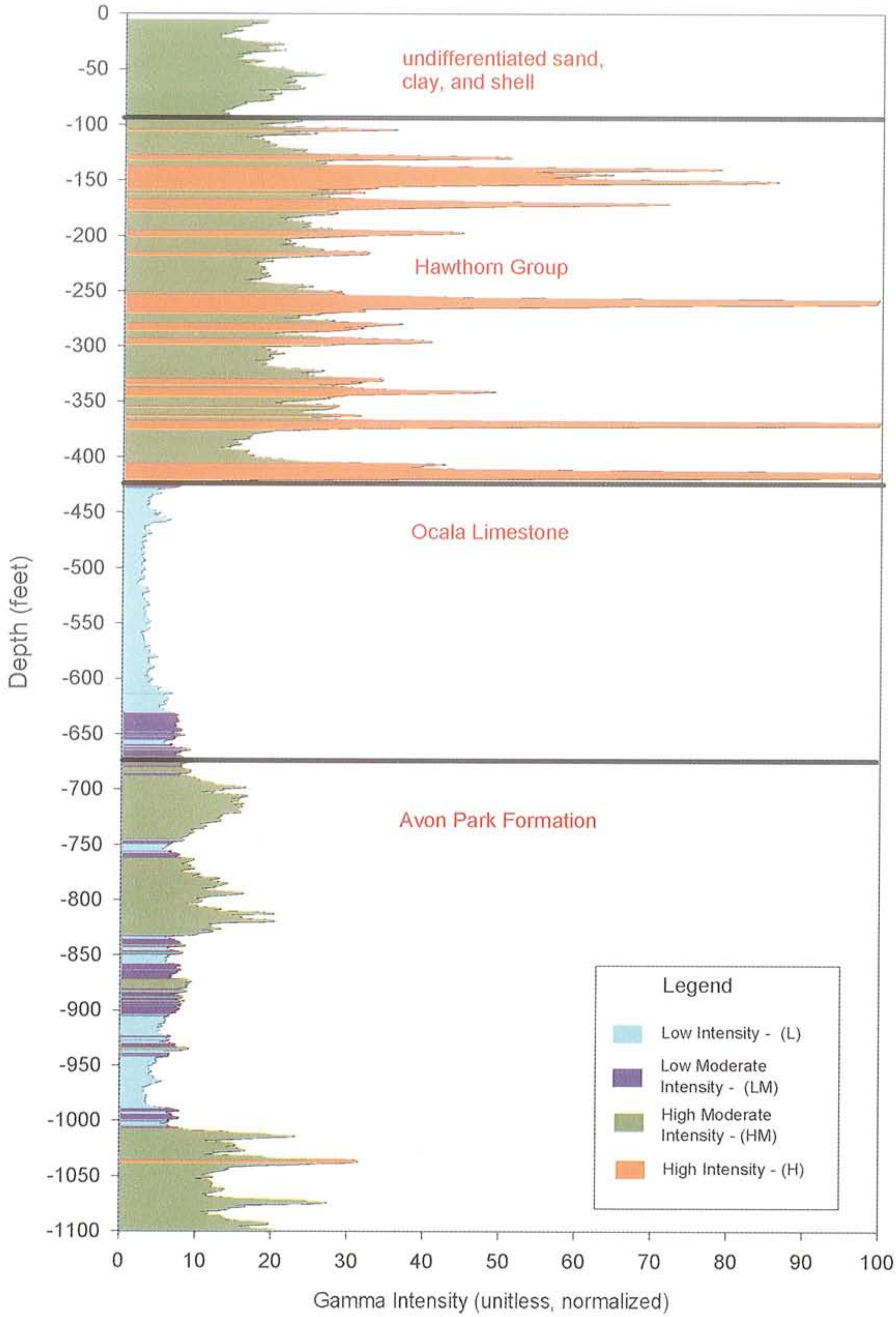

Figure 17. Gamma log of well D-0520, Duval County.

terns on electric logs due to its heterogeneous lithologic nature. In many wells, no electric logs have been recorded since the well casing has been set into the underlying Ocala Limestone and the log cannot record through the casing. Since the Hawthorn Group is composed of both siliciclastic beds, which are typically recorded as low resistivity, and carbonate beds, which are typically recorded as higher than the siliciclastic beds, electric logs can be used to differentiate these units. The volume of phosphate encountered in these sediments is insufficient to affect electric logs. Considering the limitations imposed by the presence of casing and the high variability of the sediments, the gamma log remains the best indicator for the presence or absence of the Hawthorn Group.

Upper Pliocene Series
Tamiami Formation

Mansfield (1939) proposed the name Tamiami limestone for rock exposed in shallow ditches along the Tamiami Trail (U.S. Highway 41) in Collier and Monroe Counties, Florida. Hunter (1968) modified the name to Tamiami Formation. The Tamiami Formation occurs within the SJRWMD in eastern Indian River and southeastern Brevard Counties, where the interval is less than 40 feet thick (Johnson, 1993). The interval also can be traced in the subsurface northward to the vicinity of St. Augustine, east-central St. Johns County, where it is discontinuous, and thins to between 0 and 10 feet thick. Depth to the top of the unit varies between approximately 100 and 150 feet BLS.

Lithostratigraphy

Within the SJRWMD, the Tamiami Formation typically consists of gray to tan to white, moderately to well-indurated, slightly phosphatic, quartz sandy, variably recrystallized calcarenitic limestone, to very hard, molluscan moldic, recrystallized micritic limestone (Johnson, 1993). The Tamiami Formation is most recrystallized and thickest in the immediate vicinity of the Atlantic coast (beneath the barrier islands), becoming less recrystallized (more shelly and less moldic) and pinching out inland toward the west. The Tamiami Formation directly overlies the top of the Hawthorn Group. It underlies the Pliocene to Pleistocene Okeechobee formation of Scott (1994) to the south, or the Nashua Formation (Huddlestun, 1988) to the north. These latter two formations can be differentiated from the Tamiami Formation by their content of unrecrystallized shell material, whereas the Tamiami is predominantly recrystallized and moldic.

Gamma Logs

On gamma logs, the slightly phosphatic Tamiami Formation is commonly not easily recognizable, since the formations below and above may locally incorporate phosphate grains. However, the concentrations of phosphate within the Tamiami Formation are characteristically less than those typical of the underlying Hawthorn Group; thus, the Tamiami may be recorded as uneven *low moderate* or *high moderate intensity* peaks and valleys. The Tamiami can be identified by the marked change in intensity from the underlying *high intensity* at the top of the Hawthorn Group. Moreover, because the overlying Okeechobee formation or Nashua Formation typically contain moderately radioactive clay, higher gamma intensity is locally recorded above the Tamiami Formation. An example of the gamma response to the Tamiami Formation can be seen in Figure 14, well IR0338, in the interval from 123 to 138 feet BLS. In general, however, the presence or absence of the Tamiami Formation in any given well is not determinable from the gamma log alone.

Electric Logs

In eastern Brevard and Indian River Counties, the Tamiami Formation is characteristically recorded on electric logs as a moderate resistivity peak or series of very closely spaced peaks (Johnson, 1993) between the markedly lower resistivity characteristically recorded in the uppermost Hawthorn Group, and basal (predominantly siliciclastic) Okeechobee formation. This trace pattern is depicted in Figure 14, an FGS corehole (IR0338) located in east-central Indian River County. In this well the Tamiami Formation is typically recorded as a moderate resistivity peak centered at approximately 123 feet BLS, with lower resistivity siliciclastic beds below (Hawthorn Group at 138 feet BLS) and above (Okeechobee formation above about 120 feet BLS). To the north of central coastal Brevard County, the Tamiami Formation thins and is commonly more difficult to recognize on electric logs.

Because the lithologies of the remaining post-Hawthorn Group formations are extremely variable over relatively short horizontal distances, geophysical log response is also very local and highly variable. Furthermore, these formations are relatively discontinuous and may be locally very thin or absent; reliable cores or well cuttings are required for confirmation of the presence of these intervals at any specific well location.

Upper Pliocene Series
Cypresshead Formation

Huddlestun (1988) applied the name Cypresshead Formation to Late Pliocene, clayey, gravelly quartz sands in southeastern Georgia. Scott (1988b) extended the unit into Florida. The Cypresshead Formation includes the Citronelle Formation sediments of Pirkle, et al. (1963) in peninsular Florida. The formation occurs only beneath the higher elevation ridges near the central north-northwest/south-southeast axis of peninsular Florida (e.g., the Mt. Dora Ridge). It typically varies between about 30 and 80 feet thick in the SJRWMD. Depth to the top of the unit is generally less than 20 feet BLS, and it commonly forms the land surface on the higher ridges in the central Florida peninsula.

Lithostratigraphy

The Cypresshead Formation is typically composed of unfossiliferous, variably argillaceous quartz sand, silt and gravel, that can be separated into three zones based on lithology (modified from Pirkle et al., 1963). One zone is a relatively thick basal lithozone characteristically consisting of white or lavender, thickly bedded, sparsely argillaceous, very fine to very coarse quartz sand and granule to pebble sized gravel with variable amounts of quartz silt. The middle lithozone is characteristically red, orange, white or lavender in color. It may be banded, laminated, cross-bedded quartz sand and silt which contains higher percentages of clay matrix than the basal lithozone. Quartz gravel and discrete clay beds also occur locally within the middle lithozone. The middle lithozone is typically both thinner and more thinly bedded when compared to the basal white lithozone. The upper argillaceous lithozone is characteristically comprised of dark orange to dark red, argillaceous, homogeneous, very fine to very coarse quartz sand with granule to pebble sized quartz or quartz sandstone grains scattered homogeneously throughout. This lithozone typically contains up to 10 to 20 percent clay matrix.

The Cypresshead Formation is overlain by undifferentiated sand, clay, and shell (UDSCS) or forms the land surface, and is underlain by the Hawthorn Group. Because the Cypresshead Formation lacks all traces of phosphate, the interval is easily distinguished from the phosphatic Hawthorn Group below.

Gamma Logs

On gamma logs, the Cypresshead Formation is locally recorded as a relatively thick *low* to *low moderate intensity* interval (correlating with the basal white lithozone), a middle somewhat higher intensity interval (correlating with the middle somewhat more argillaceous lithozone), and an upper thinner section comprised of one to three, *low* to *low moderate intensity* peaks (representing the upper argillaceous lithozone). An example of the gamma response from the Cypresshead Formation can be seen in Figure 18, well M-0410 in the interval from 33 to 45 feet BLS. However, the presence of this trace pattern on a gamma log obtained from a well in the correct geographical area is not conclusive proof of the existence of the Cypresshead Formation in any given well. In the immediate vicinity of the inland ridges, peaty quartz sand overlying clean quartz sand and gravel (UDSCS) also locally produce a similar gamma trace pattern. Good quality well samples are always required to confirm the presence of the Cypresshead Formation.

Electric Logs

The Cypresshead Formation cannot be distinguished from UDSC on electric logs due to similar local compositions (i.e., quartz sand) and because the Cypresshead, where present, is stratigraphically located at or near the top of the column at or near land surface (like UDSCS) and is typically cased or screened off.

Upper Pliocene to Pleistocene Series
Nashua Formation and Okeechobee formation

Matson and Clapp (1909) proposed the name Nashua marl for molluscan fossiliferous sands exposed near the town of Nashua, on the St. Johns River, in St. Johns County. Huddlestun (1988) elevated the unit to a formation, and included within it the Pliocene and Pleistocene shelly sands in northeastern Florida and southeastern Georgia.

Scott (1993; 1994) applied the name Okeechobee formation (informal) to similar age molluscan fossiliferous units in the southern peninsula. The Okeechobee formation encompasses all or parts of several units originally named on biostratigraphic criteria, including the Caloosahatchee, Bermont, and Ft. Thompson Formations. The Nashua Formation grades southward into the Okeechobee formation. Nashua Formation - Okeechobee formation sediments typically vary from about 50 to 115 feet thick, with a maximum thickness of 135 feet observed in one well in Volusia County. Depth to the top of the units ranges from land surface

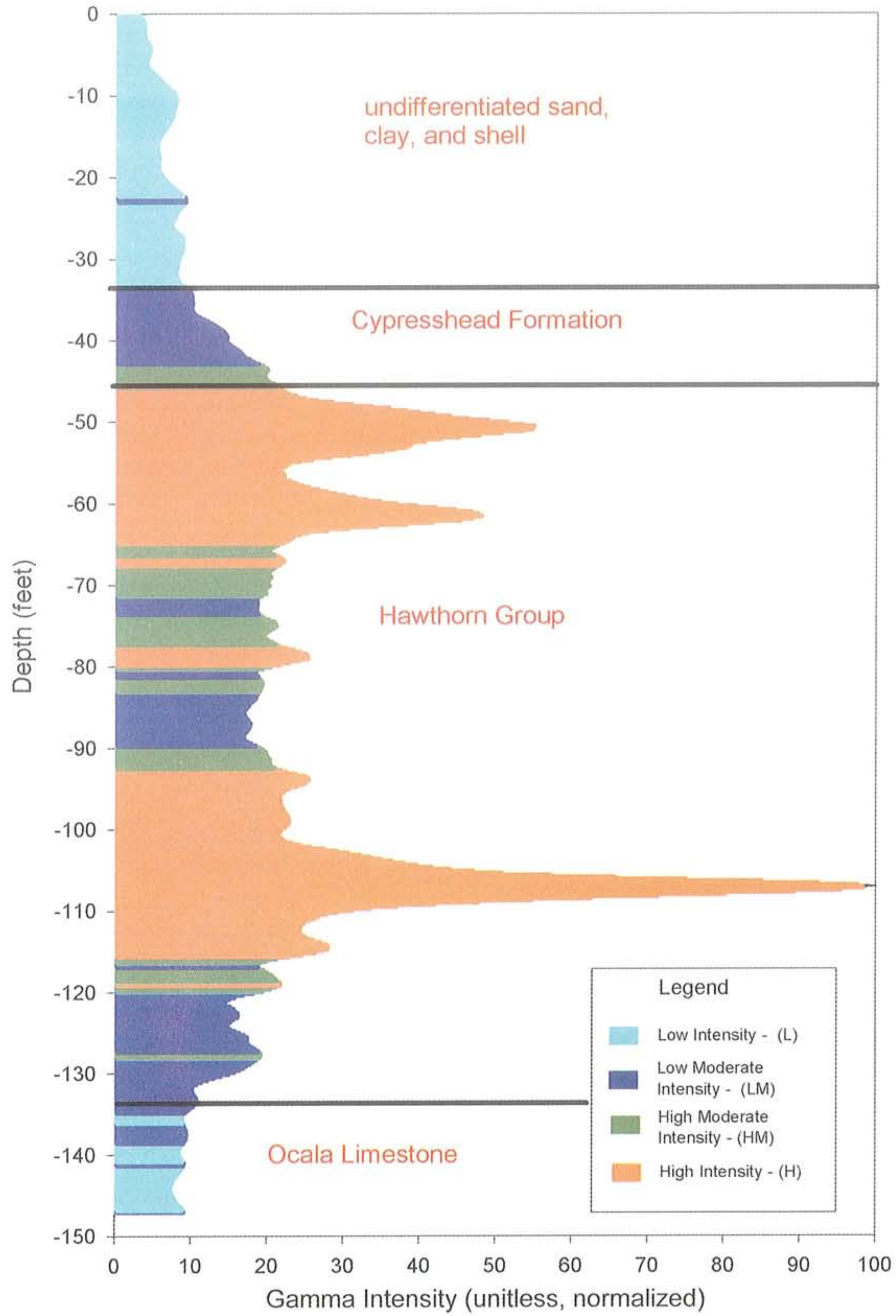

Figure 18. Gamma log of well M-0410, Marion County.

to 90 feet BLS.

Lithostratigraphy

The Nashua Formation and Okeechobee formation consist of gray to tan to brown to green-gray to black, variably fossiliferous and variably phosphatic, argillaceous quartz sand; quartz sandy clay; quartz sandy, molluscan limestone; and variably argillaceous quartz sandy shell beds. Each specific lithology occurs discontinuously, grading into other lithologies or pinching out over horizontal distances of a few feet to a few miles. The Nashua Formation occurs from Volusia and Seminole Counties north to Nassau County, while the Okeechobee formation occurs in the same stratigraphic position from Indian River County to northern Brevard, southern Orange, and eastern Osceola Counties. The Nashua Formation grades to the west and north into the Cypresshead Formation (Huddlestun, 1988) in Clay, Baker, Duval and Nassau Counties by becoming mostly unfossiliferous, completely siliciclastic, and very fine grained.

The predominant defining characteristic of the Nashua Formation and Okeechobee formation is the presence of unaltered macrofossil material, in highly variable concentrations. Typical macrofossils present in these formations include mollusks (pelecypods, gastropods, scaphopods), corals, bryozoans, barnacles, crabs, echinoids and echinoid spines. Characteristically, this fossil material is unworn and unabraded, frequently whole, and pelecypods locally remain articulated and in life position. This occurs because these formations were deposited in low energy paleoenvironments (e.g., lagoonal, landward of a barrier island). The pelecypod *Chione cancellata* is common throughout both intervals, but may be locally rare to absent. The upper portion of the Okeechobee formation is typically less fossiliferous than the lower portion, and locally contains beds of unfossiliferous, peaty, quartz sand.

The Nashua Formation and Okeechobee formation are underlain by either the Tamiami Formation (along the Atlantic coast north to the vicinity of St. Augustine, east-central St. Johns County) or the upper siliciclastic lithozone of the Hawthorn Group (in the remainder of the SJR-WMD). The Nashua Formation and Okeechobee formation differ from the Tamiami Formation in that the latter is composed almost exclusively of fully recrystallized molluscan moldic limestone, whereas the Nashua and Okeechobee are predominantly siliciclastic. Locally, where the basal Nashua Formation or Okeechobee formation contains beds of limestone, this lithology is characteristically less recrystallized, with most of the contained shell material unaltered. Where these two formations are underlain by the Hawthorn Group, the substantially higher phosphate concentrations typically occurring in the upper siliciclastic Hawthorn lithozone serve to distinguish the interval from the Nashua Formation and Okeechobee formation. Moreover, the Hawthorn Group characteristically contains substantially lesser concentrations of macrofossils such as mollusks when compared to the overlying Nashua Formation or Okeechobee formation. Additionally, the Nashua Formation becomes discontinuous in the northern portion of the SJR-WMD (Clay, Baker, Duval, northern St. Johns, and Nassau Counties).

Gamma and Electric Logs

Due to the variable lithologies and variable amounts of phosphate found within these two formations, geophysical log response is also quite variable. Figure 19 illustrates the gamma log

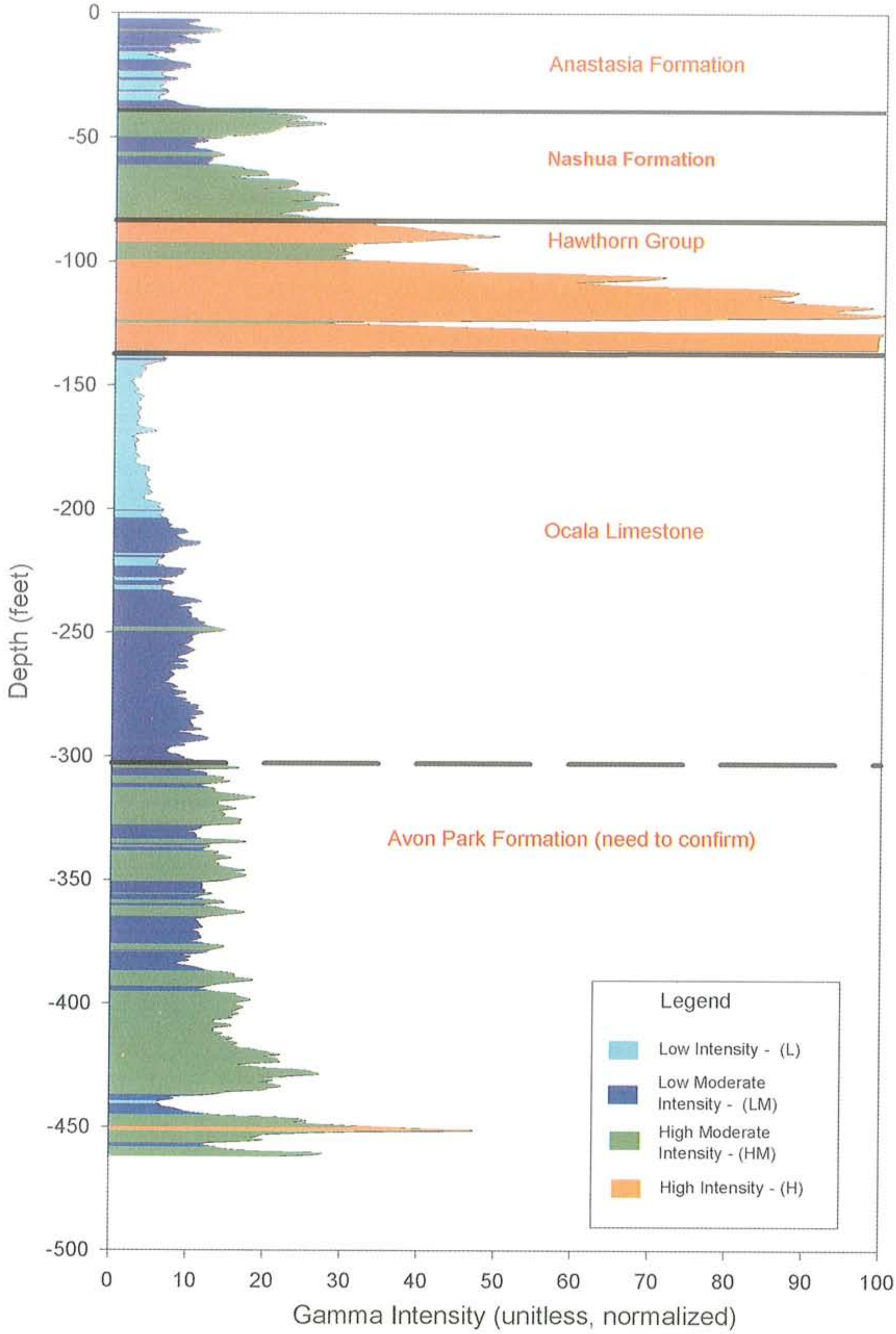

Figure 19. Gamma log of well F-0019, Flagler County.

obtained from an FGS corehole (W-15282; Washington Oaks State Gardens #1; F-0019) located in northeastern Flagler County on the barrier island. The Nashua is recorded in this well between 40 and 92 feet BLS, and consists of a series of *low moderate* to *high moderate intensity* peaks, culminating in a *high intensity* peak representing a moldic limestone at the base of the unit. In general, argillaceous and somewhat phosphatic lithologies are recorded as very uneven, *low moderate* to *moderate intensity* on gamma logs; clay content is recorded as very low to low resistivity on electric logs; and nonphosphatic, quartz sandy limestone beds or shell beds are recorded as *low intensity* on gamma logs and as low moderate to moderate resistivity peaks on electric logs. Again, some form of reliable well sample is necessary to accurately determine presence or absence of these formations in any specific well.

Pleistocene Series
Anastasia Formation

Sellards (1912) applied the name Anastasia Formation to shelly sands and coquina rock exposed along the east coast of the Florida peninsula. The relatively discontinuous Anastasia Formation occurs within the SJRWMD only along the Atlantic coast from Indian River County north to southeastern St. Johns County (vicinity of St. Augustine). It forms the core of the Atlantic Coastal Ridge along much of its length. In the SJRWMD, maximum thickness is about 70 feet. The top of the Anastasia Formation varies from land surface to about 30 feet BLS.

Lithostratigraphy

The Anastasia Formation is characteristically comprised of nonphosphatic, orange to tan to white, worn and abraded shell (predominantly mollusk) beds, molluscan limestone, and variably shelly unconsolidated quartz sand to moderately consolidated quartz sandstone (Johnson, 1994). The shell beds vary locally and may contain traces of black to dark brown very finely particulate peat as stringers and laminae. The Anastasia Formation represents high-energy beach, intertidal or offshore bar paleoenvironments of deposition. Shell material is characteristically worn, abraded and predominantly fragmental (Johnson, 1994). Additionally, the common presence of *Donax variabilis,* a small pelecypod, underscores the depositional higher energy nature of the Anastasia Formation (Johnson, 1994).

The Anastasia Formation occurs beneath the Atlantic barrier islands and extends no more than 15 miles inland on the mainland to the west, grading into the upper portion of the Okeechobee formation in Brevard and Indian River Counties by change in environment of deposition from high to low energy. The lower portion of the Okeechobee formation or the Nashua Formation occurs stratigraphically below the Anastasia Formation in the southern and northern portions, respectively, of the SJRWMD. Either Holocene UDSCS (typically black, unconsolidated, peaty quartz sand) occurs above the Anastasia Formation, or the interval forms local land surface.

Gamma Logs

On gamma logs, the Anastasia Formation is recorded as either even *low intensity*, representing nonphosphatic, nonargillaceous, nonpeaty shell beds, limestone or quartz sand/sandstone, or as uneven *low moderate intensity* where peat or other (nonphosphatic) locally occurring heavy mineral grains are present within these lithologies. Figure 19 illustrates the gamma log obtained from a corehole (W-15282; F-0019) located in northeastern Flagler County on the barrier island. The Anastasia Formation is recorded at this specific location as uneven *low* to *low moderate intensity* from approximately 40 feet BLS (top of the *high moderate intensity* peak representing the top of the Nashua Formation) to very near land surface. However, where peat and/or heavy minerals occur, where the borehole is larger in diameter, or in other areas to the south away from the type area (Anastasia Island), the gamma trace may be poorly defined and not recognizable. Where reliable well samples are available and lithologies typical of the Anastasia Formation are confirmed present, its basal contact with the underlying Nashua Formation (north) or lower Okeechobee formation (south) is typically distinguishable on gamma logs. The uppermost portions of these underlying formations typically contain both phosphate grains and clay, recorded as a sharp and significant increase in intensity with respect to basal nonphosphatic and nonargillaceous Anastasia Formation. This gamma trace pattern is also illustrated on Figure 19; the top of the phosphatic argillaceous Nashua Formation is recorded as a distinct *moderate intensity* peak centered at approximately 45 feet BLS, just below the much lower intensity of basal Anastasia Formation.

Electric Logs

On electric logs, interbeds of dense, relatively nonporous limestone and well-consolidated, nonporous quartz sandstone within the Anastasia Formation are recorded as relatively broad, low moderate resistivity peaks alternating with low resistivity valleys representing porous intervals (such as unconsolidated shell beds or clean quartz sand). This even to uneven, low peak and valley pattern on both gamma and electric geophysical logs is not exclusive to the Anastasia Formation; thus, the formation generally cannot be distinguished reliably on the basis of geophysical logs alone. Again, reliable core or well cutting samples must be utilized to detect the presence of the Anastasia Formation in any particular well within its area of occurrence.

Pleistocene to Holocene Series
Undifferentiated Sand, Clay and Shell

Undifferentiated sand, clay and shell (UDSCS) occurs discontinuously throughout the SJRWMD, varying from zero to over 200 feet in thickness. In this report, the UDSCS has been used to label the post-Miocene sediments on most of the figures and cross sections. The exception to this are Figure 18 (M-0410), showing an example of the gamma response in the Cypresshead Formation, and Figure 19 (F-0019), showing an example of the Nashua and Anastasia Formations. Since the post-Miocene units are difficult, if not impossible, to correlate using gamma logs alone, this seemed to be the most practical solution.

Lithostratigraphy

This interval (which does not constitute a formal formation) is extremely lithologically variable: quartz silt/sand/gravel to clay to shell material to limestone, and all combinations of these lithological continua end points. Moreover, lithologies commonly change over extremely short horizontal distances, on the order of inches to feet. However, the most common lithology encountered in the SJRWMD is tan to gray, very poorly consolidated to unconsolidated, unfossiliferous, pure to peaty quartz sand which contains very low percentages of sand sized, undifferentiated heavy mineral grains. In addition, brown to dark gray, unfossiliferous, variably argillaceous quartz sand is also relatively common throughout the SJRWMD.

Gamma and Electric Logs

Due to the pronounced lithological variability and discontinuity of the UDSCS stratigraphic interval, no reliable and correlatable patterns occur on geophysical logs; good quality well samples must be available in order to identify the interval in any specific well. Generally, pure quartz sand is recorded on gamma logs as even *low* to *low moderate intensity*, whereas peaty quartz sand is recorded as uneven *low* to *low moderate intensity*, and argillaceous quartz sand or quartz sandy clay as *low moderate intensity* peaks. Furthermore, because the UDSCS interval is stratigraphically located at land surface at the top of the Cenozoic column, is not everywhere water saturated, and is typically cased or screened in most water supply wells, neither electric nor neutron logs can be used for identification or correlation.

SUBSURFACE FEATURES AFFECTING THE STRATIGRAPHY AND LOG CORRELATIONS IN THE SJRWMD

The geologic strata discussed above were deposited in a relatively flat-lying sequence, with progressively younger sediments overlying older units. The aerial extent, dip, and thickness of these geologic units have been influenced by a number of local and regional factors, including pre-existing structural features, paleo-erosion events, post-depositional subsidence and karst activity. Data are largely lacking on the local extent of paleo-erosion and subsidence. However, two better-documented types of features which significantly affect the configuration of the strata underlying the SJRWMD are buried paleosinks and regional subsurface geologic structural features.

Paleosinks

The term paleosink (paleokarst) is generally used to describe a buried karst feature that was formed under different conditions than the current geologic setting (Ford and Williams, 1992). The karst features include cover collapse sinkholes, solution sinkholes, cover subsidence sinks and solution pipes. The feature may or may not have visible signs at land surface. Paleosinks have been blamed for anomalous results in drilling projects such as unusually thick or missing sections and can even be mistaken as evidence of faults. One of the best ways to understand what a buried paleosink looks like is to see results from surface geophysical techniques such as high resolution seismic reflection profiling (HRSP). HRSP has been used extensively to map paleokarst beneath lakes (Kindinger et al., 1994, 1999, 2000; Locker et al., 1988; Sacks et al., 1991) in northeast Florida.

To identify paleosinks using borehole geophysical techniques it generally requires logs from several closely spaced wells. An excellent example of using gamma logs to identify a paleosinkhole was done at the University of Florida motor pool site (Edelstein, 1993). During this study, fifteen wells were drilled in and around an area containing a leaking underground fuel storage tank. The *high intensity* of the Hawthorn Group could be seen only in wells around the perimeter of the paleosink whereas only *low moderate* or *high moderate intensity* units could be seen in the area disturbed by the sinkhole subsidence. In other cases, the *high intensity* units of the Hawthorn Group may show marked changes in elevation over short distances with an accompanying thickening of the overlying sands and clays. This is a strong indication that the wells were drilled along the slope of a buried paleosinkhole. Other effects of paleokarst on gamma logs occur where clays and phosphates from the Hawthorn Group have been transported downward into voids in the underlying limestones. The gamma counts may be higher than would be expected from the pure limestone. Gamma logs used in this report were chosen more to reflect the regional trends rather than the localized effects that paleokarst would cause. When correlating gamma logs, the effects of paleosinks should be considered when anomalies are identified.

Structure

A series of subsurface geologic structures significantly influence the distribution and configuration of the Middle Eocene and younger geologic units underlying the SJRWMD. Early literature on these features generally attributed their formation to structural events, such as uplift, faulting, or structural downwarping. Due to a paucity of data on the features, their actual modes of origin are uncertain. Therefore, modern nomenclature for the features attempts to avoid a deformational connotation (Scott, 1988). In general, positive (high) features bring Eocene carbonate units close to the surface. This has resulted in either non-deposition of younger units, or erosion of younger units that once covered the carbonate bedrock comprising the feature. Negative (low) features are basins, with the top of Eocene carbonates lying deeper than adjacent areas. These basins typically accumulated increased thicknesses of post-Eocene siliciclastic sediments. Figure 20 illustrates the locations of the major subsurface structural features affecting the SJRWMD. As detailed below, the influence of the features on the geologic strata may be observed on cross sections in Appendix A.

Lying just west of the SJRWMD is one of the most significant subsurface structures in Florida: a broad, northwest-southeast trending positive feature named the Ocala Platform (Hopkins, 1920; Vernon, 1951; Scott, 1988a). The Ocala Platform crests under Levy County and forms an extensive karst plain, comprised of Middle Eocene to Oligocene carbonates under the central Big Bend and north-central peninsular areas. The carbonates dip in all directions away from the crest of the Ocala Platform. Dips are generally around 0.1 degree, or about 10 feet per mile (Tom Scott, 2001, personal communication). The top of the Eocene Ocala Limestone typically deepens from approximately 90 feet above MSL in northern Alachua County (Well A-0438, cross section E-E') to over -500 feet MSL in northeastern Nassau County (Well N-0277, cross section A-A') in the trough of the adjacent Jacksonville Basin. Younger geologic units pinch out against the flanks of the Ocala Platform. Cross section JJ-JJ' runs approximately parallel to the strike of this feature, along its eastern flank. This section shows the generally shallow and gently-dipping structural surfaces of the Eocene Avon Park Formation and Ocala Limestone in the western part of the SJRWMD. The Miocene Hawthorn Group is absent over the crest of the Platform, west of the SJRWMD. It dips and thickens to the east-northeast off the eastern flank of the platform (section E-E').

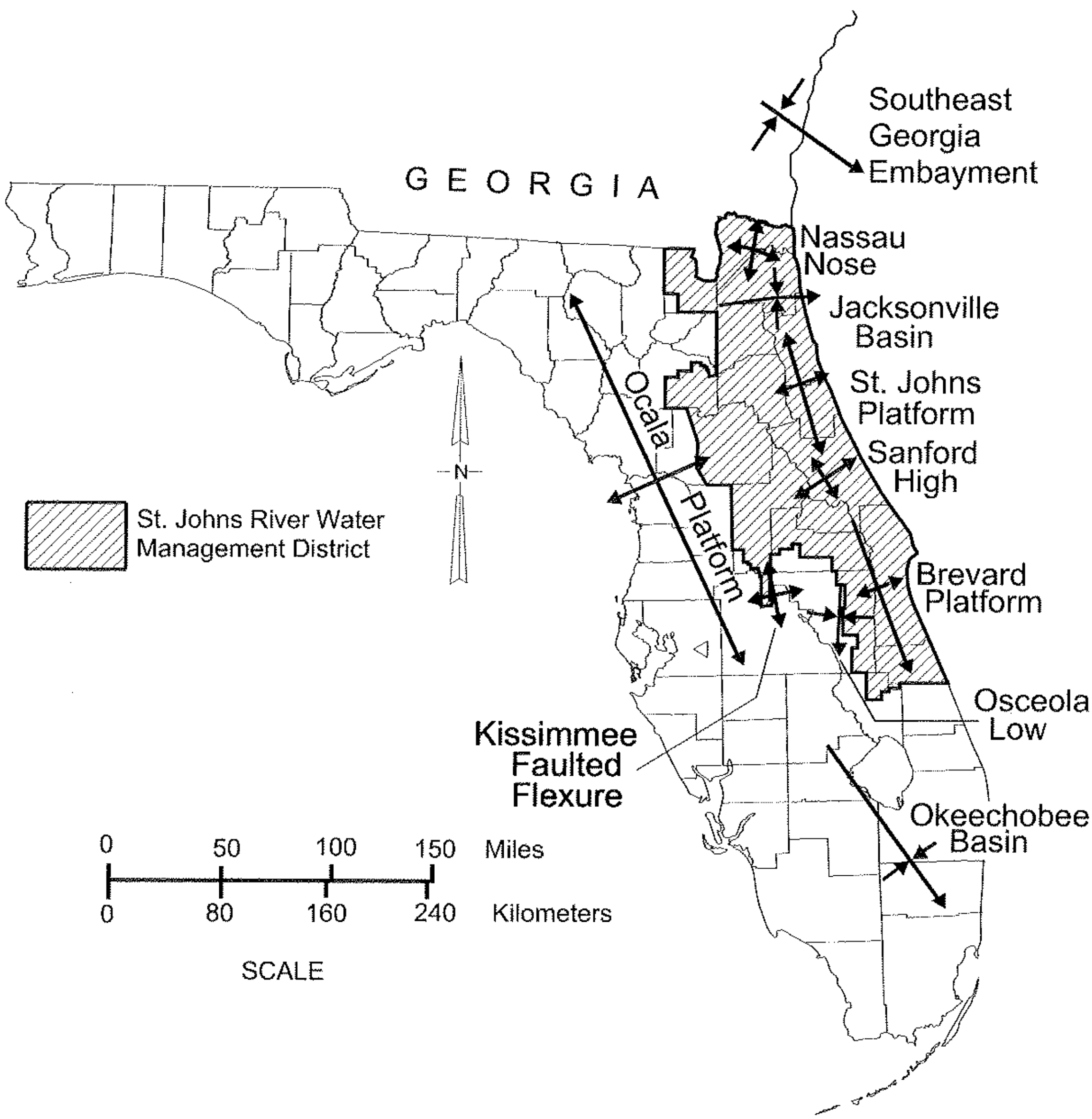

Figure 20. Subsurface structures in the SJRWMD (modified from Scott, 1988a).

The Jacksonville Basin (Goodell and Yon, 1960) underlies Duval and eastern Nassau Counties. It is the most prominent subsurface low in the northern Florida peninsula. In the trough of the basin, Hawthorn Group sediments attain thicknesses in excess of 450 feet (Well D-1118, cross section AA-AA'). The Jacksonville Basin is a sub-basin of the much larger Southeast Georgia Embayment, and is separated from the latter by a positive feature named the Nassau Nose (Scott, 1983). The Nassau Nose is situated under north-central Nassau County, where its influence causes a slight rise of the top of Ocala Limestone (Well N-0221, cross sections U-U' and KK-KK').

The Sanford High (Vernon, 1951) is a positive subsurface feature located under Seminole and Volusia Counties. Cross section I-I' illustrates the influence of this feature on the local strata. The structural surfaces of the Avon Park Formation and Ocala Limestone rise at the crest of the high at wells L-0122 and V-0254. Middle Eocene Avon Park Formation carbonates form the core of the feature, and the Ocala Limestone and Hawthorn Group may be missing from some areas (well V-0254) over the crest of the Sanford High. In these areas Avon Park Formation carbonates lie immediately below post-Hawthorn sediments.

North and south of the Sanford High two low, broad structural platforms are evident on the erosional surface of the Ocala Limestone. The St. Johns Platform (Riggs, 1979a, b) extends northward under St. Johns County, plunging gently into the Jacksonville Basin. Well F-0251 (cross section AA-AA') is drilled near the crest of the St. Johns Platform. West-east cross section D-D' illustrates the Hawthorn Group sediments deepening off the Ocala Platform on the west, then climbing onto the St. Johns Platform at well SJ0164.

To the south, the Brevard Platform (Riggs, 1979a, b) underlies Brevard County, and plunges gently to the south-southeast towards the Okeechobee Basin of southern Florida. Section II-II' runs nearly parallel to the strike of the Brevard Platform and illustrates the gently dipping nature (three feet per mile) of the Avon Park Formation and Ocala Limestone along the feature. At the southern end of the platform the dip of the Eocene strata increases (to about 20 feet per mile) southward into the basin. Cross section HH-HH' illustrates the southward-dipping surfaces of the Eocene and Oligocene units off the Brevard Platform into the Okeechobee Basin.

Situated between the southern ends of the Ocala and Brevard Platforms are two significant subsurface features named the Kissimmee Faulted Flexure and the Osceola Low (Vernon, 1951). The Kissimmee Faulted Flexure, originally considered by Vernon to be a fault-bounded block, is a high on the Middle Eocene Avon Park Formation (Scott, 1988a). Well PO0013 in cross section P-P' represents the crest of the feature. Although not shown on the present sections, Ocala Limestone and Hawthorn Group sediments may be absent over a portion of the feature due to erosion. The Osceola Low is a north-south trending low, or trough, on the erosional surface of the Ocala Limestone. Sediments of the Hawthorn Group are thicker within the low than in immediately adjacent areas. The middle portion of cross section P-P' and cross section Z-Z' (wells OS00005A and OS0068) illustrate this thickening. Here Hawthorn sediments attain a maximum thickness of about 200 feet. Although Vernon (1951) noted up to 350 feet of Miocene sediments within the Osceola Low, this anomalous data was apparently derived from a well drilled in a paleosinkhole located in the trough of the low (Tom Scott, 1999, personal communication).

The stratigraphy of the southernmost portion of the SJRWMD is influenced by a large negative structure named the Okeechobee Basin (Riggs, 1979a, b). This feature underlies much of southern Florida. Eocene and Oligocene carbonates and the overlying Hawthorn Group sediments dip and thicken into the basin towards the south and southeast. The southern portions of cross sections Z-Z', DD-DD', and HH-HH', spanning southern Brevard, St. Lucie, Indian River, and Okeechobee Counties, illustrate the accentuated dip of the strata into the Okeechobee Basin.

GAMMA LOG SIGNATURES AND CROSS SECTIONS

The gamma log cross sections (Appendix A) not only show the subsurface structural features but also illustrate the similarities and variations in gamma log signature from one region to the next. Gamma log signature can be described as a characteristic pattern of peaks and valleys in a log that can also be recognized in other gamma logs. The idea of signature is more obvious when viewed in a cross section since the pattern of peaks and valleys for individual gamma logs can be recognized in the other logs of the cross section.

The gamma log for well D-0176 (Figure 11) demonstrates a typical signature for a complete stratigraphic sequence from land surface down into the Avon Park Formation. The log has four characteristic zones. One is an upper zone with *low* and *low moderate intensity* peaks which correspond to the post Hawthorn Group sediments (0 to 48 feet BLS). It is underlain by zone two which is predominately *high* and *high moderate intensity* peaks but also contains *low* and *low moderate intensity* peaks which correspond to the Hawthorn Group sediments (48 to 505 feet BLS). Below that is zone three which consists of *low intensity* peaks underlain by *low moderate intensity* peaks which corresponds to the upper and lower lithozones of the Ocala Limestone (505 to 730 feet BLS). The lowest zone is predominately *high moderate* and *low moderate intensity* peaks but may be interbedded with *low* and *high intensity* peaks (730 to 1275 feet BLS). The actual thickness of the different zones will vary greatly throughout the SJRWMD, however, the general pattern (or parts thereof) can be recognized over most of the region. Many of the cross sections demonstrate this recognized signature that can be traced laterally for many miles. Sections A-A', B-B', C-C', F-F', J-J', N-N', R-R', T-T', U-U', V-V', W-W', DD-DD', FF-FF', and JJ-JJ' are good examples of typical log signature patterns.

An anomaly to this simplistic pattern can be seen in gamma log cross section KK-KK' (Appendix A). This section runs through the center of the SJRWMD from the northern boundary in Nassau County almost to the southern boundary in Indian River County. This covers a distance of approximately 230 miles. The signature discussed above is best illustrated in the northern wells (N-0221, C-0142, and C-0123) and in the southern wells (OR0015, OS00005, and IR0314). The central part of the cross section at well V-0254 highlights the most variability of a gamma log signature. The only similarities in V-0254 to a complete stratigraphic sequence occur in the Avon Park Formation sediments which show the *low moderate* and *high moderate intensity* sections. Even the undifferentiated sand, clay, and shell contains a 20' thick *high intensity* unit instead of the normally *low* and *low moderate intensity* that is generally seen.

The east-central region of the SJRWMD illustrates how the signature changes over the structural highs where complete sections have been eroded or never deposited. Scott (1988a) constructed an isopach of the Hawthorn Group sediments that shows the areas in this region where the Hawthorn Group is missing. In cross section BB-BB', for example, Hawthorn Group and Ocala Limestone sediments are missing from all wells south of F-0294 and F-0251, respectively. The extreme variation of the Hawthorn Group sediments in thickness of the entire group, thickness of individual units, and lateral continuity or discontinuity of individual *high intensity* units can be seen by trying to trace a particular unit from one well to the next.

The change in gamma intensity between the Avon Park Formation and the overlying Ocala Limestone can be traced laterally for many miles as demonstrated in the gamma cross sections. A good example of how the contact can be traced laterally is demonstrated in gamma cross section W-W' which runs from northern Nassau County for 70 miles into southern Putnam County. The top of the Avon Park Formation can easily be identified in all of the logs where the formation is present. Other sections such as B-B', K-K', S-S', Y-Y', Z-Z', and DD-DD' demonstrate the general character of the contact. Since the change is generally from either *low intensity* to *low moderate intensity* or *low moderate* to *high moderate intensity*, borehole conditions such as cavities or a large diameter bore can attenuate the gamma response and greatly limit the ability to distinguish the contact.

The top of the Hawthorn Group in many sections (e.g. B-B', C-C', and D-D') can often be identified as the first *high intensity* peaks. However, there are many logs where the top is located on either *low moderate* or *high moderate intensity* peaks (e.g. OR0614 in section Y-Y', OS00005a in section Z-Z', SJ0163 in section AA-AA', SJ0025 in section FF-FF', and N-0117 in section FF-FF'). Wells OR0015 and P-0418 in section KK-KK' illustrate the problems associated with identifying the top of the Hawthorn Group from the gamma logs alone. The boundary for OR0015 required lithologic data because the change in gamma intensity was too slight to use for identification. In P-0418, the Hawthorn Group is overlain by sediments with *high intensity* units that were identified as younger sediments. Gamma cross section EE-EE' demonstrates the extremes seen in the east-central region of the district. In EE-EE' there is no Hawthorn Group in any of the logs, the Ocala Limestone pinches out to the west, and the gamma peaks in the undifferentiated sand, clay, and shell range from a *high intensity* signature that could be confused with the Hawthorn Group (wells V-0254, V-0267, and V-0304) to a *low intensity* (well V-0819).

The gamma log cross sections for areas north of G-G', south of N-N', and west of V-V' show fairly typical gamma signatures except for variations in thickness. The gamma signature for the region bordered by G-G', N-N', V-V' and the Atlantic Ocean either have units missing, or units that are very thin. Correlations between logs in this region are further complicated because units near the surface may be comprised of reworked Hawthorn Group sediments that contain sufficient clay and phosphate to produce *low moderate* to *high intensity* peaks that can be confused with original Hawthorn sediments. In the regions over the structural highs, it is important to have other supporting data when identifying geologic unit boundaries.

CONCLUSIONS

The SJRWMD and the FGS reviewed the databases of geophysical and lithologic well logs to identify *reference logs* for correlation of geologic units throughout the SJRWMD. This cooperative effort has resulted in 38 gamma log cross sections and descriptions of key gamma log signatures for the geologic units within the Cenozoic Era.

Typical gamma log signatures for most geologic units may be recognized in a newly logged well by the following procedure. First, the location of the well should be identified relative to the nearest cross section to determine approximate depths the units are to be expected and if they are to be present at all (e.g. units are missing in Volusia and northeast Seminole Counties). Second, the relative gamma log intensity for particular zones should be determined based on a qualitative visual estimation or a quantitative determination of intensity zones. The quantitative method described herein requires a general idea of where the Ocala Limestone and Hawthorn Group sediments occur in the log. For a log that penetrates a complete Cenozoic section, zones of *low intensity, low moderate intensity, high moderate intensity* and *high intensity* can be identified. The examples presented were normalized first to minimize the differences due to equipment, units of measurement (cps, API), and borehole effects. The examples presented also utilized a standard color scheme to help in correlating units from one log to another. Third, the log can be compared to the nearest cross section or reference log to correlate signatures.

A compilation of *reference logs* was developed (Appendix B) as documentation of the log data that were used to establish contacts of geologic units. The *reference logs* are from wells that have detailed lithologic descriptions either from that well or from one or more nearby wells. In most cases, the lithologic logs were used to identify the geologic unit and the geophysical logs were used to define the elevation of contact.

The gamma log cross sections in Appendix A were developed to demonstrate how gamma log signatures are consistent over large areas and to identify the areas with the highest variability. There is sufficient cross section coverage such that any new logs should have a cross section close enough for correlation purposes. The *reference logs* can be used to correlate additional gamma logs so that more detailed cross sections can be constructed.

The majority of wells within SJRWMD either have incomplete or no lithologic data available to help identify geologic contacts in geophysical logs. With this foundation of *reference logs*, a large data base of correlated geophysical logs can now be developed with sufficient coverage to provide input for ground water models, create maps of geologic surfaces, and provide a framework for predictive geologic assessments for drilling and water supply investigations.

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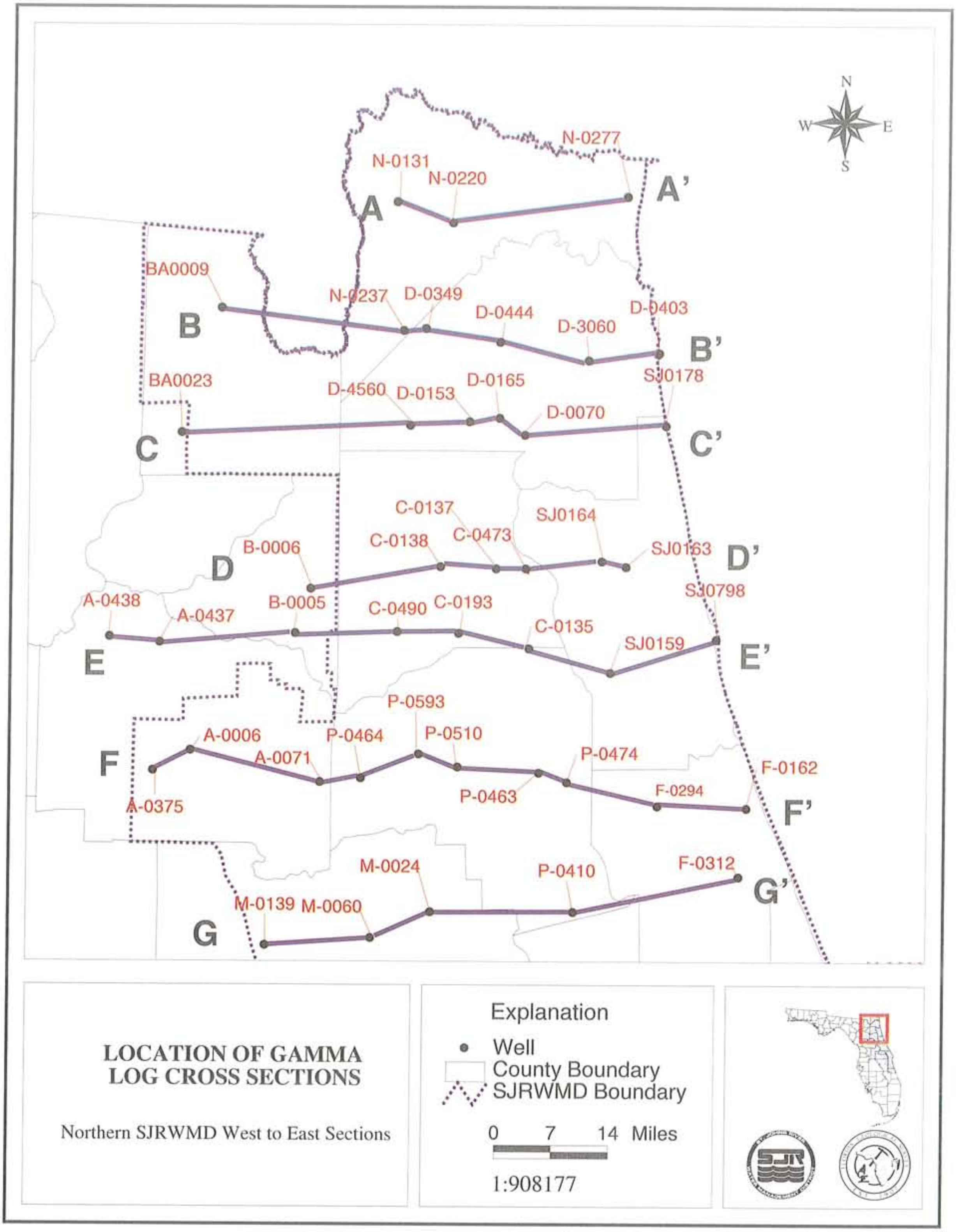
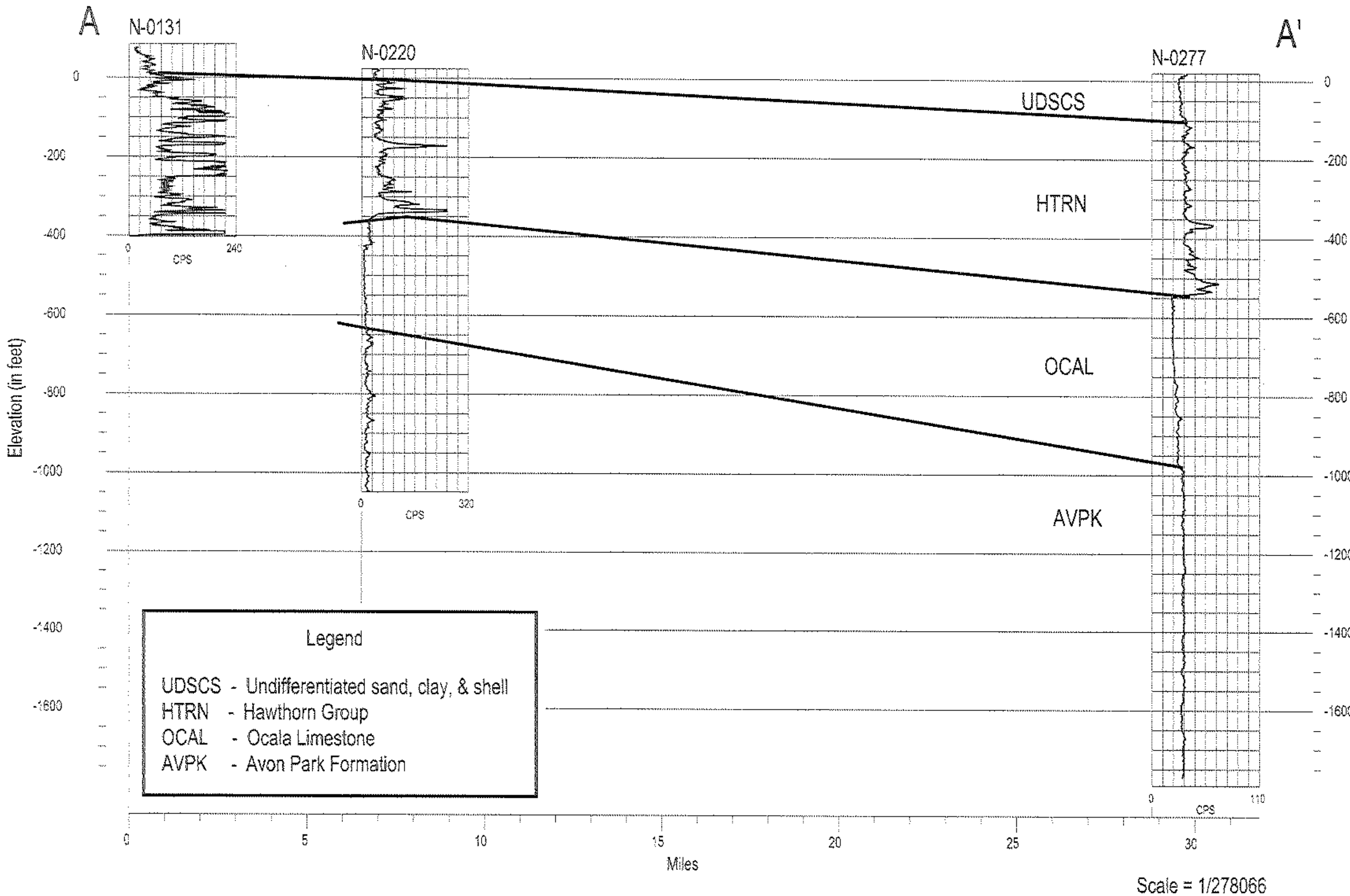
APPENDIX A: Cross Sections through the SJRWMD

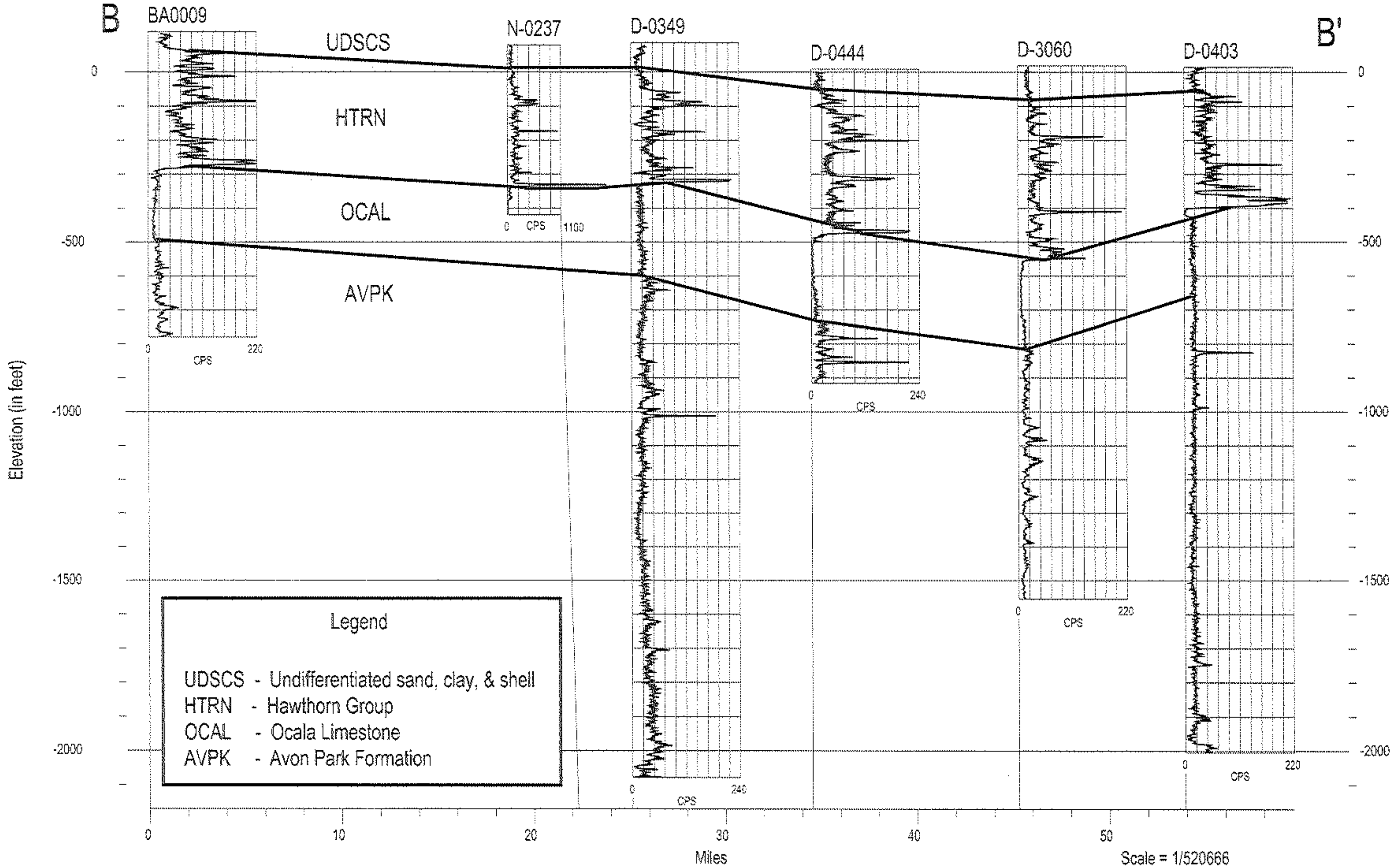


Location of gamma log cross sections, northern SJRWMD
West to East Sections

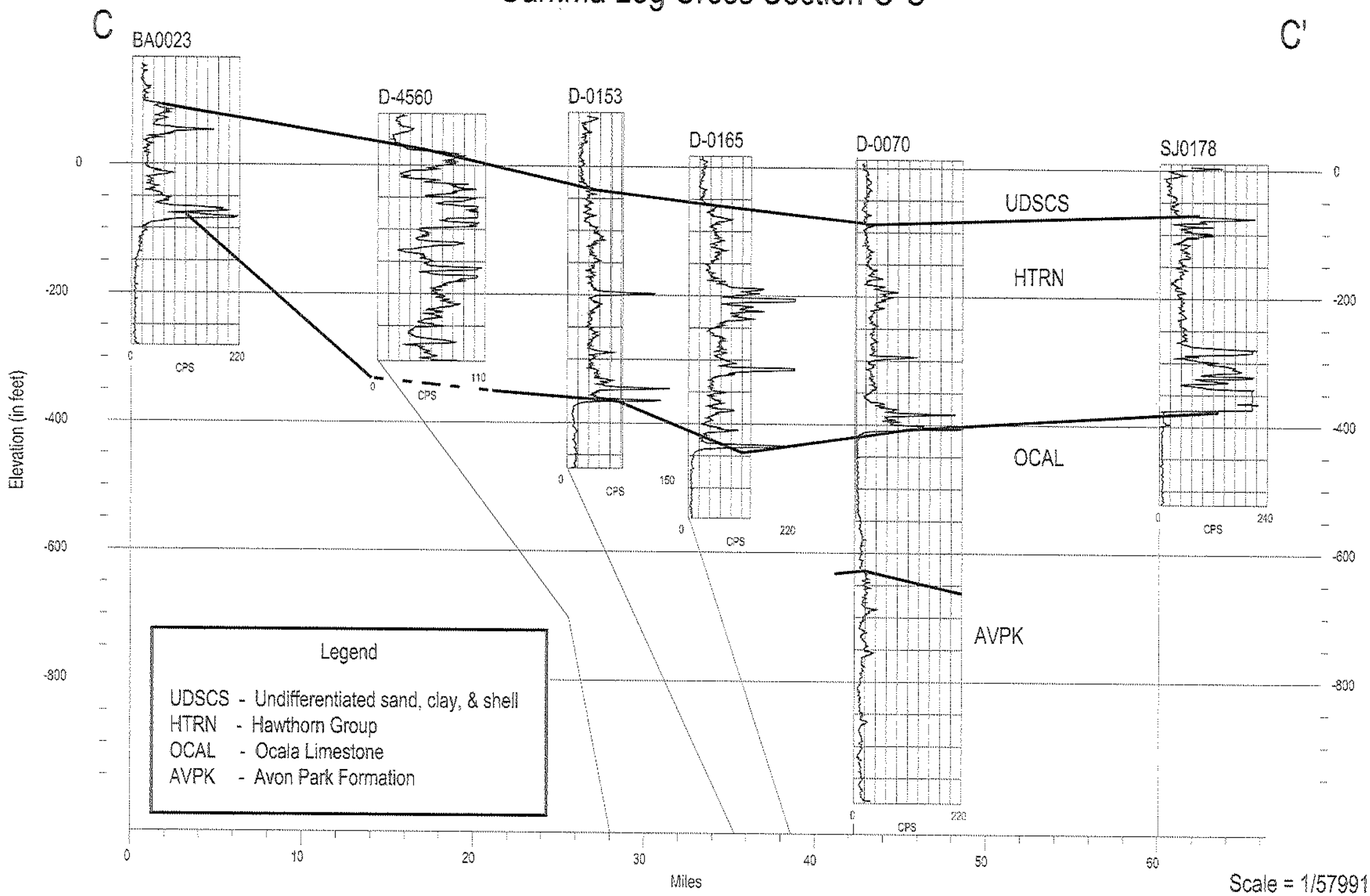
Gamma Log Cross Section A-A'



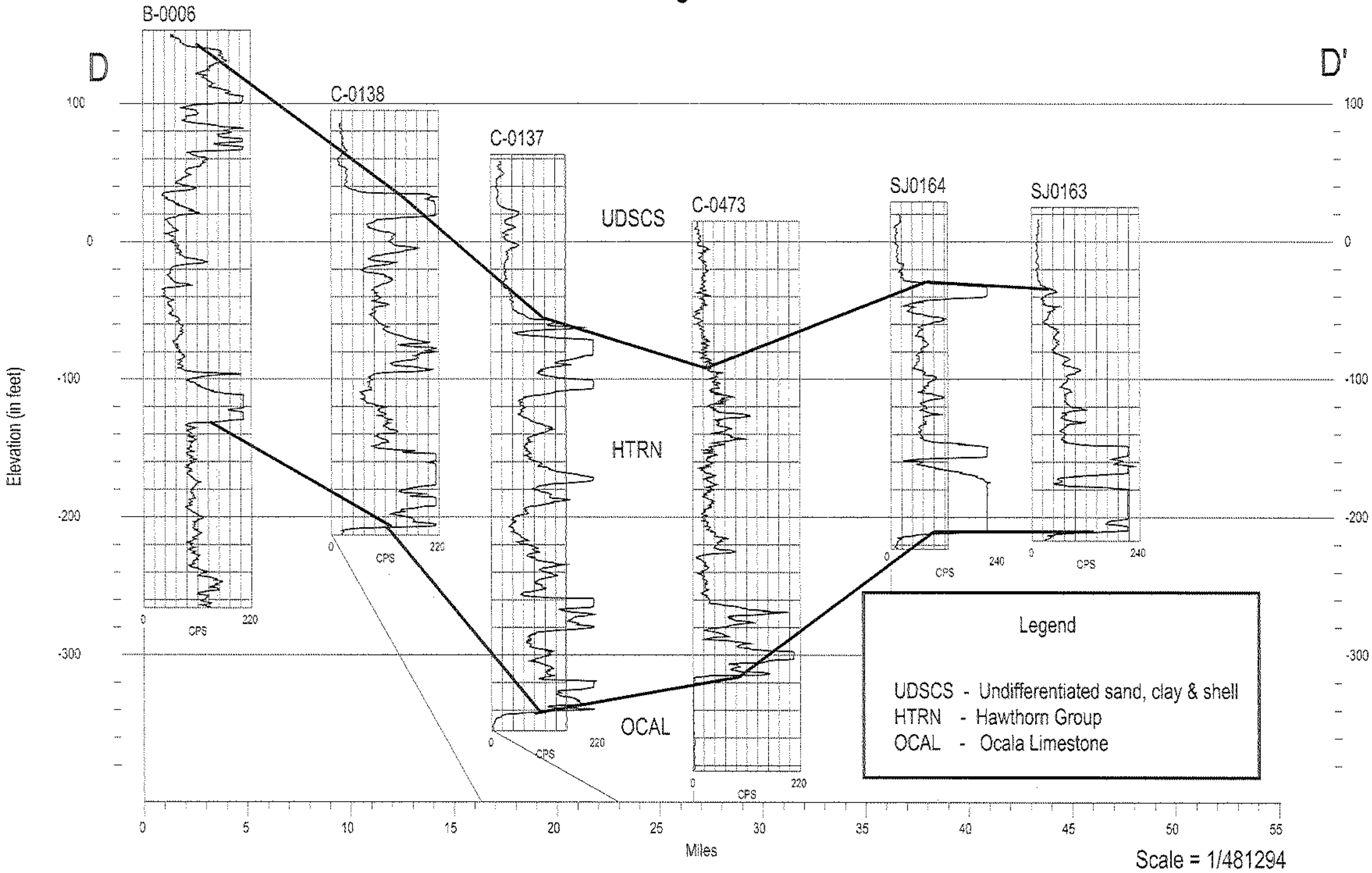
Gamma Log Cross Section B-B'



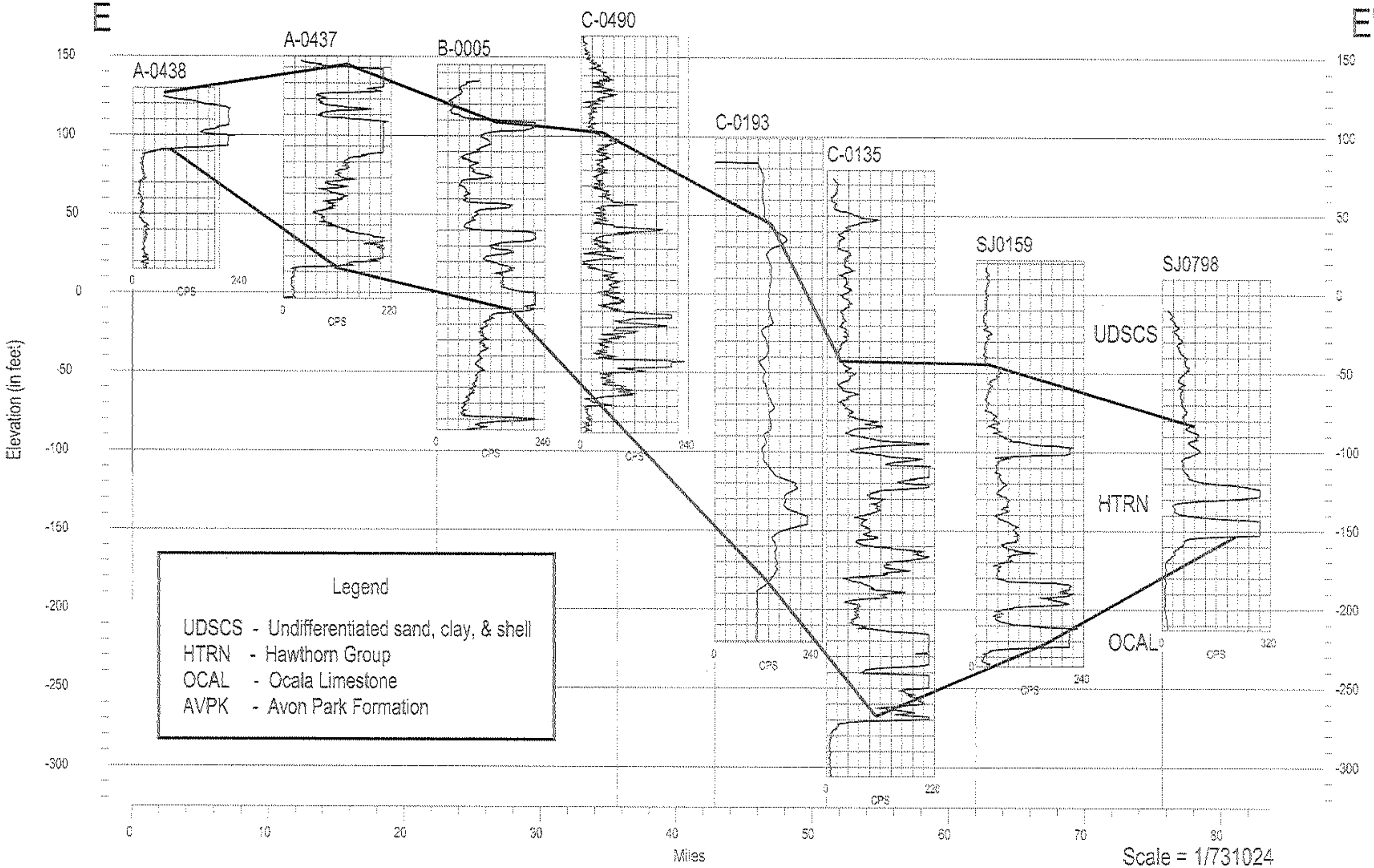
Gamma Log Cross Section C-C'



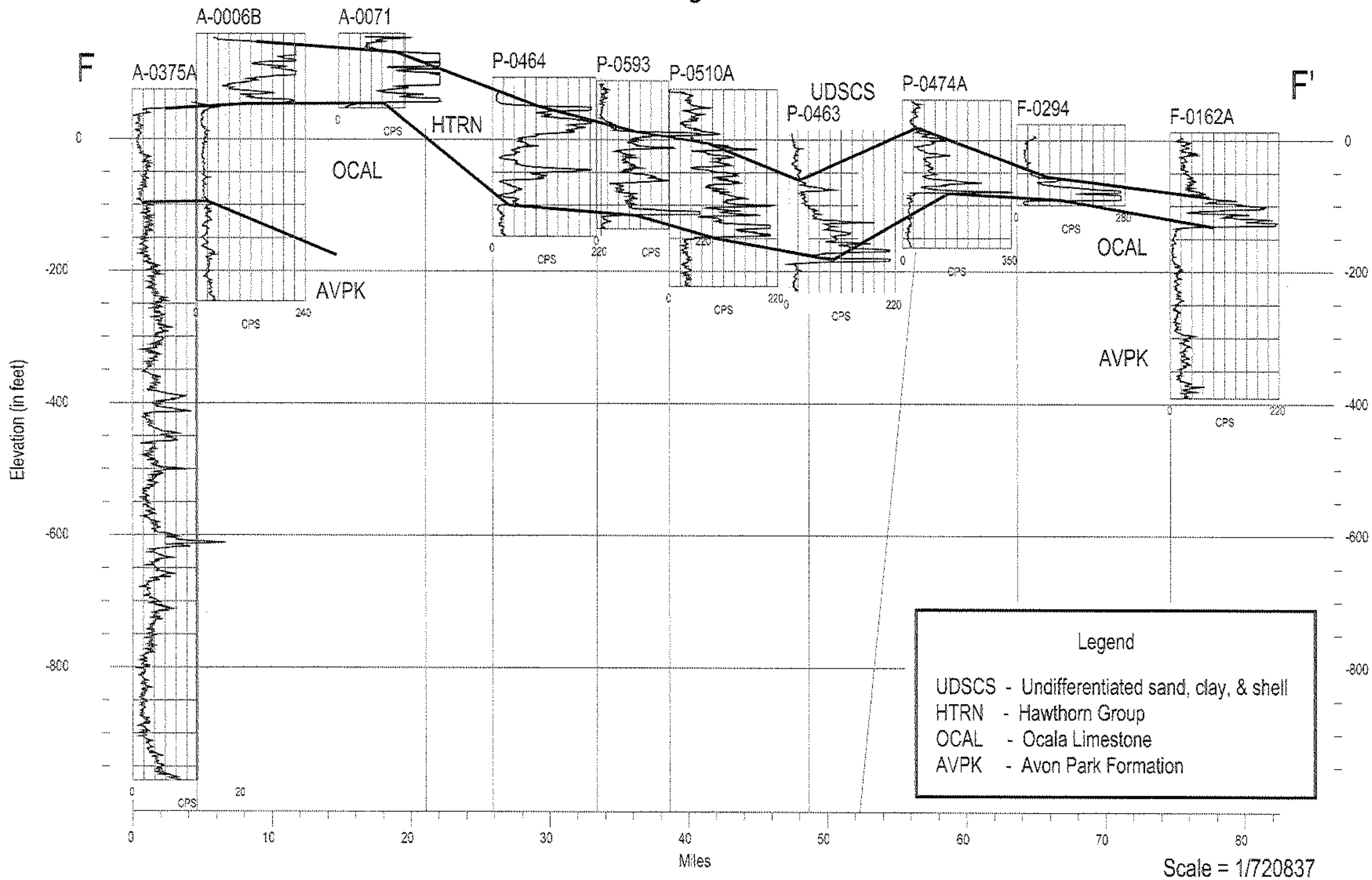
Gamma Log Cross Section D-D'



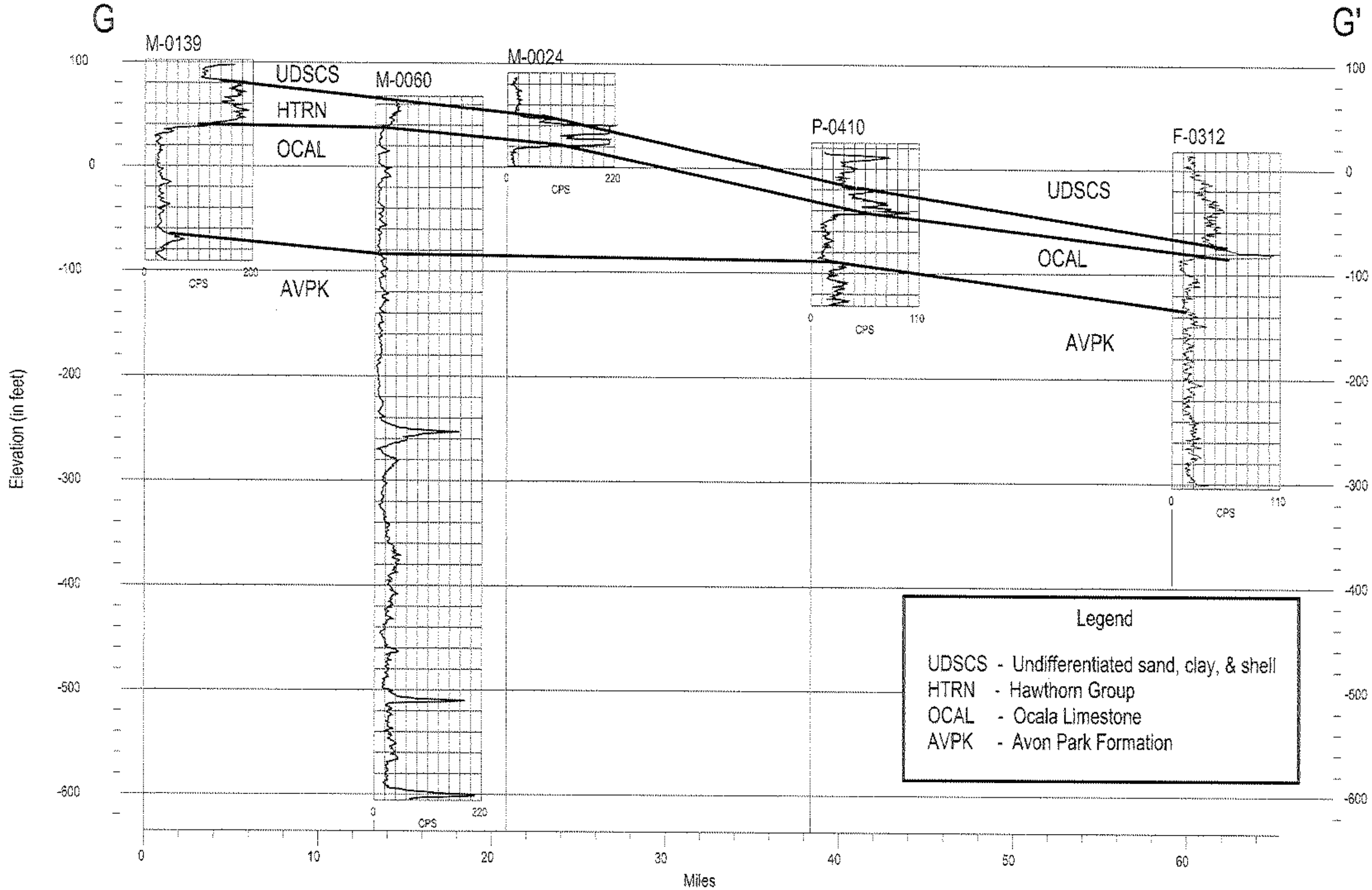
Gamma Log Cross Section E-E'



Gamma Log Cross Section F-F'



Gamma Log Cross Section G-G'



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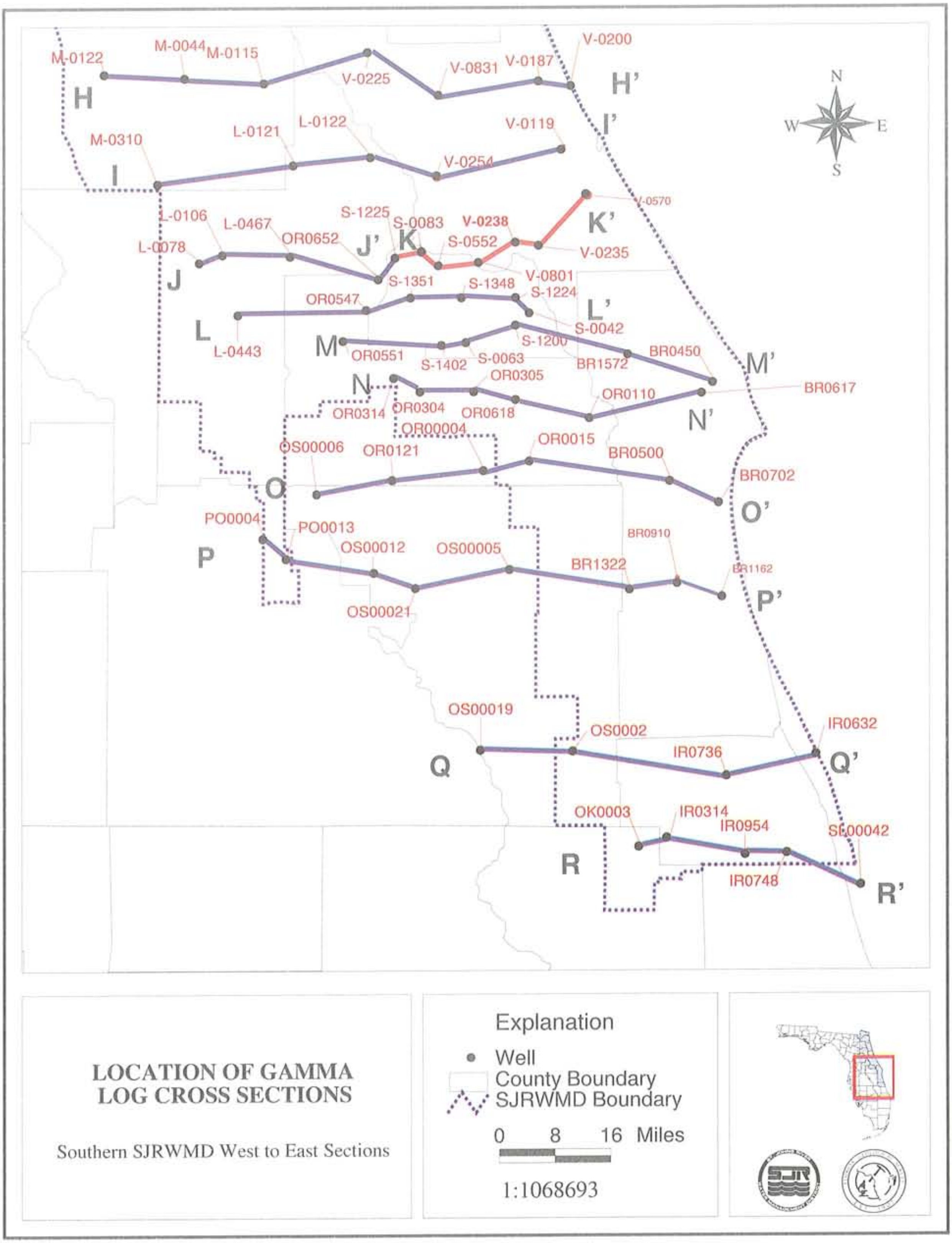
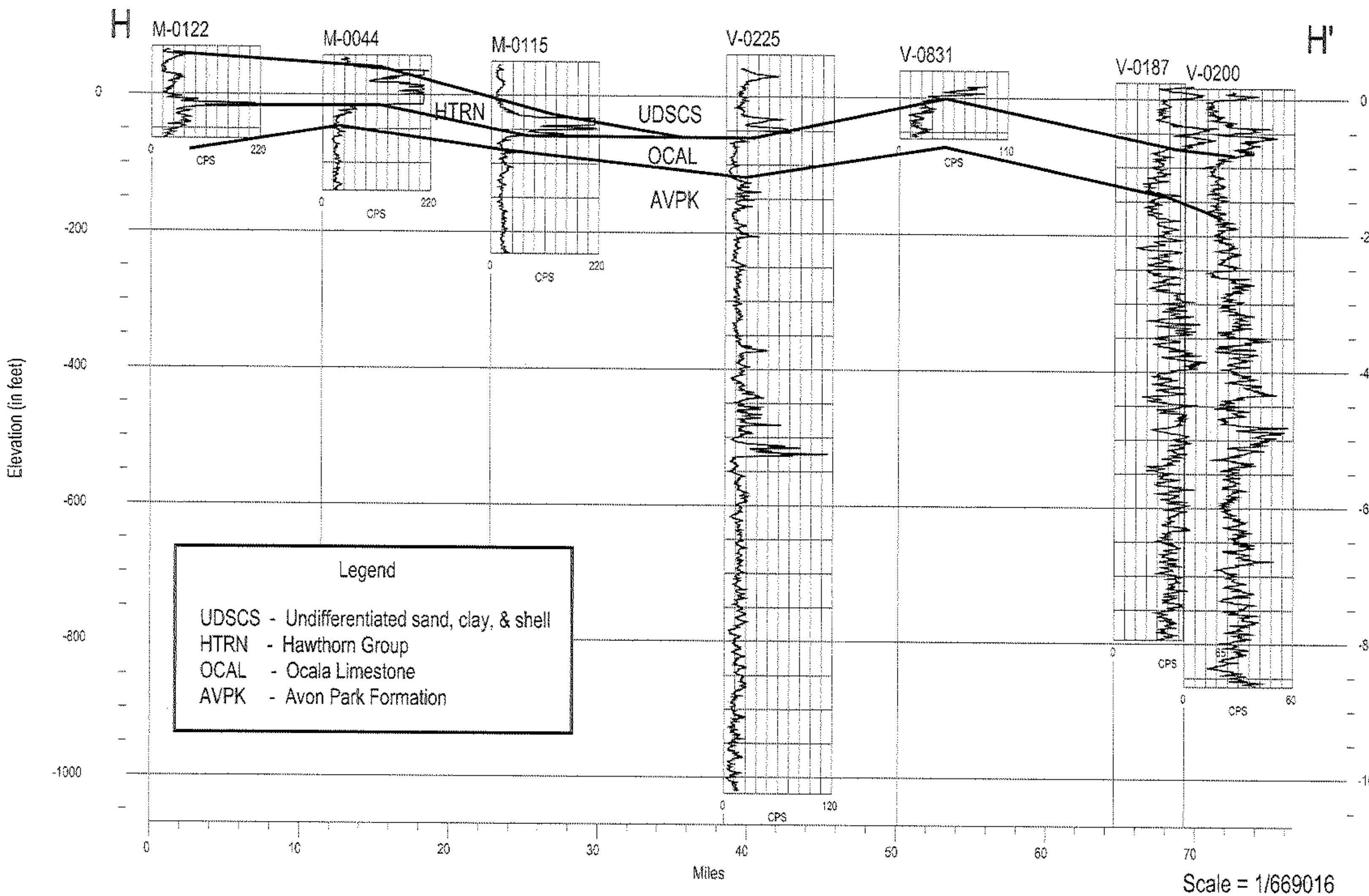
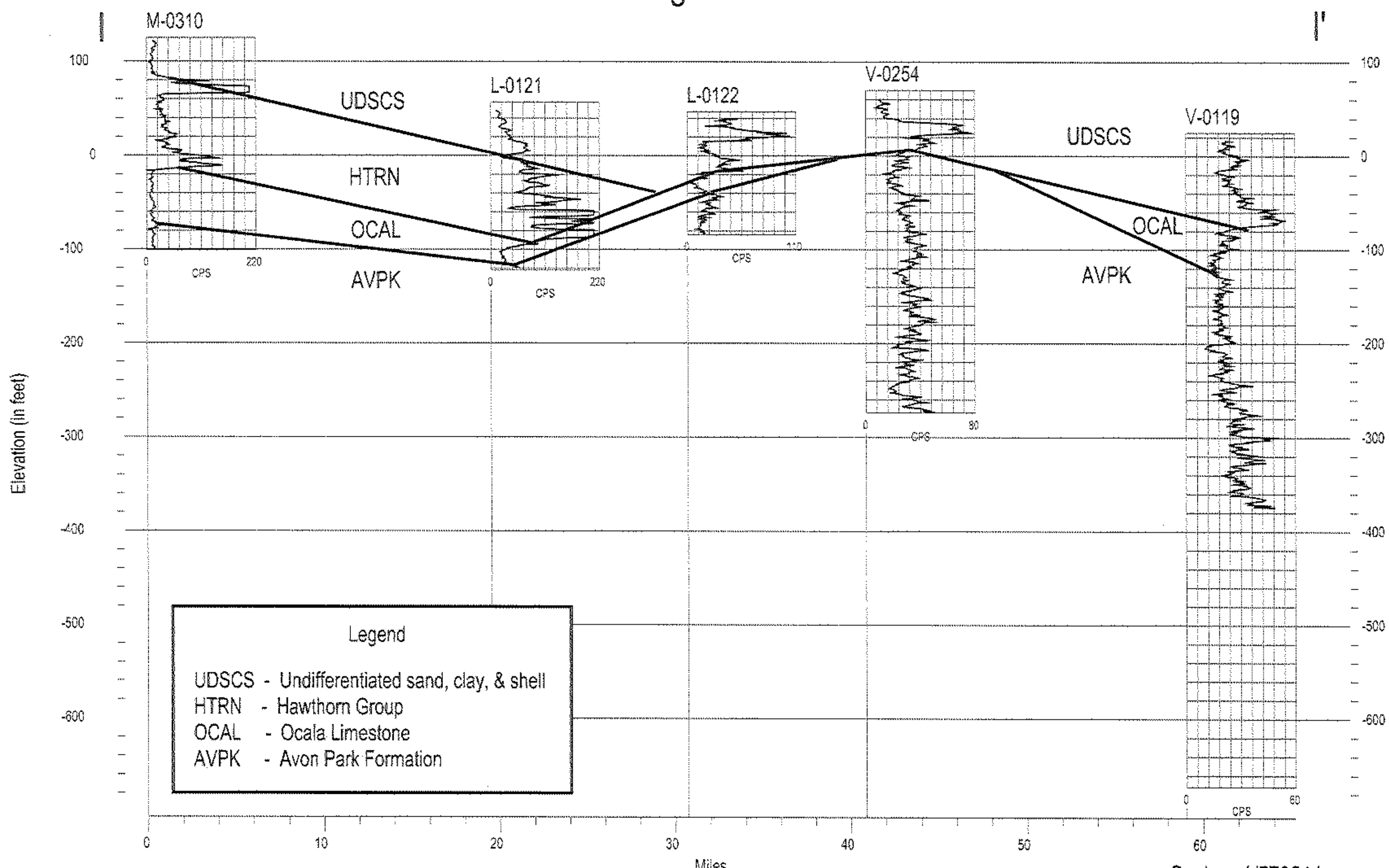


Location of Gamma Log Cross Sections, southern West to East sections.

Gamma Log Cross Section H-H'



Gamma Log Cross Section I-I'



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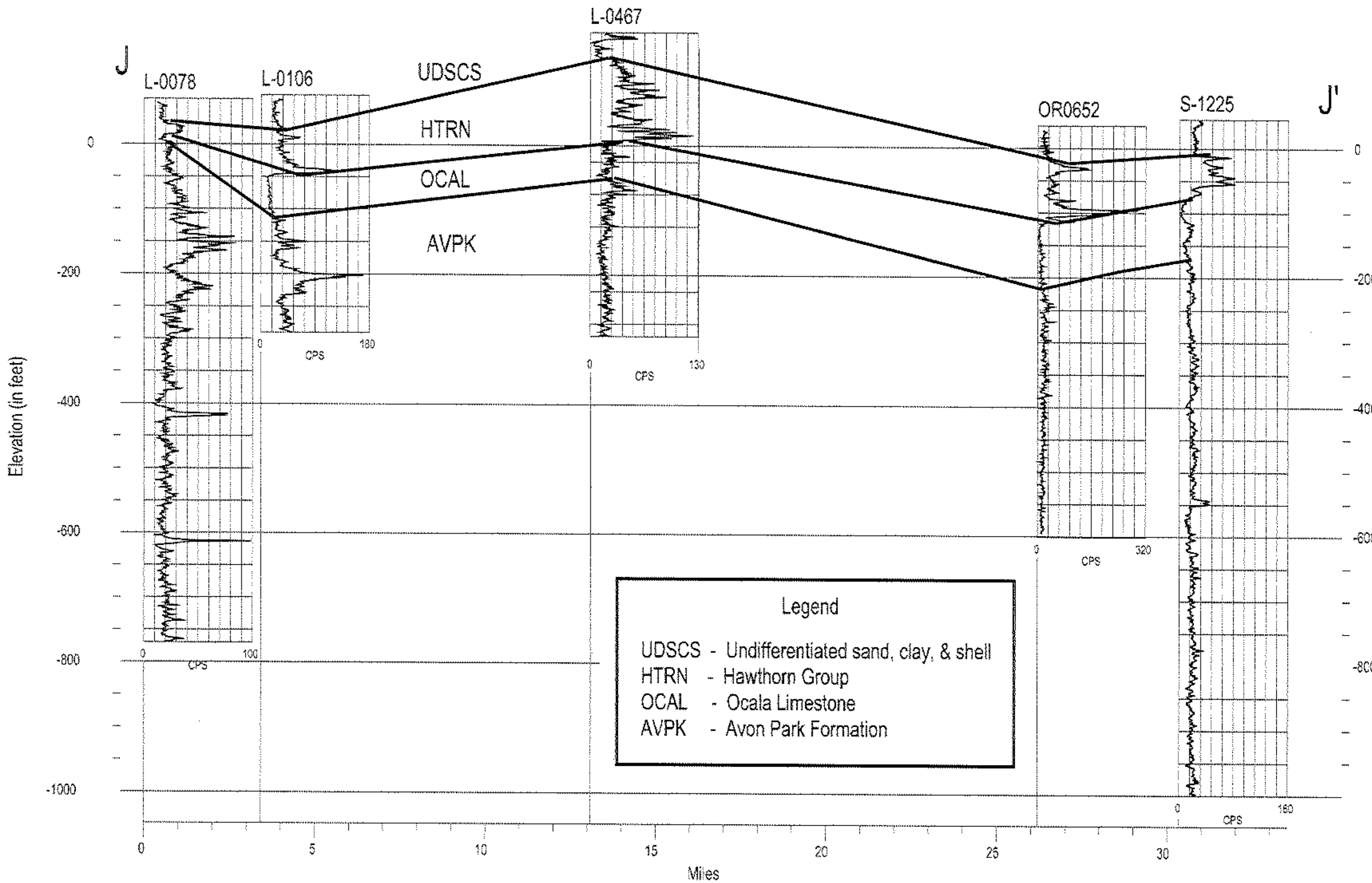
Gamma Log Cross Section J-J'



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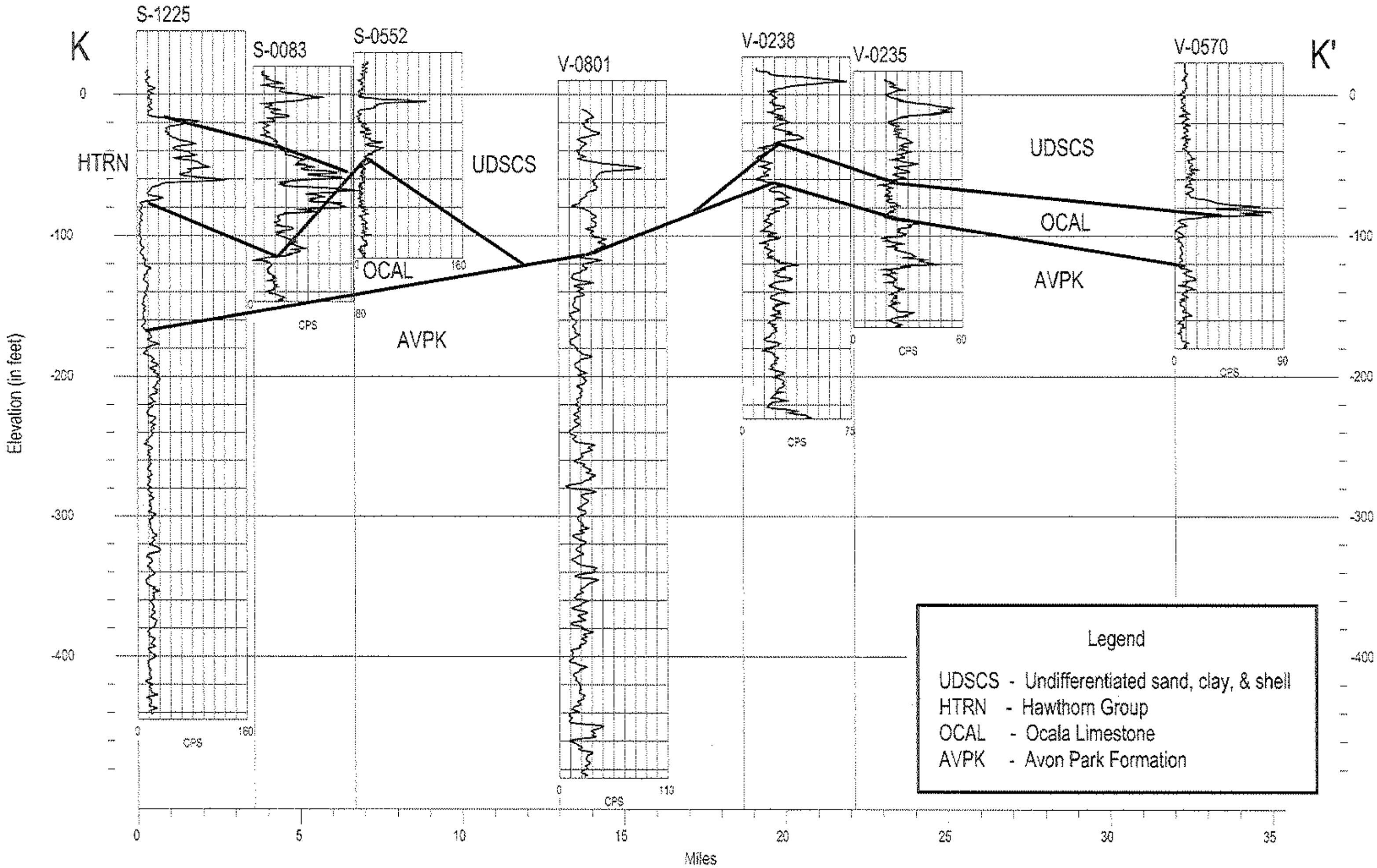
Gamma Log Cross Section K-K'



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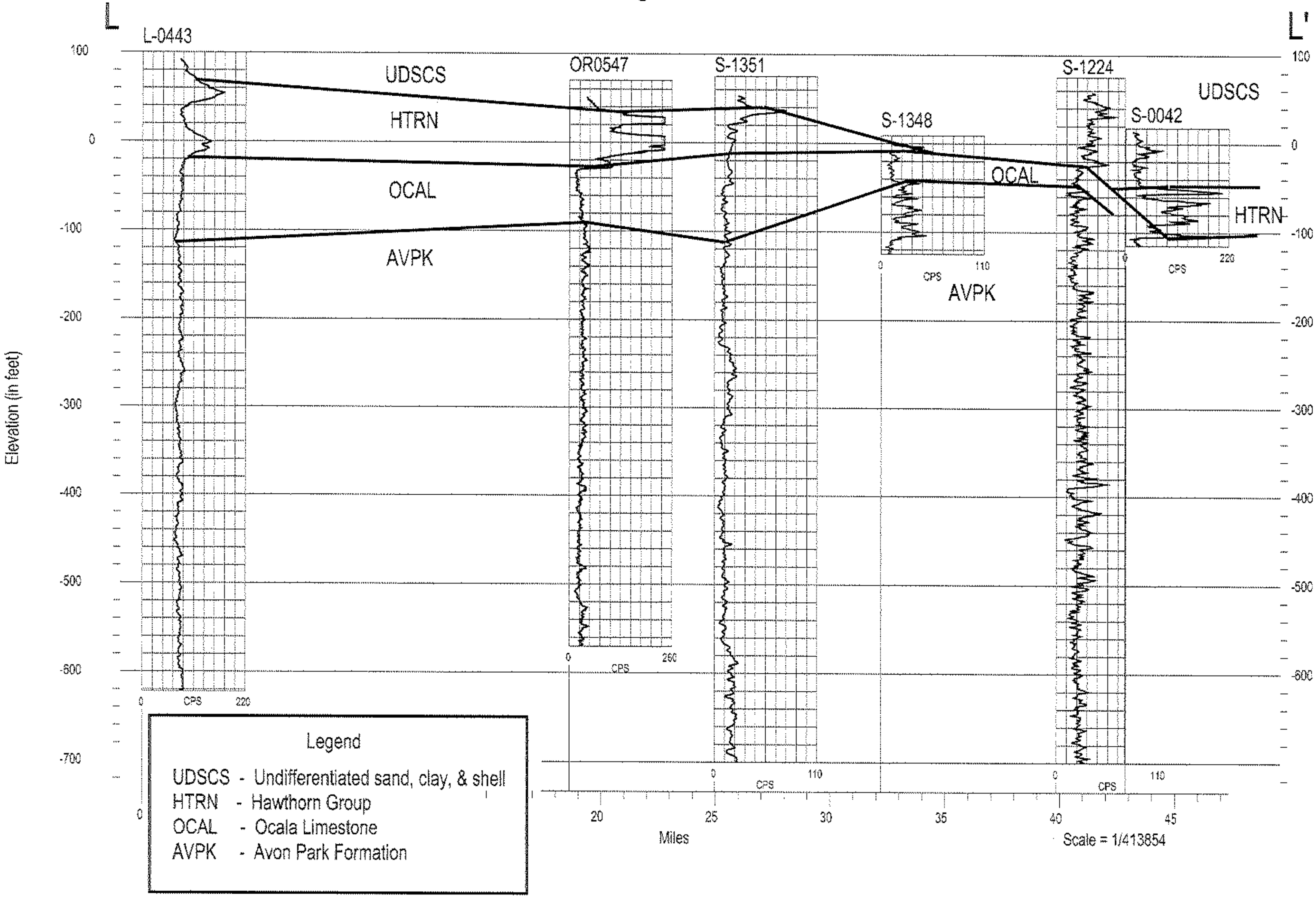
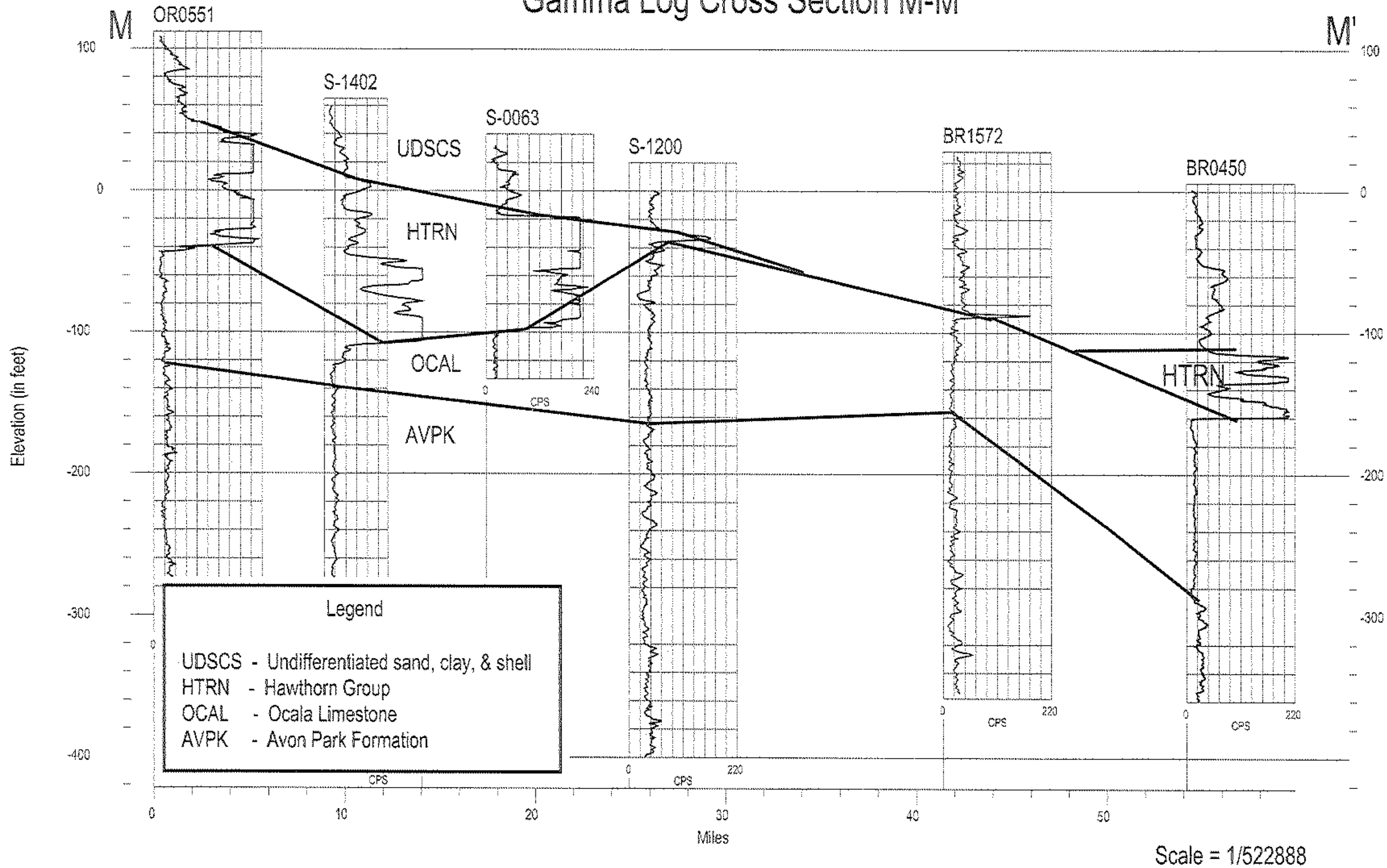
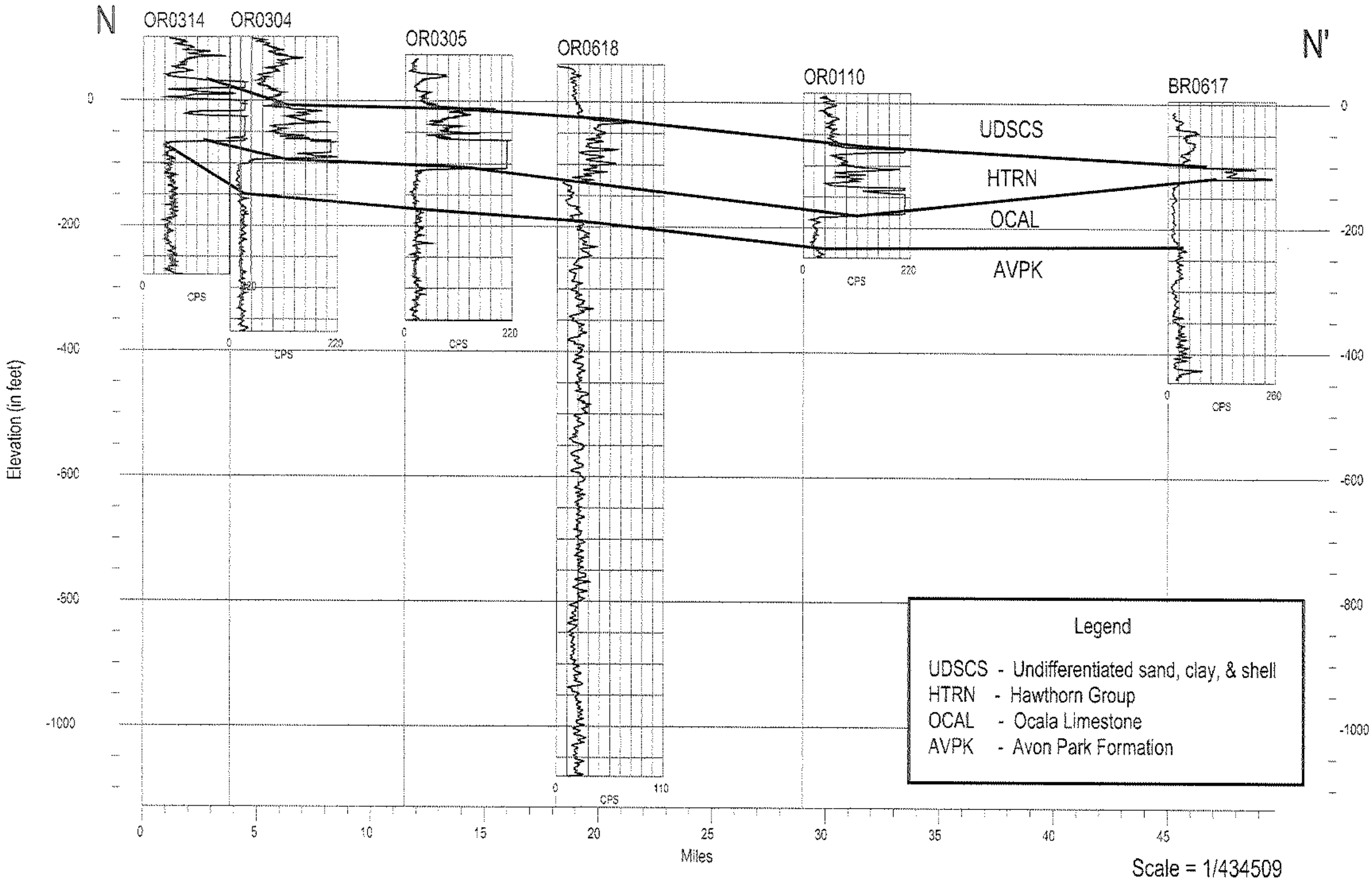
Gamma Log Cross Section L-L'



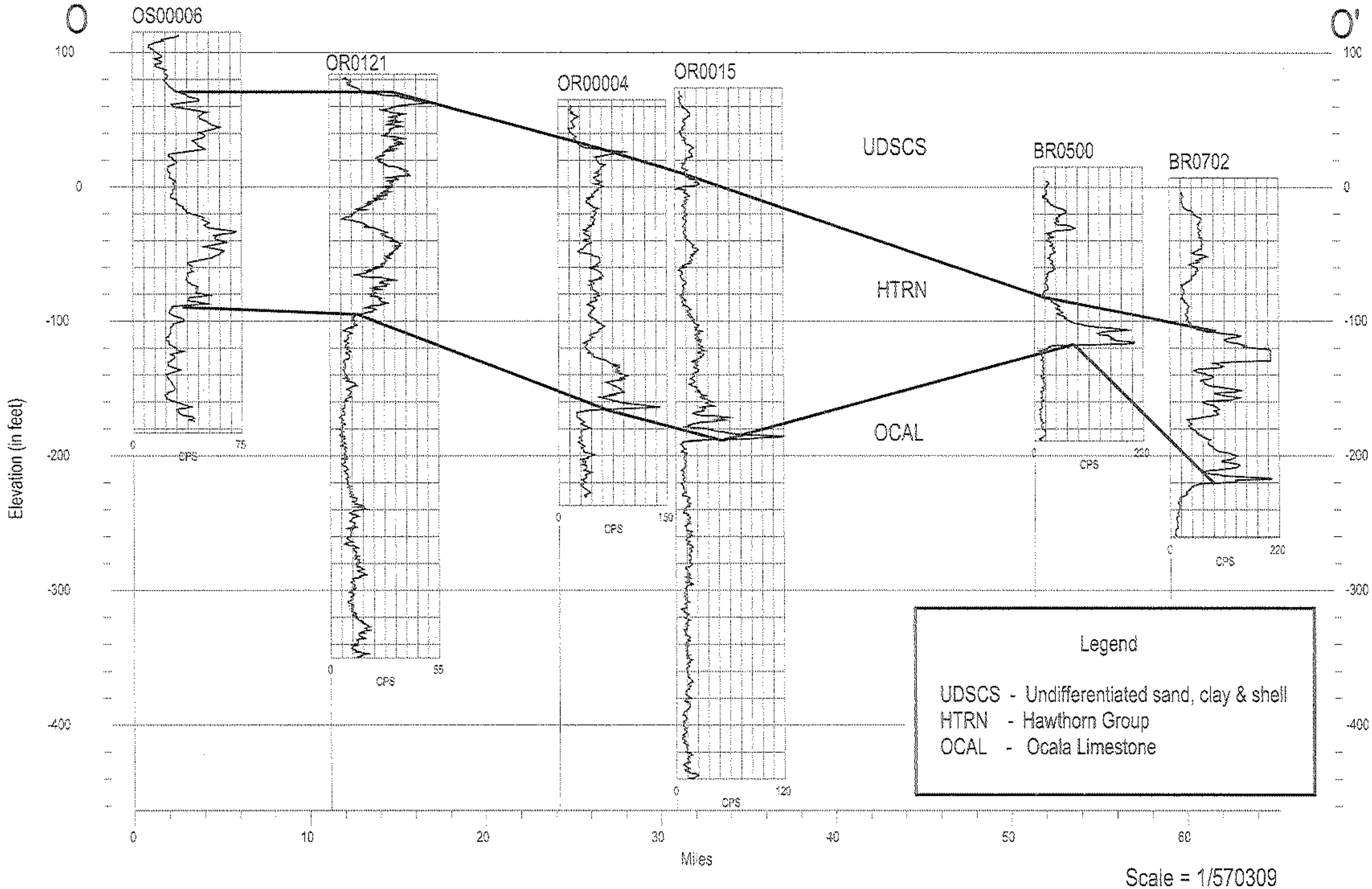
Gamma Log Cross Section M-M''



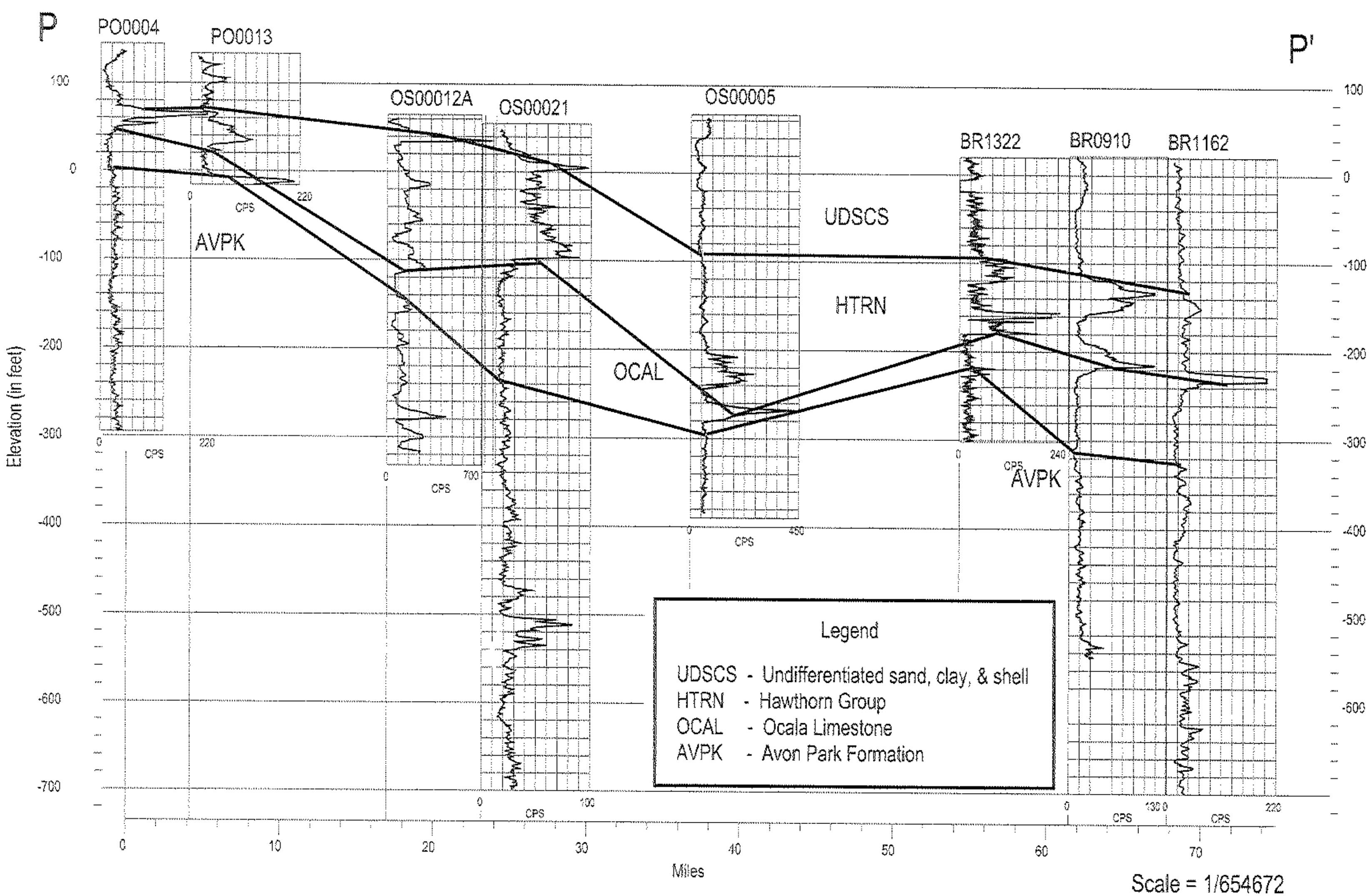
Gamma Log Cross Section N-N'



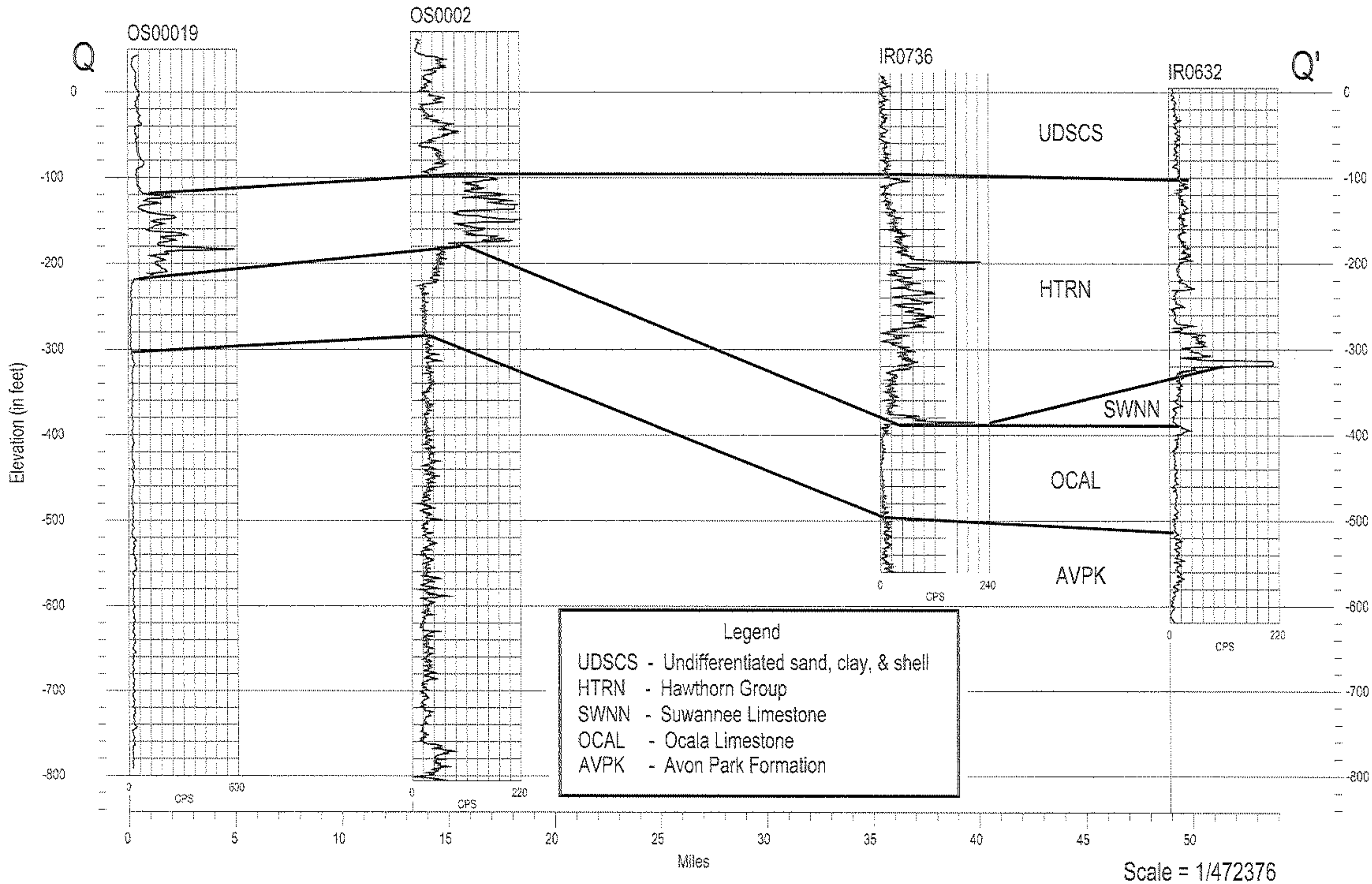
Gamma Log Cross Section O-O'



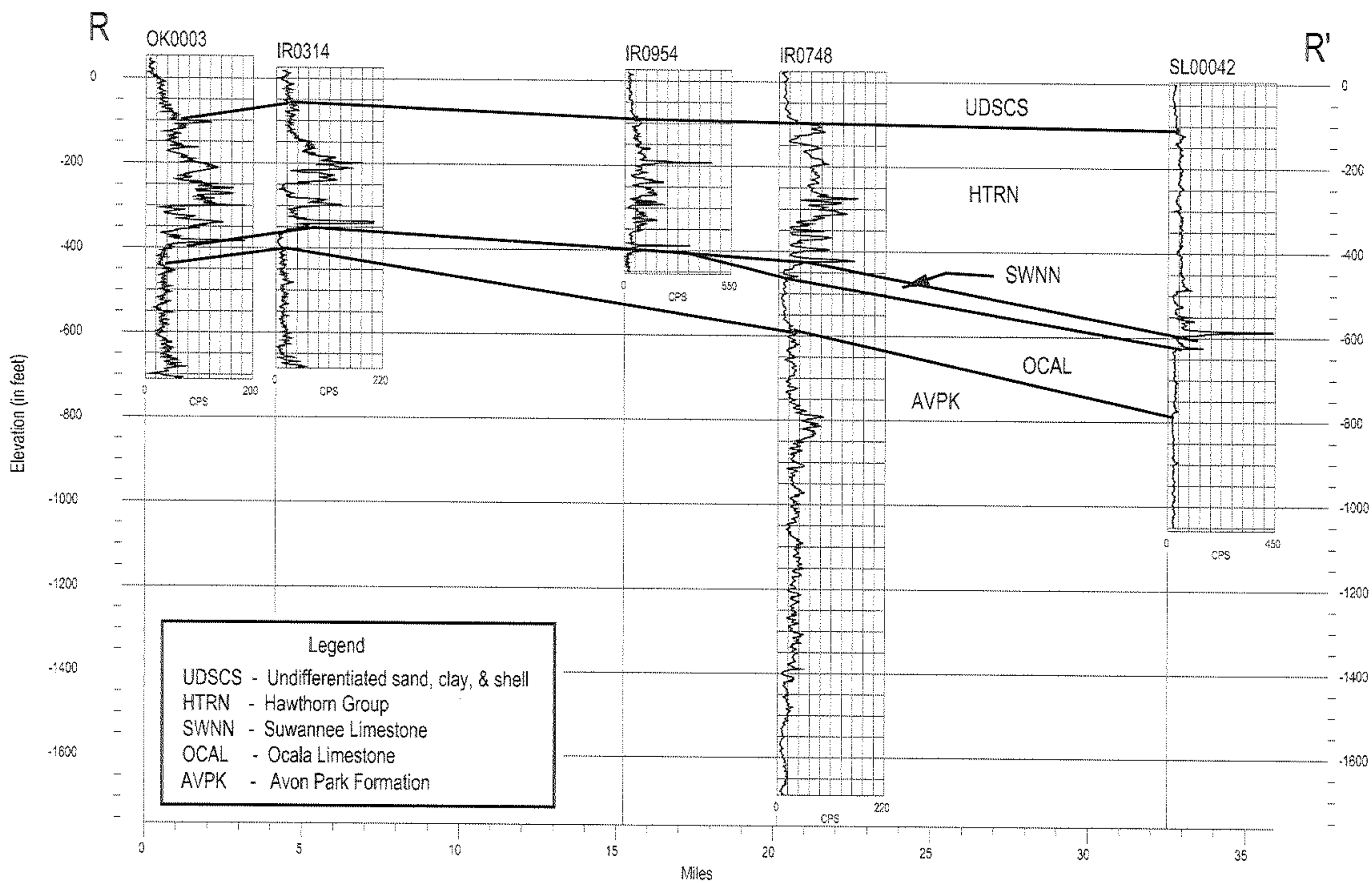
Gamma Log Cross Section P-P'



Gamma Log Cross Section Q-Q'



Gamma Log Cross Section R-R'



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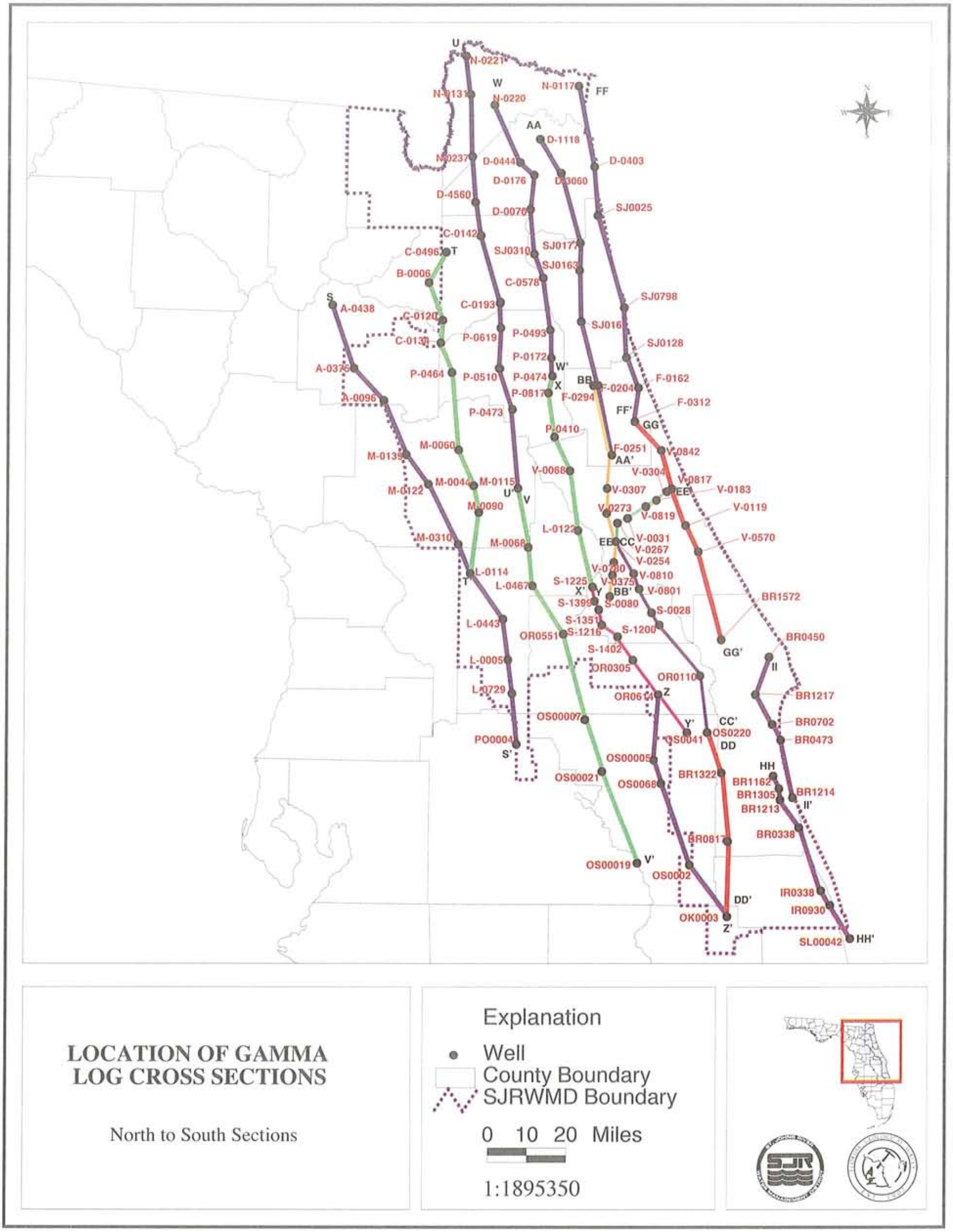
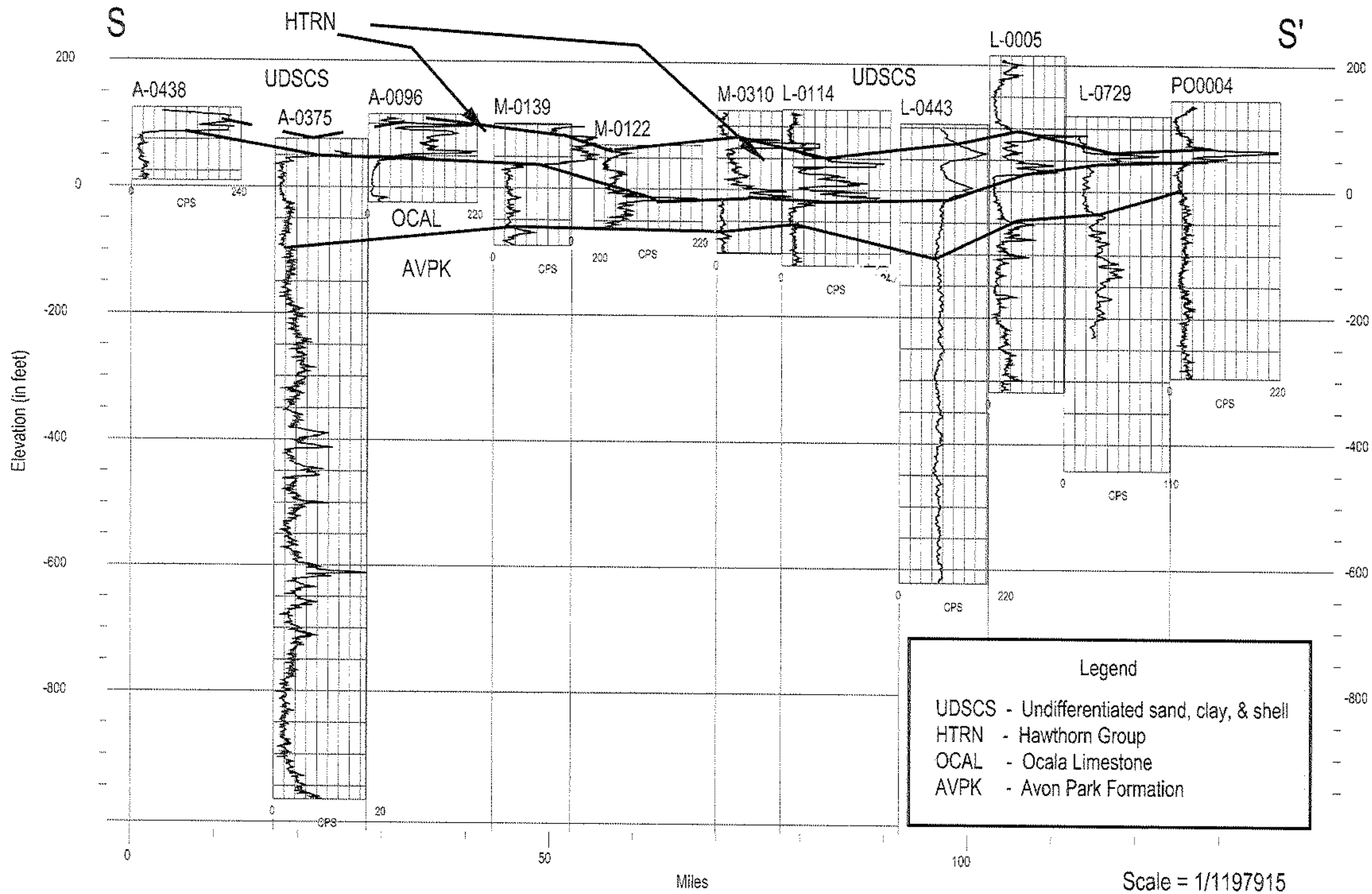
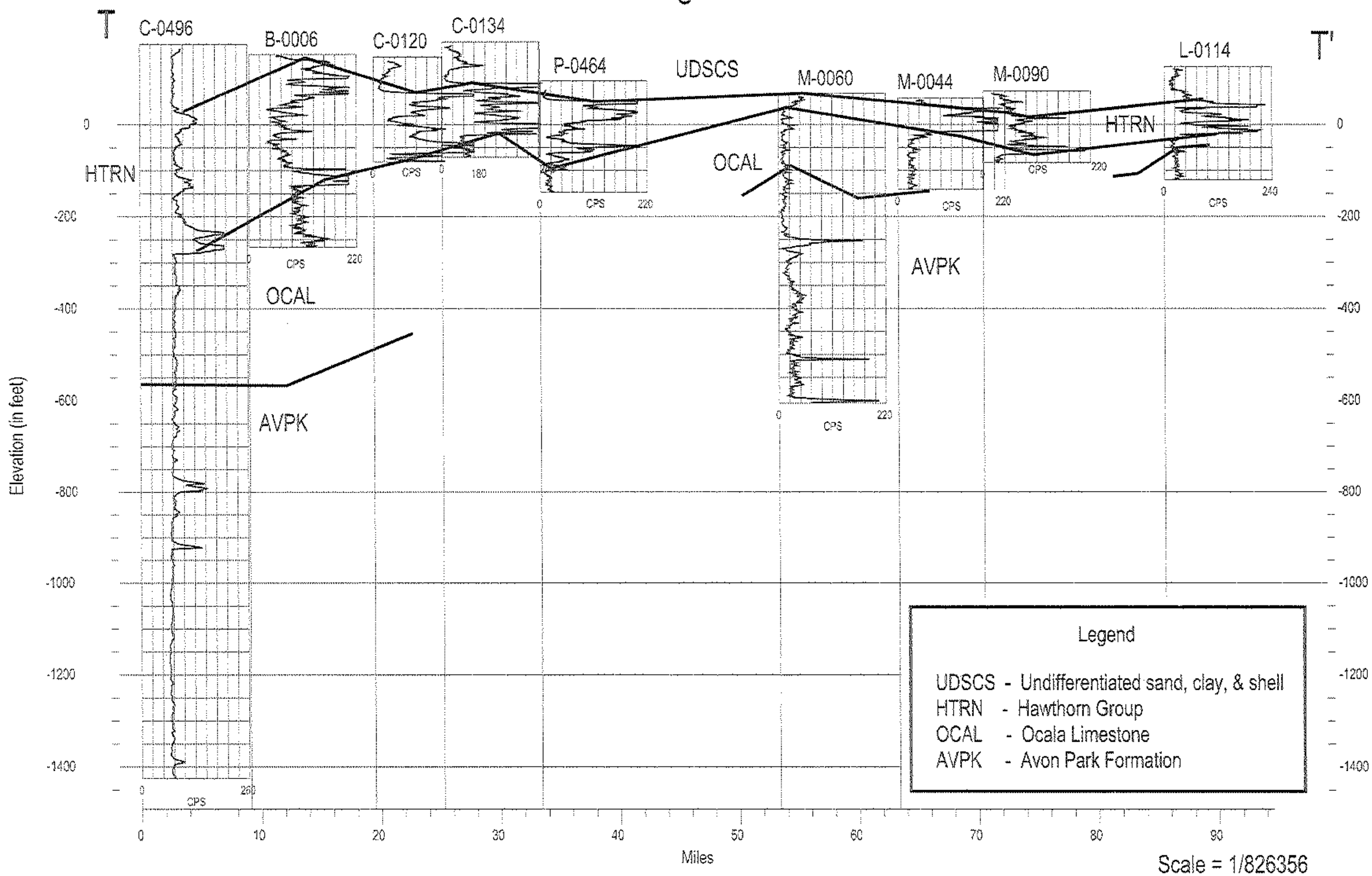


Location of Gamma Log Cross Sections, North-South Sections

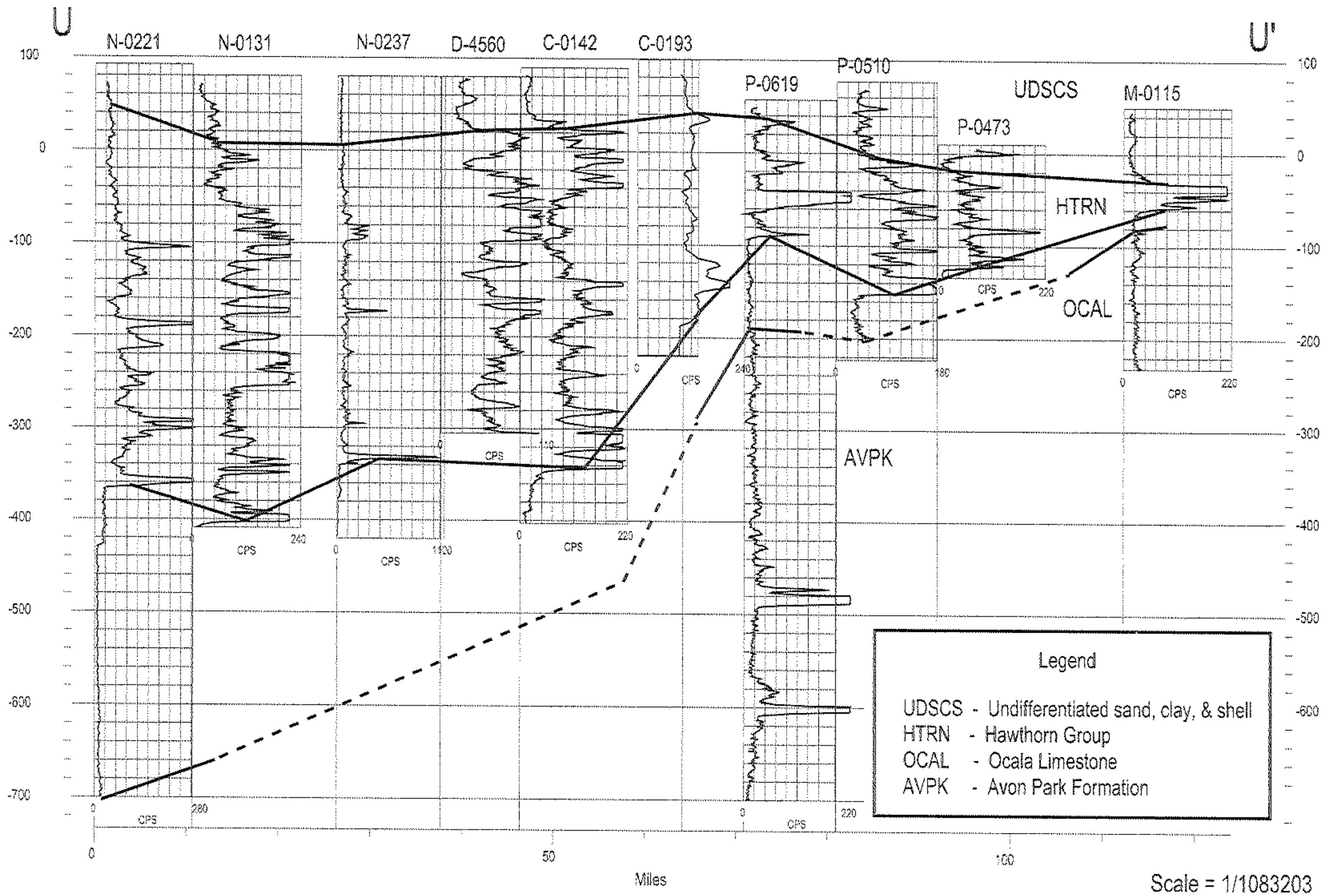
Gamma Log Cross Section S-S'



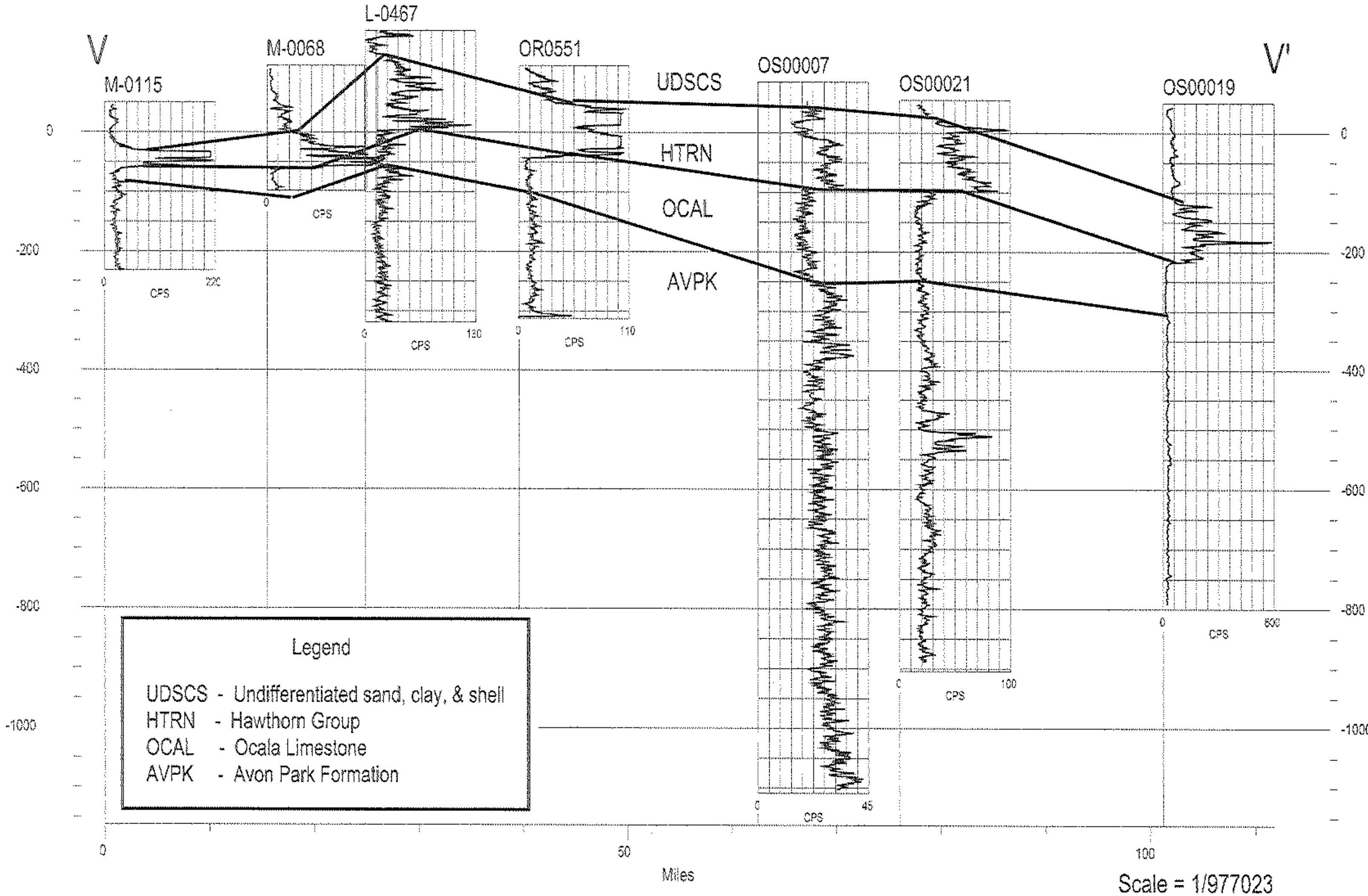
Gamma Log Cross Section T-T'



Gamma Log Cross Section U-U'



Gamma Log Cross Section V-V'



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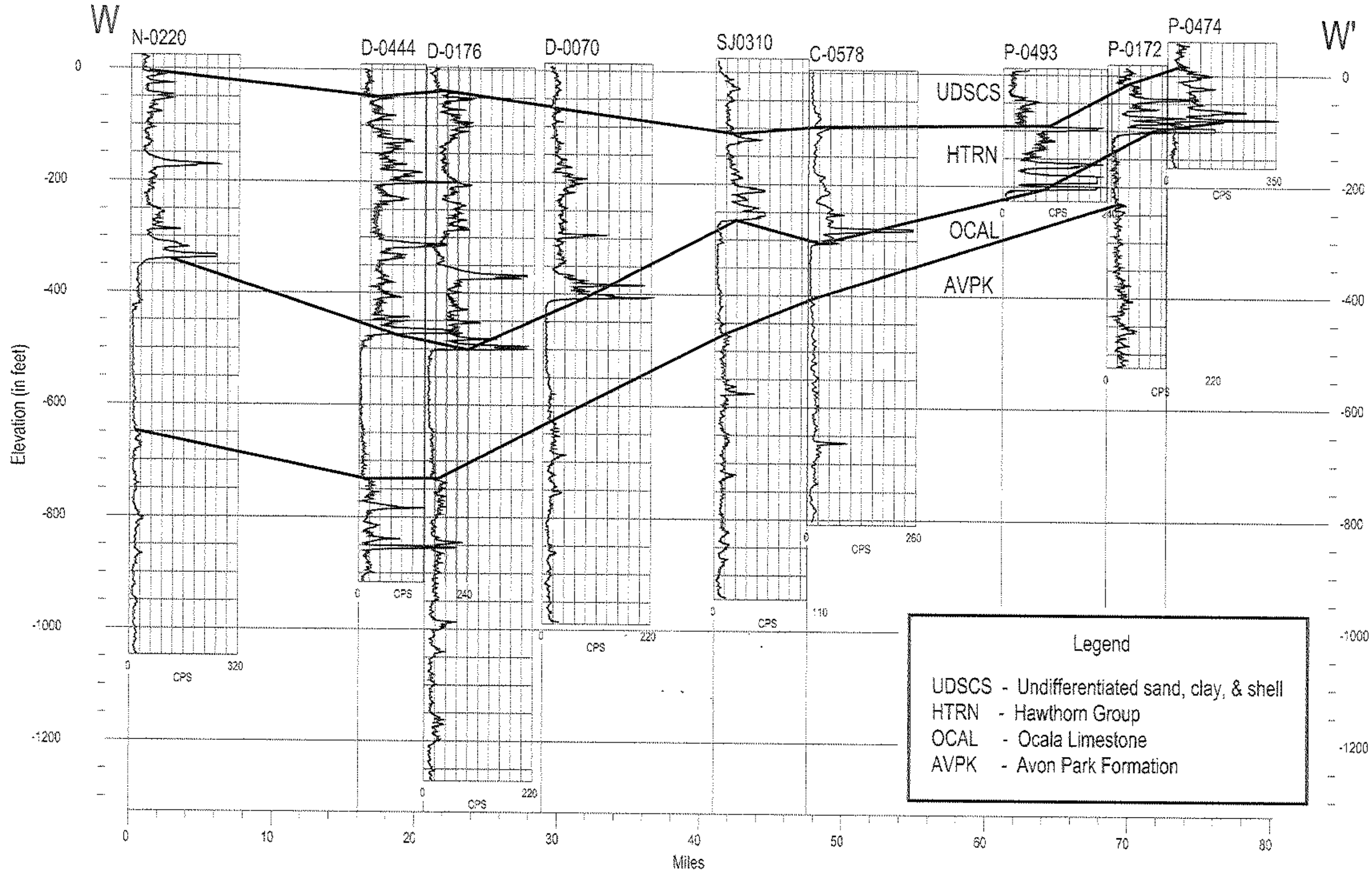

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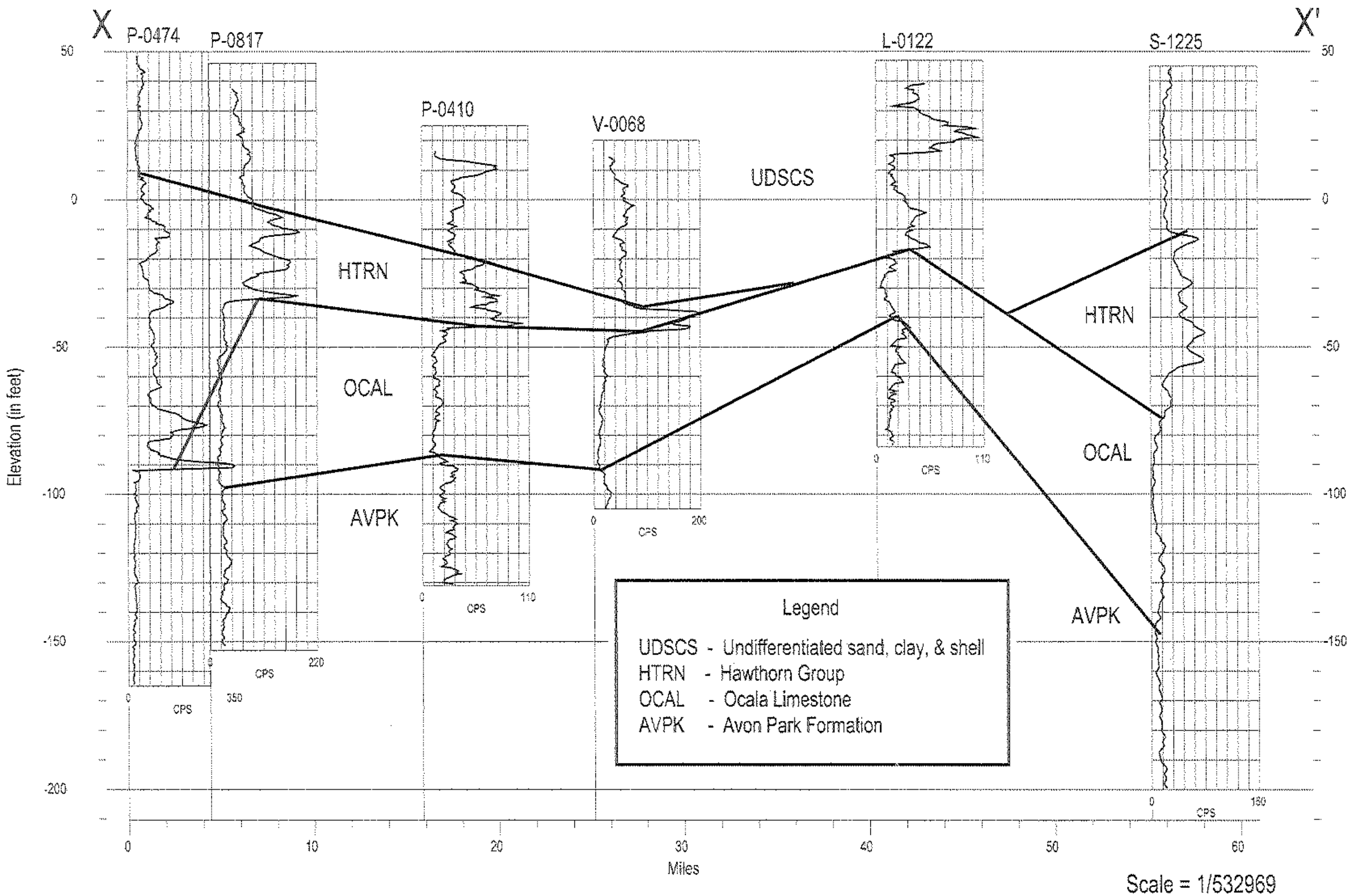

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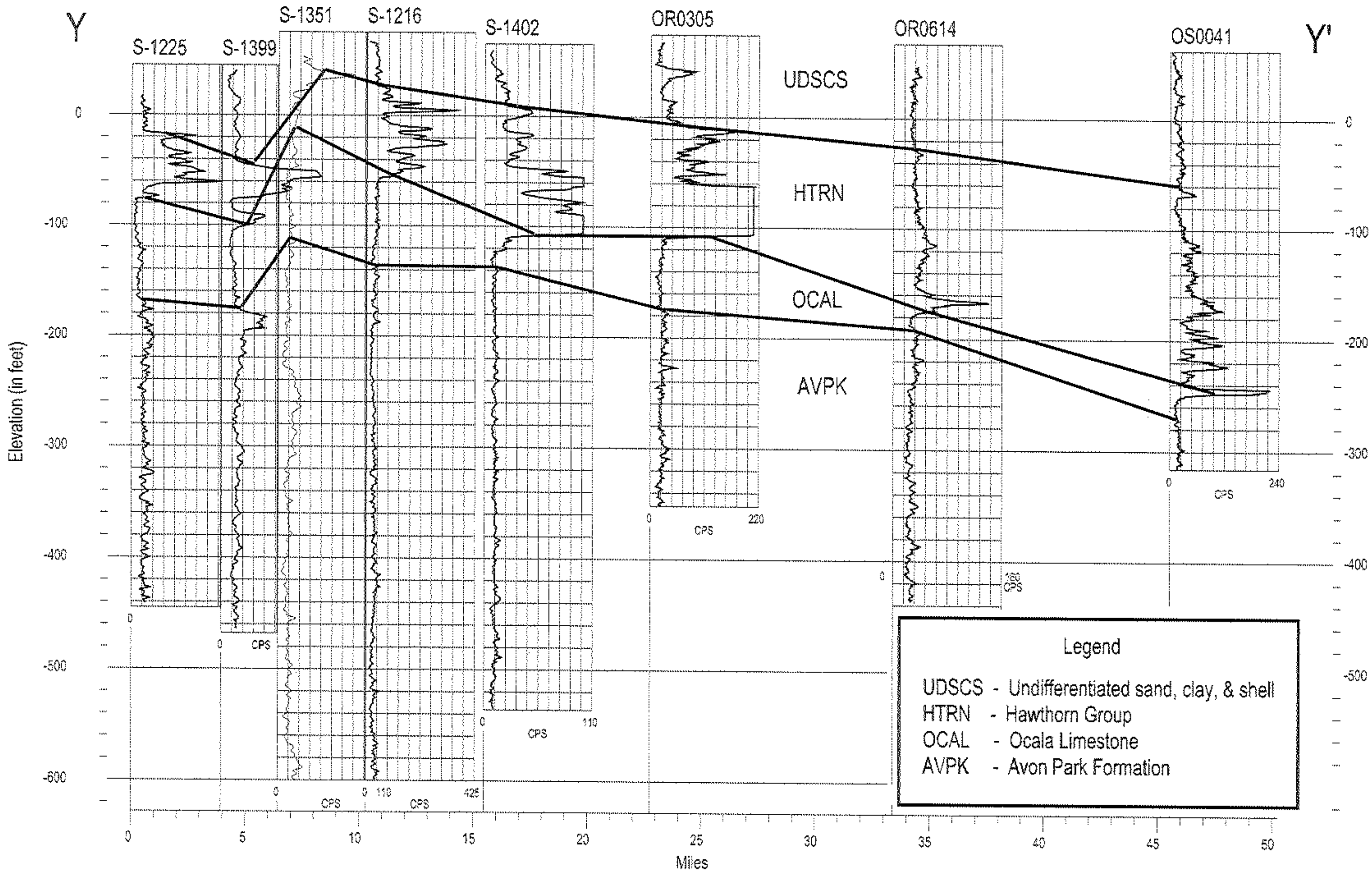

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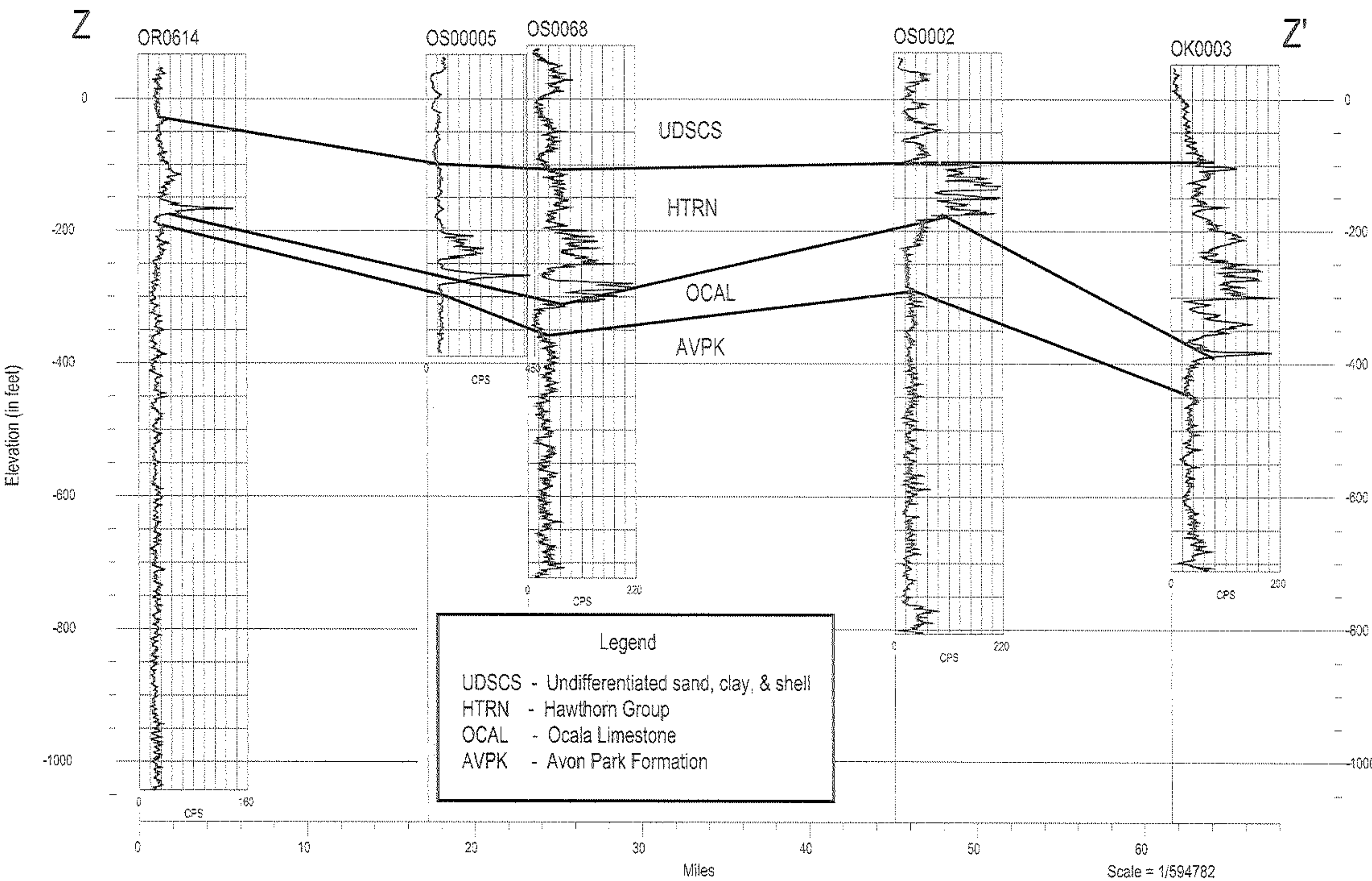
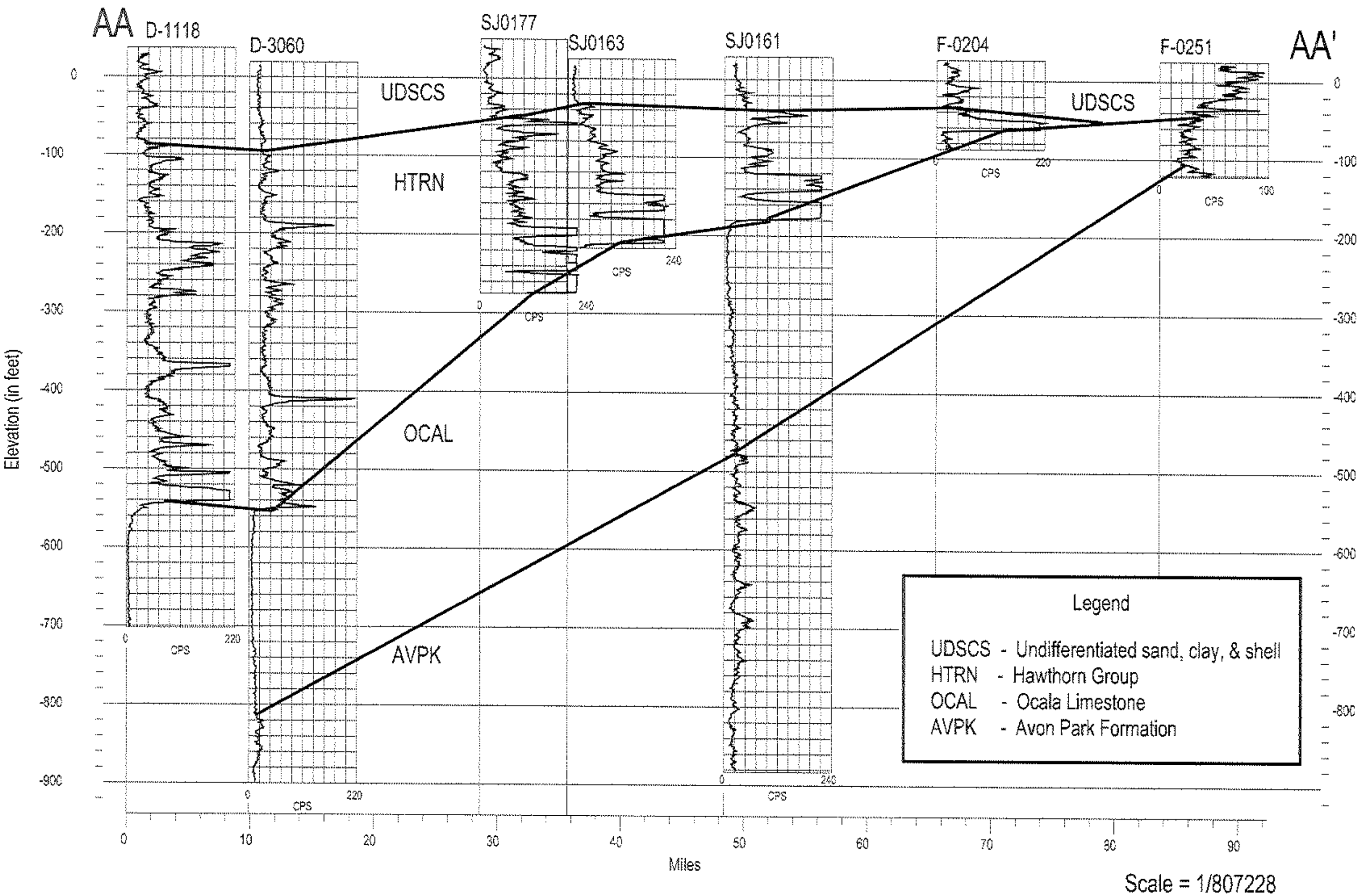
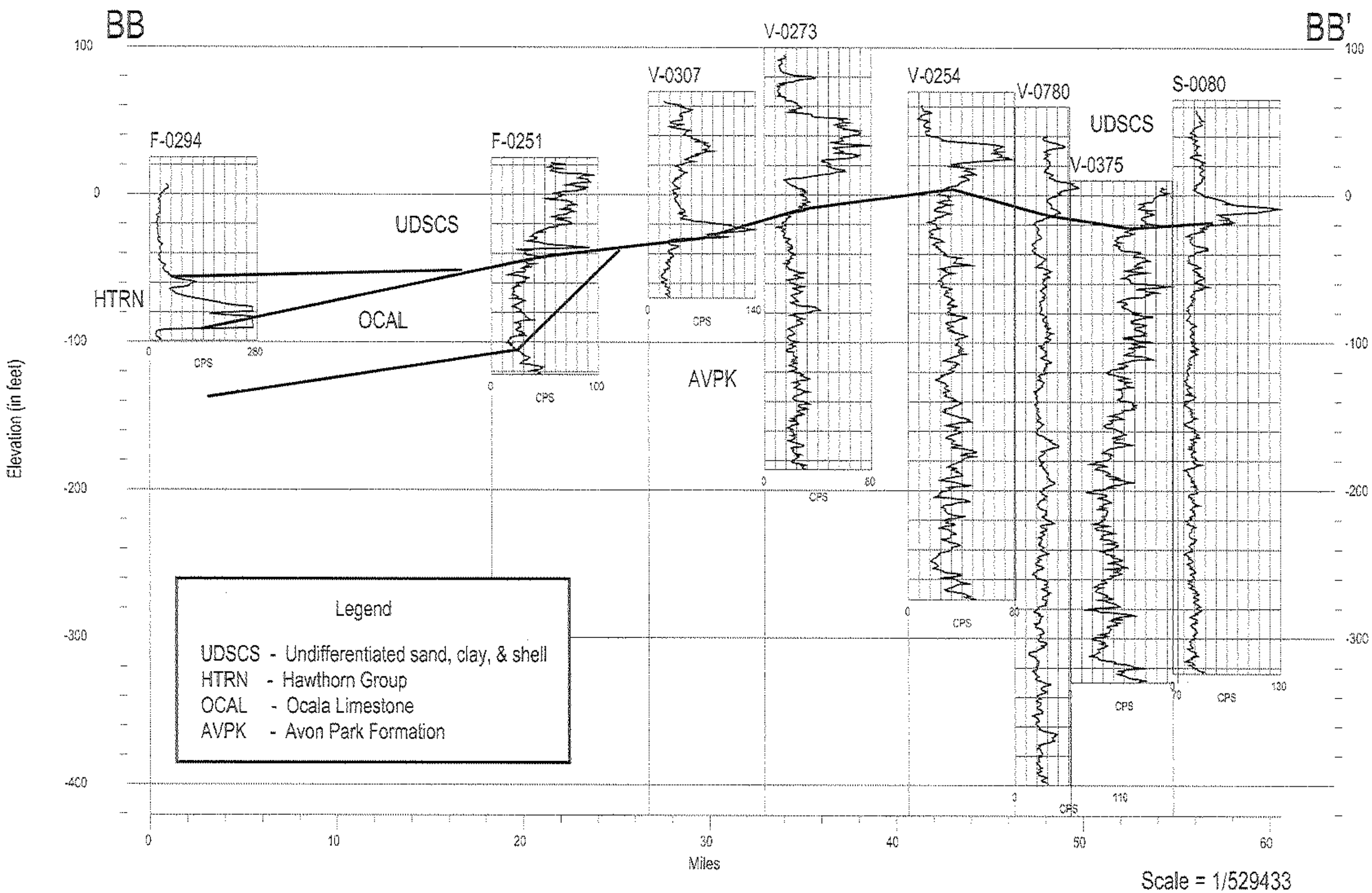


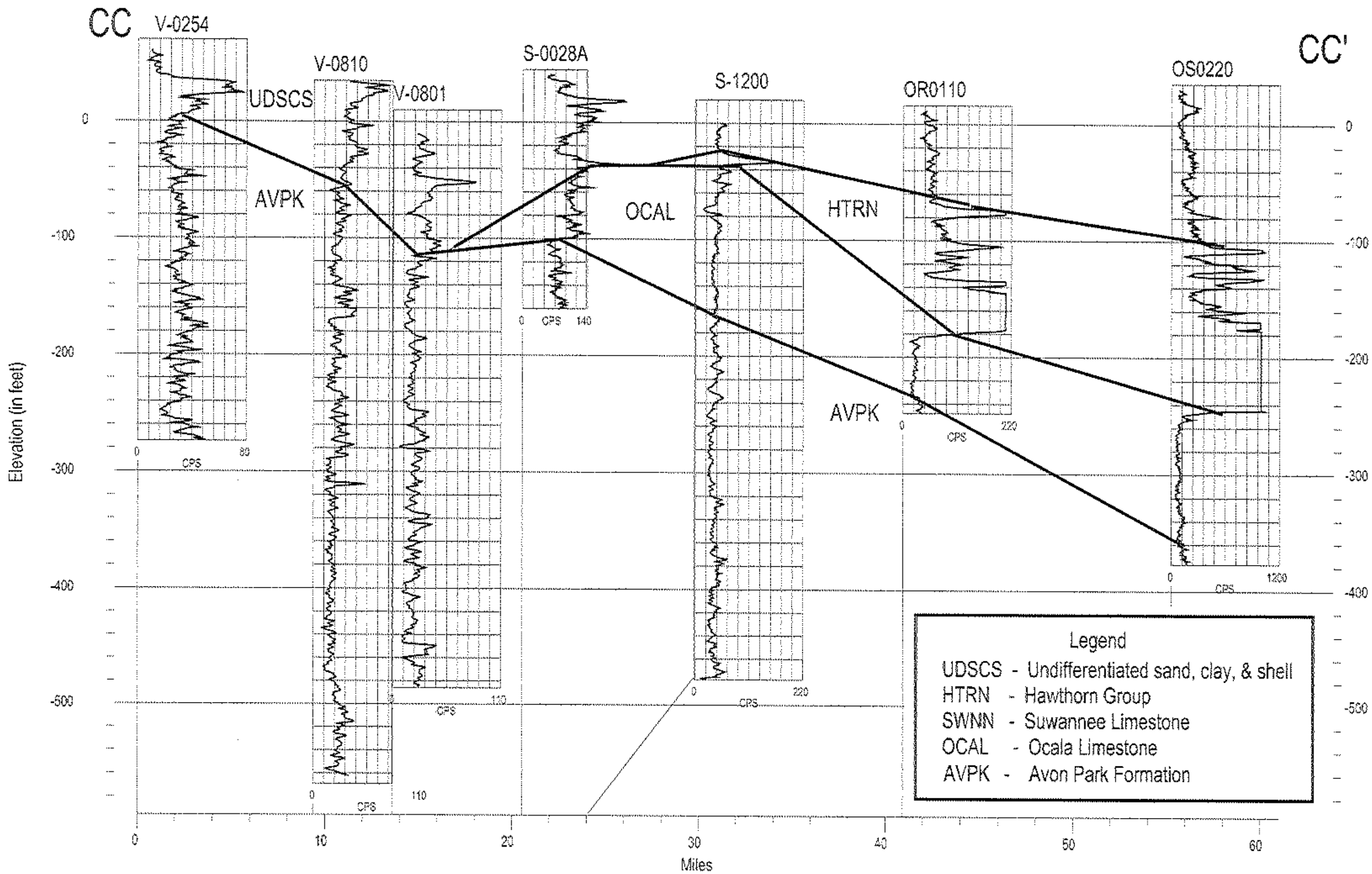
Gamma Log Section AA-AA'



Gamma Log Cross Section BB-BB'



Gamma Log Cross Section CC-CC'



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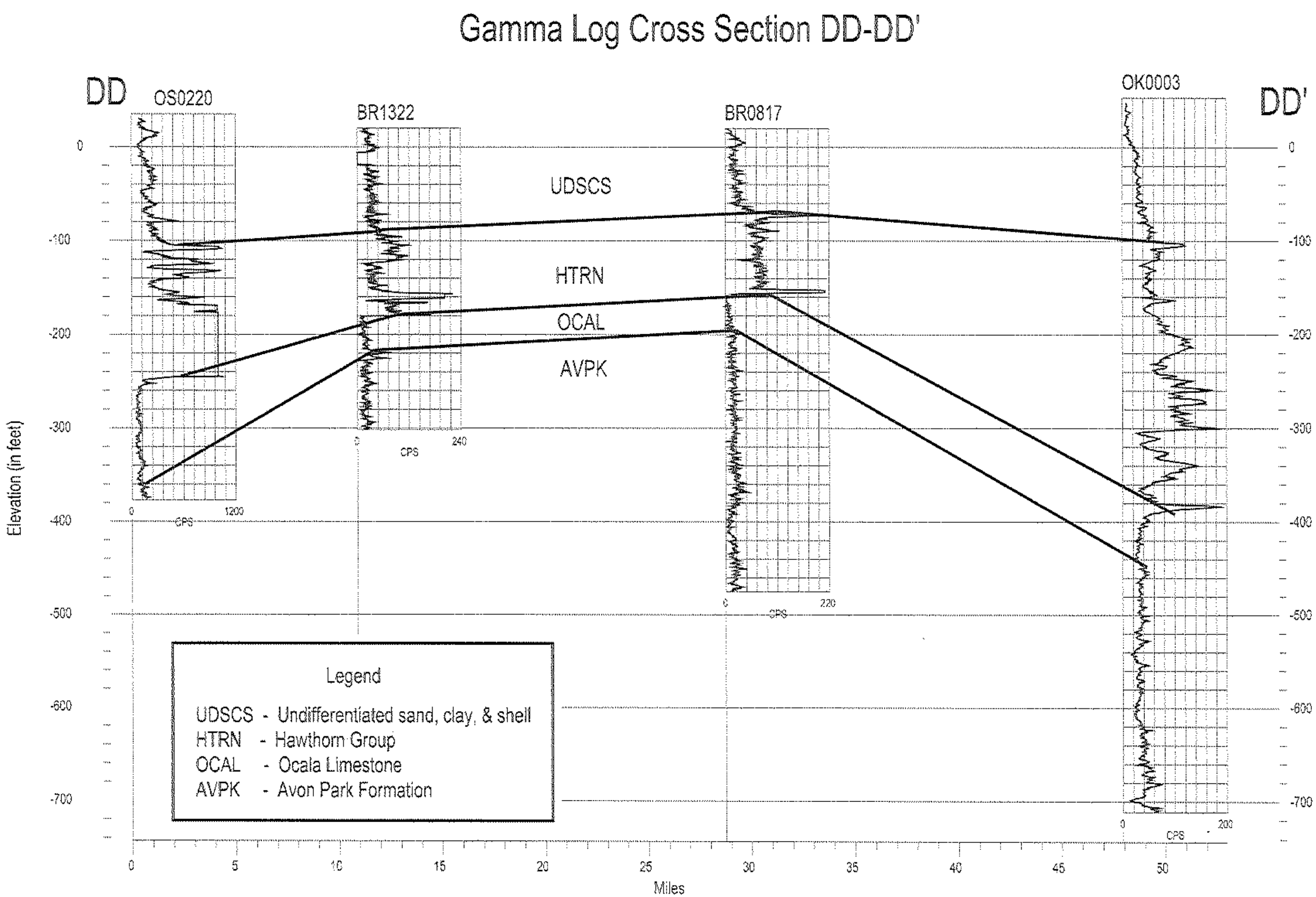

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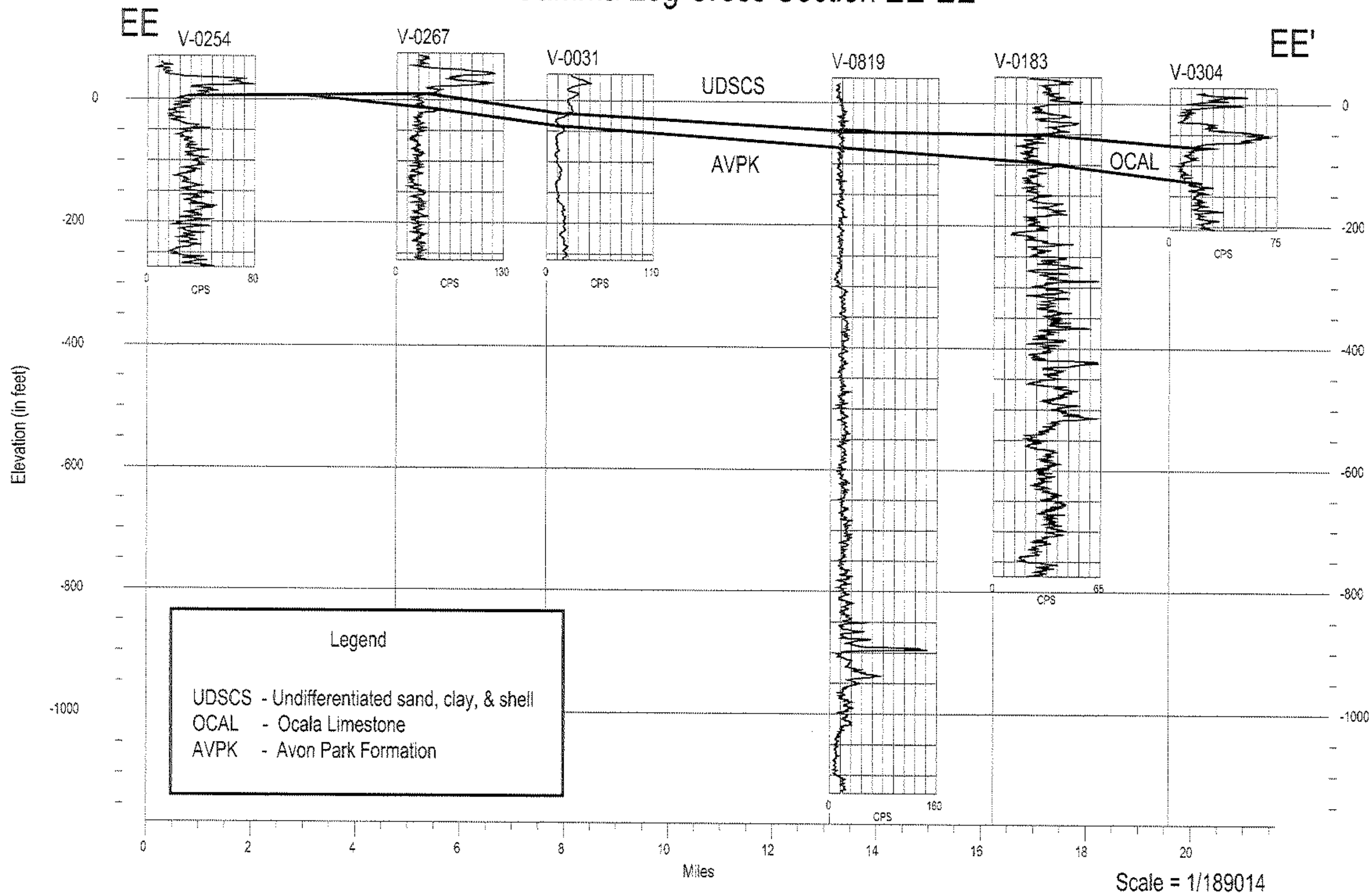
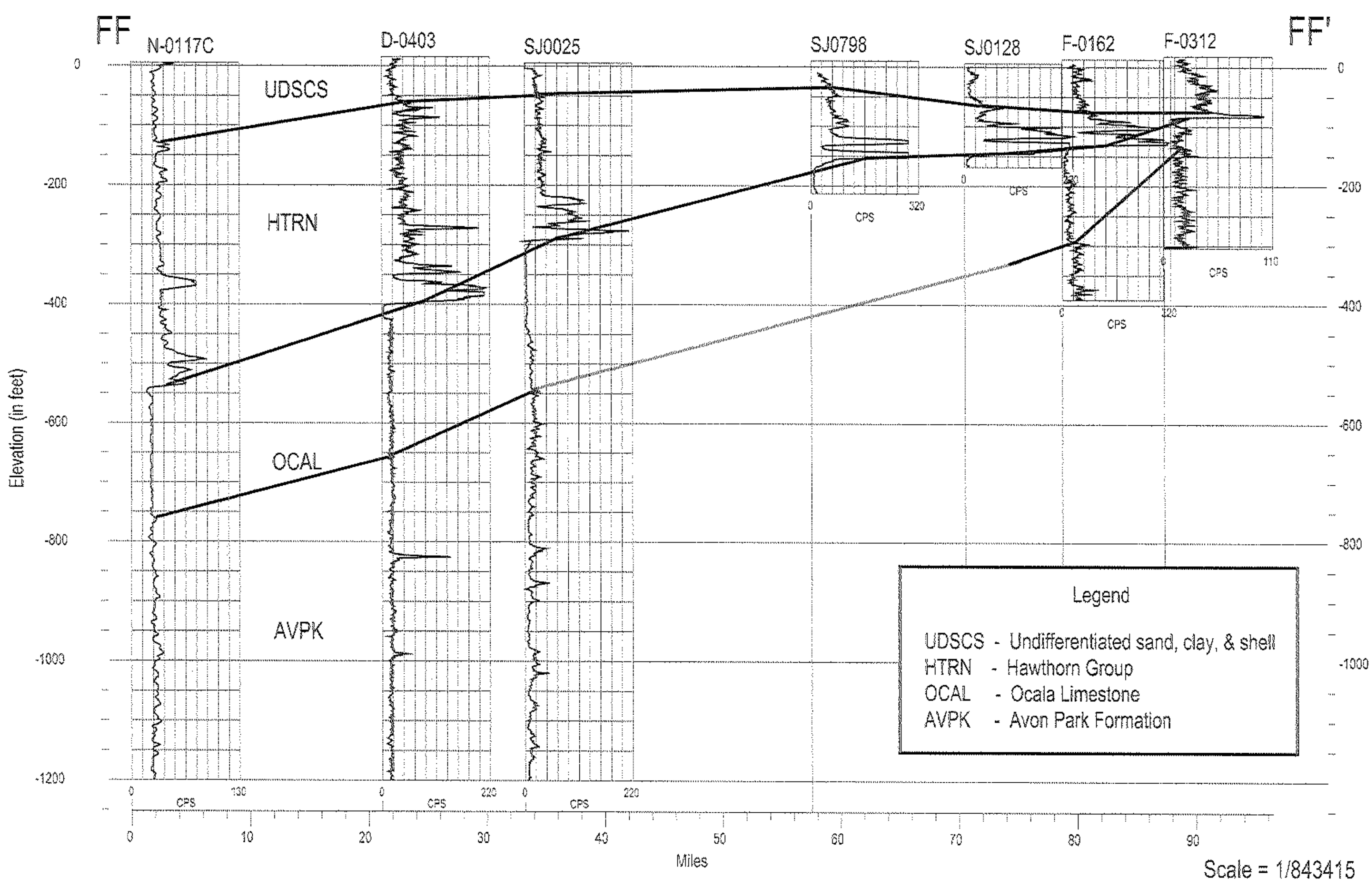
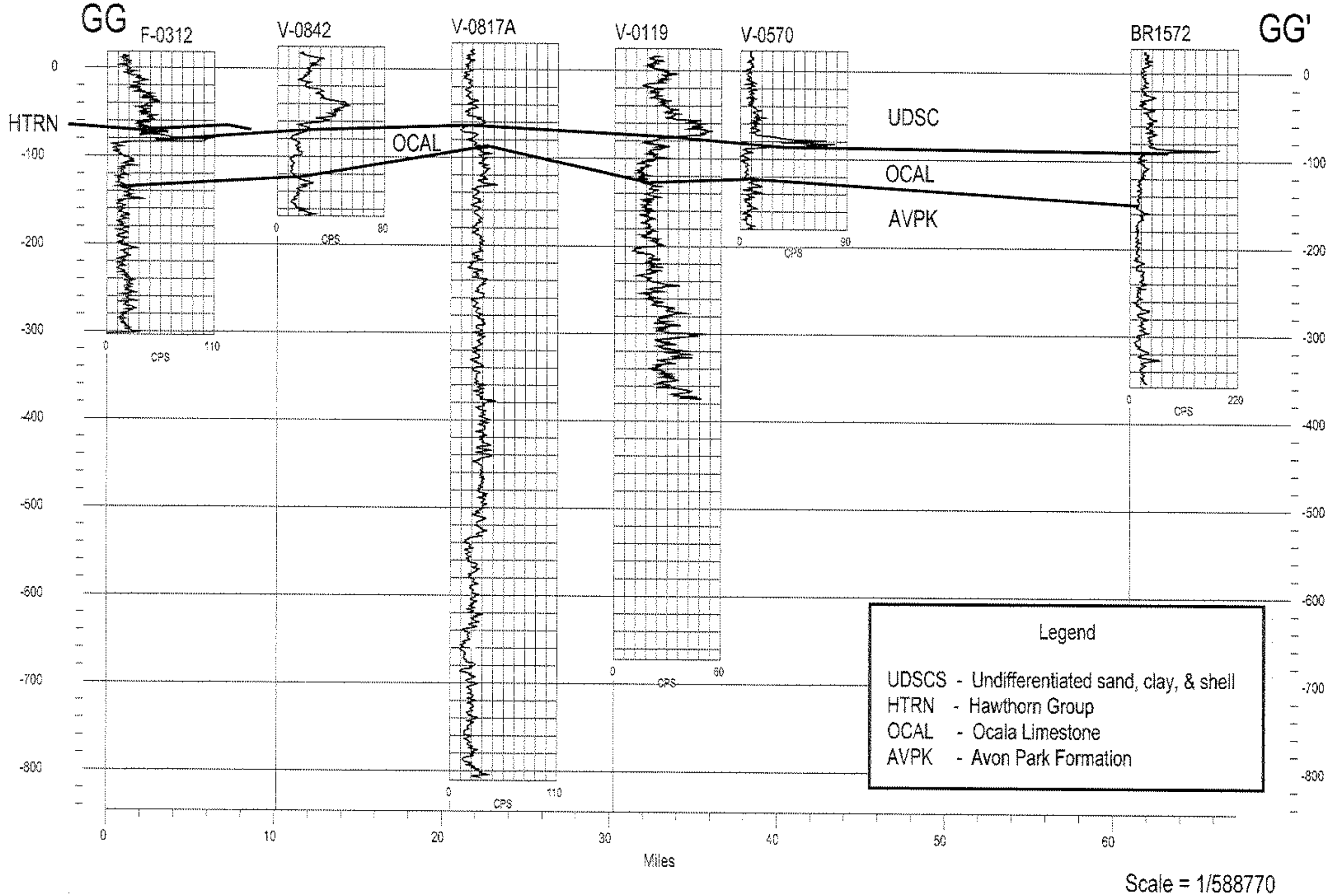
Gamma Log Cross Section EE-EE'



Gamma Log Cross Section FF-FF'

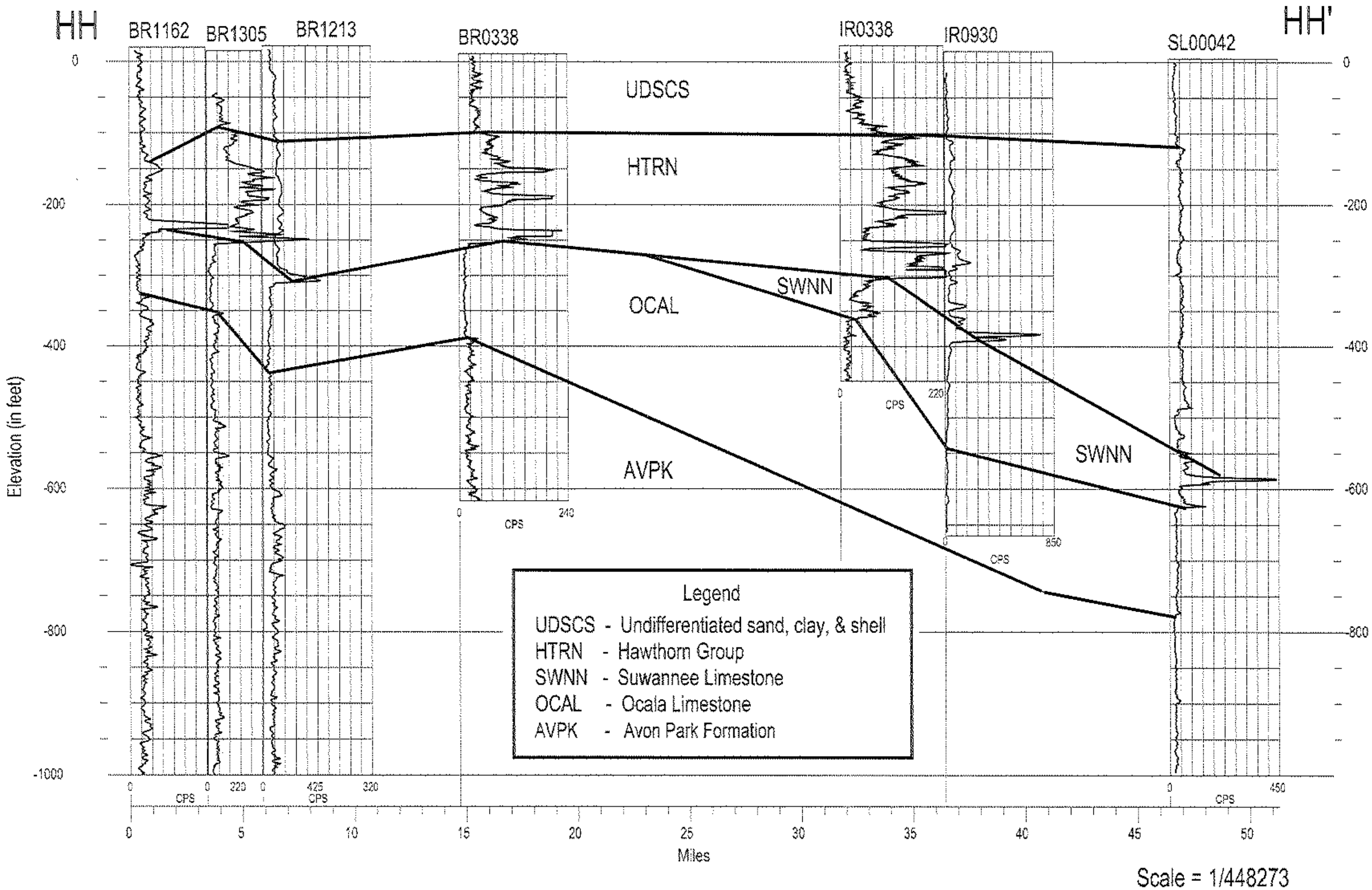


Gamma Log Cross Section GG-GG'

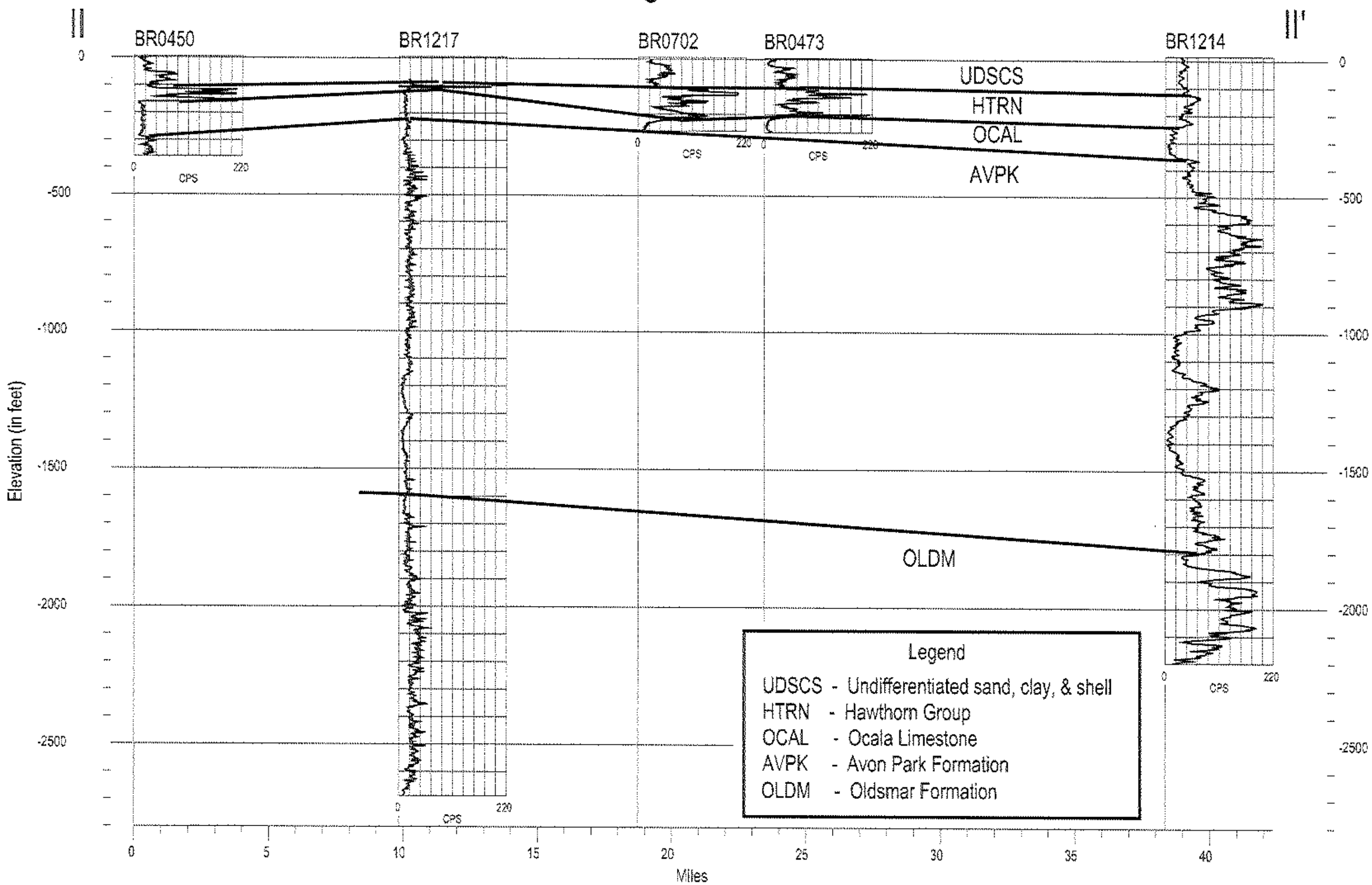


FLORIDA GEOLOGICAL SURVEY

Gamma Log Cross Section HH-HH'



Gamma Log Cross Section II-II'



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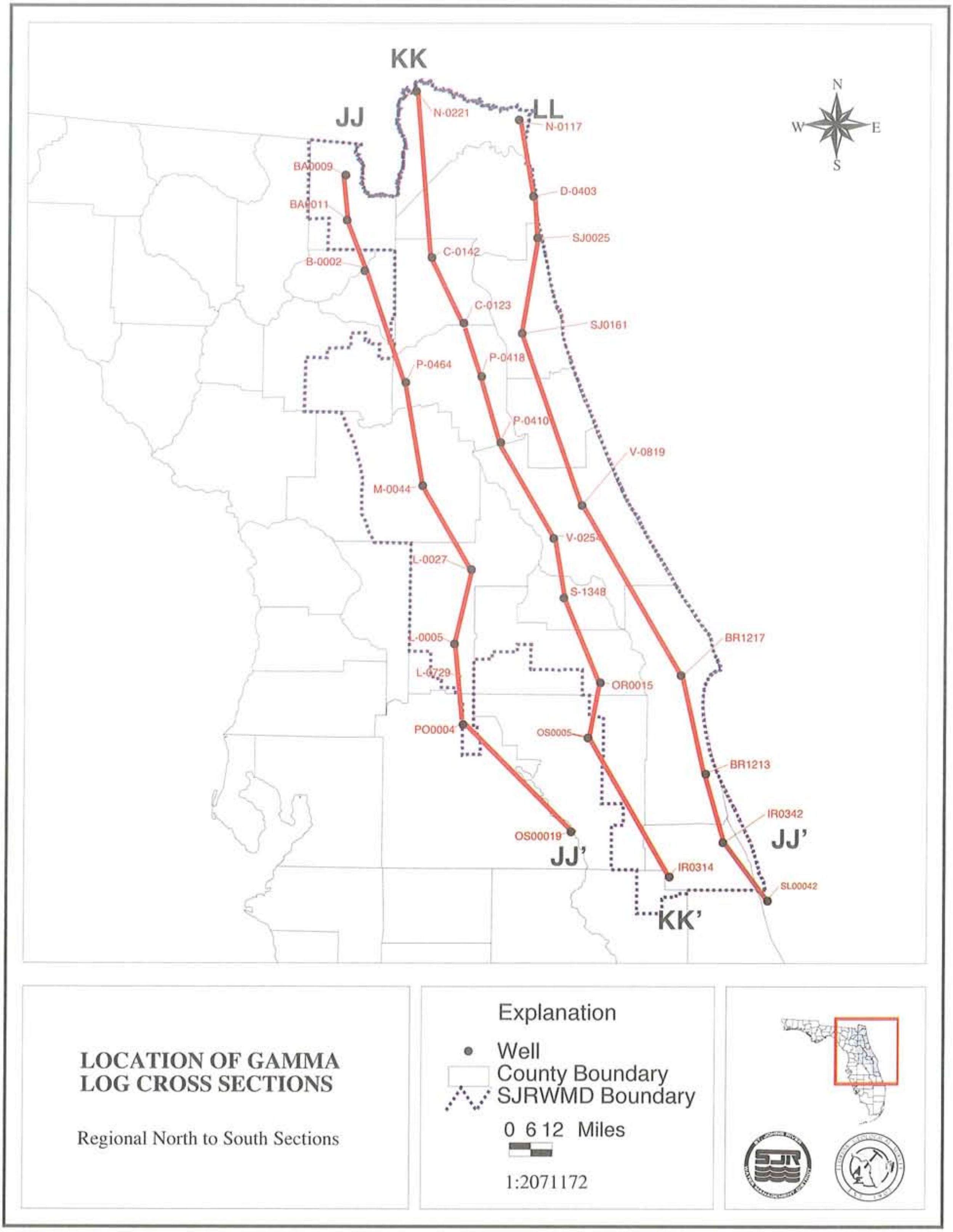
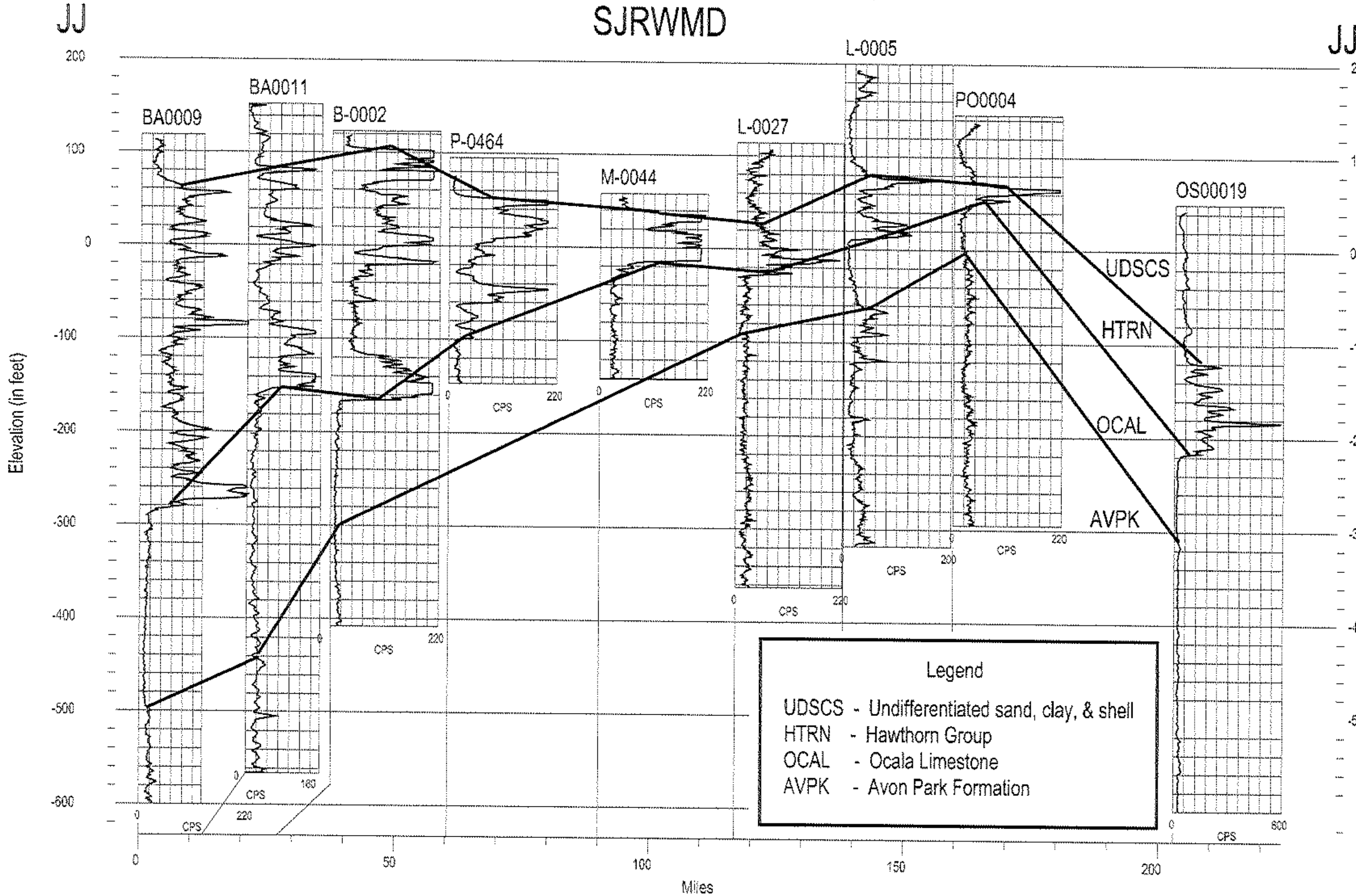


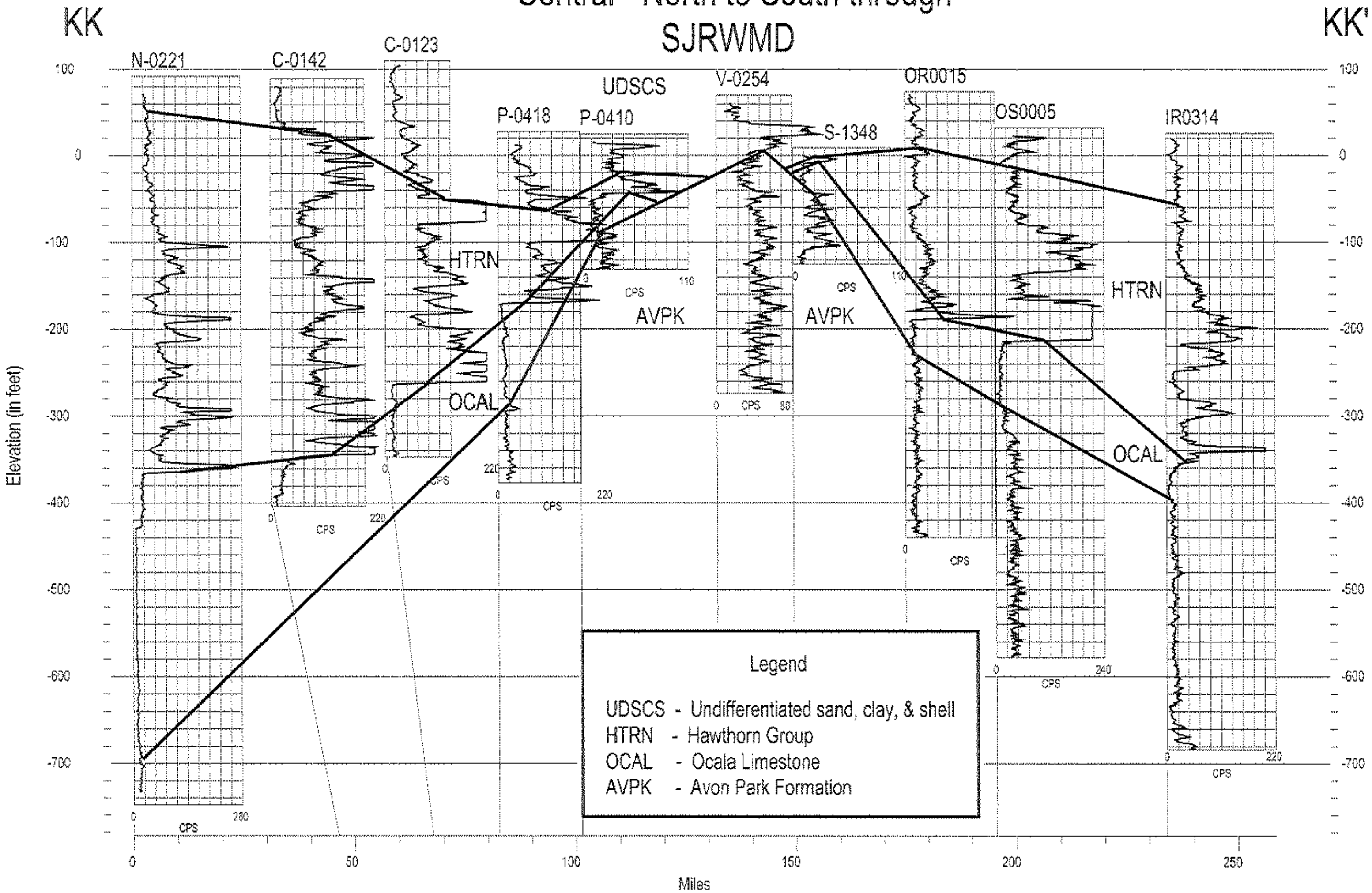
Location of Gamma Log Cross Sections, Regional North to South Sections.

Gamma Log Cross Section JJ-JJ'
Western - North to South through
SJRWMD



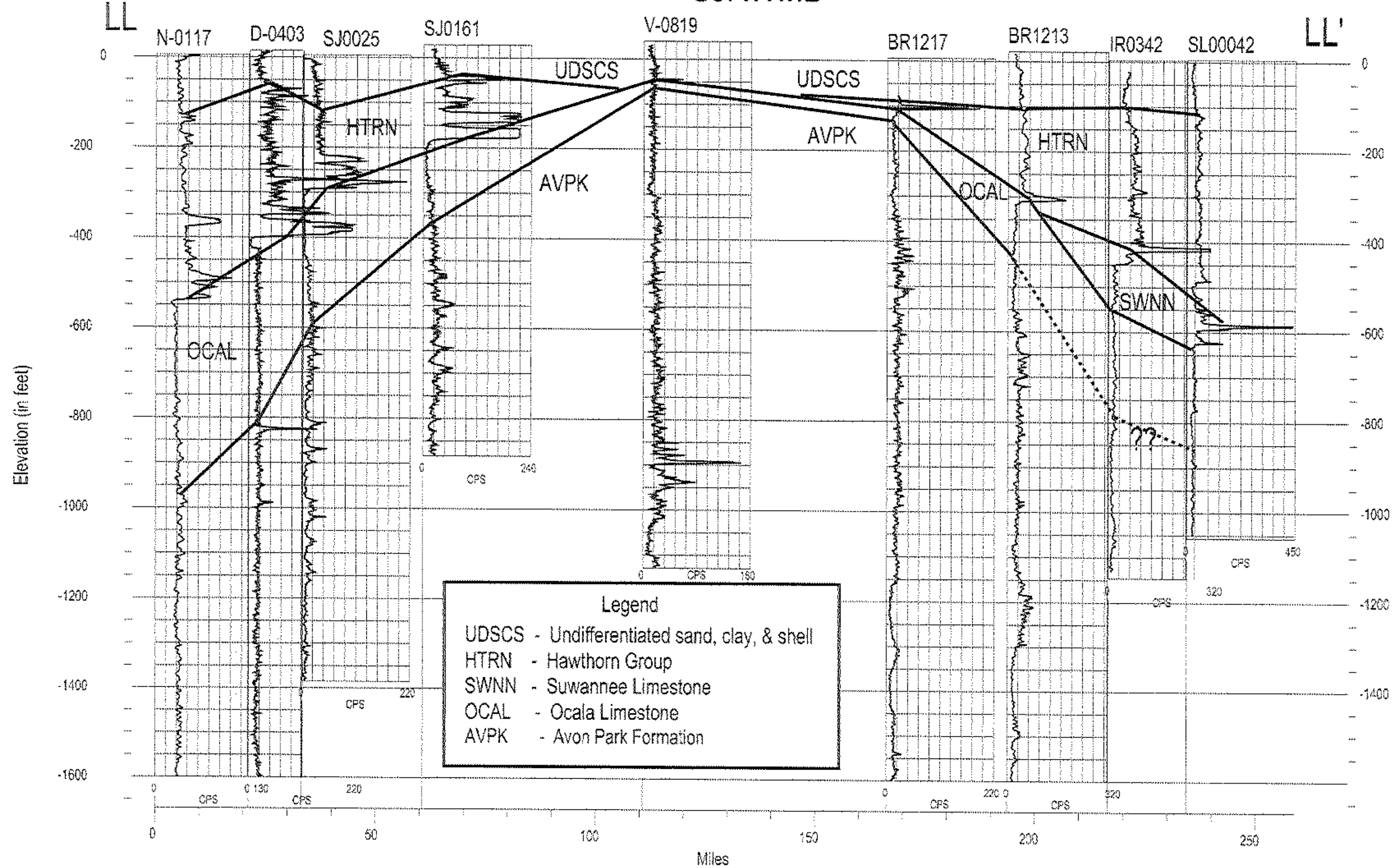
Scale = 1/1959335

Gamma Log Cross Section KK-KK'
Central - North to South through
SJRWMD



Scale = 1/2259576

Gamma Log Cross Section LL-LL'
Eastern North to South through SJRWMD



Scale = 1/2262341

APPENDIX B: Table of Reference Logs used in this study.

Well	Reference (FGS lithologic log, site name)	Lat.	Long.	Land Surf. Elev.	Total Depth bls	Elevation of top of Geological Units, msl						Cross Section or Figure
						HTRN	SWNN	OCAL	AVPK	OLDS	CDKY	
A-0006	W-13615, UF Geology building seismic well	293856	822038	160	406	146		52	-90			F
A-0071	W-1505	293556	820432	160	113	131		56				F
A-0096	W-13693, Micanopy public supply standby	293013	821706	116	140	100		45				S
A-0375	W-13094	293711	822446	76	1047			50	-100			F, S
A-0437	W-484	295046	822437	147	154	140		14				E
A-0438	W-16200	295105	823040	130	115	122		92				E, S
B-0002	W-14230, Raiford State Prison east well	300345	821108	123	531	105		-160	-360			JJ
B-0005	W-531, Gainesville Northwood water treat. plant	295146	820818	145	232	110		-11				E
B-0006	W-6261, Starke public supply	295628	820608	153	419	140		-131	-240			D, T
BA0009	W-6500, USGS observation, Taylor	302620	821735	118	898	70		-280	-500			B, JJ
BA0011	W-6502, USGS observation, Sanderson	301535	821620	153	718	80		-150	-442			JJ
BA0023	W-13773, Olustee Prison public supply	301252	822219	166	448	98		-85				C
BR0338	W-104	275550	803137	11	628	-100		-250	-390			HH
BR0450	W-927, W-5919, W-5913	283337	803913	6	366	-115		-160	-290			M, II
BR0473	W-15177	281502	803617	5	271	-110		-212				II
BR0500	W-1683	282130	804504	15	204	-83		-118				O
BR0617	W-5915	283219	804052	5	451	-98		-120	-235			N
BR0702	W-8042	281845	803808	7	268	-108		-220				O, II
BR0817	W-13076, FGS core Ms Caucus #1	275245	804910	20	495	-65		-158	-195			DD
BR0910	Lake Washington	280858	804355	22	993	-120		-220	-328			P
BR1162	W-30016, Melbourne injection well, DB Lee	280709	803757	20	2419	-130		-230	-330			P, HH
BR1213	W-15944	280219	803611	22	2807	-110		-320	-440			HH, LL
BR1214	W-15890, South Beaches injection well	280226	803256	16	2214	-120		-240	-350			II
BR1217	W-16226, Merritt Island injection well #2	282526	804216	6	2694	-95		-110	-238	-1655	-2450	II, LL, Figure 2
BR1305	W-16297, Grant St. injection well Melbourne	280426	803634	15	2699	-100		-260	-355			HH
BR1322	W-13881, FGS core Red Fern #1	280810	805051	20	322	-95		-180	-218			P, DD
BR1572	W-17528, Astronaut High School	283730	805101	28	386	-81		-89	-155			GG, M
C-0120	W-5330, USGS observation well #10	294808	820209	147	228	69		-62				T
C-0123	W-14521	295015	814334	110	457	-50		-260				KK
C-0134	W-5331, USGS 4-corners well, Melrose	294310	820244	180	251	90		-22				T
C-0135	W-14521, FGS core Miss J #1	295028	813948	79	385	-80		-270				E
C-0137	W-14476, FGS core Kuhrt #1	295857	814322	63	418	-57		-345				D
C-0138	W-13769	295902	815002	95	308	35		-210				D
C-0142	W-14219, FGS core Jennings #1	300655	815257	90	493	32		-345				U, KK
C-0193	W-5347, USGS observation well	295206	814749	99	320	41		-190				U, E
C-0473	W-3478, W-2753, W-522	295843	813944	15	399	-90		-315				D
C-0490	W-14301, FGS core Varnes #1	295202	815513	165	252	102		-70				E
C-0496	W-6299, E I DuPont Highlands Plant injection well	300321	820138	175	1600	35		-280	-500			T
C-0578	W-3478	295733	813654	5	1177	-70		-305	-410			W

Well	Reference (FGS lithologic log, site name)	Lat.	Long.	Land Surf. Elev.	Total Depth bls	Elevation of top of Geological Units, msl						Cross Section or Figure
						HTRN	SWNN	OCAL	AVPK	OLDS	CDKY	
D-0070	W-514	301313	814027	13	1002	-75		-410	-630			W, C
D-0153	W-3542	301423	814652	84	555	-30		-366				C
D-0165	W-6830, Jacksonville, Timaquana Heights	301455	814336	17	564	-58		-440				C
D-0176	W-304	302022	813934	4	1275	-40		-500	-740			W, Figure 11
D-0349	W-8881, Garden St, Monticello Drug Co	302415	815225	87	2166	10		-330	-600	-1433	-1898	B, Figure 5
D-0403	W-3718	302200	812357	15	2020	-50		-400	-648			B, FF, LL
D-0444	W-531, Jacksonville public supply, Ribault Heights	302302	814304	9	925	-50		-480	-730			B, W
D-0520	Montgomery Correctional Institute	303215	814330	16	1100	-79		-404	-674			Figure 17
D-1118	W-10920, Oceanway School	302806	813754	37	739	-80		-550				AA
D-3060	Arlington East deep outpost well	302051	813231	19	1574	-80		-560	-820			B, AA
D-4560	W-3990	301422	815412	80	385	25						U, C
F-0019	FGS core Washington Oaks Gardens #1 N	293813	811238	7	462	-80		-129	-295			Figure 19
F-0162	W-12339, Palm Coast LW-10	293320	811225	13	404	-78		-130	-292			F, FF, Figure 13
F-0204	SJRWMD core DOWN #1, Dinner Island	293337	812303	26	114	-38		-65				AA
F-0251	W-4057	291818	811904	25	147	-32		-37	-110			AA, BB
F-0294	Dinner Island	293344	812323	25	124	-57		-92				F, BB
F-0312	W-12340	292556	811315	18	322	-67		-83	-135			G, FF, GG
IR0314	W-3021	273649	804527	26	710	-60		-350	-400			R, KK
IR0338	W-13958, FGS core Phred	274150	802608	23	472	-105	-300	-360	-410			HH, Figure 14
IR0342	W-3019, W-3034	274535	802408	4	1150	-100	-425	-550	-750			LL
IR0632	W-3019	274704	802444	5	624	-100	-325	-390	-510			Q
IR0736	W-3017	274435	803729	23	584	-73		-385	-500			Q
IR0748	W-14167, Hercules injection-monitor well	273511	802855	25	1714	-100	-415	-460	-590			R, Figure 7
IR0930	W-3022	273820	802350	15	680	-110	-395	-550				HH
IR0954	W-17694, Snook Rd	273514	803444	27	482	-95		-407				R
L-0005	W-1893	283303	814447	215	533	90		25	-40			S, JJ, Figure 8
L-0027	W-2320	285104	814048	114	477	45		-30	-90			JJ
L-0078	W-6266	284826	815133	70	840	35		12	-80			J
L-0094	Astatula Estates	284252	814314	91	321	-15		-99	-169			Figure 12
L-0106	W-735	284935	814826	76	366	13		-44	-100			J
L-0114	W-1632	285212	815428	127	247	52		-20	-60			T, S
L-0121	W-898, Ocala National Forest Pittman Work Center	290046	813829	57	179	-5		-95	-115			I
L-0122	W-10935	290150	812726	47	131	31		-17	-40			X, I
L-0443	W-12702	284210	814622	106	728	85		-10	-110			S, L
L-0467	W-12176, W-335, W-2927	284935	813851	170	489	130		2	-60			J, V
L-0729	Lake Louisa State park	282520	814340	120	358	62		43	-30	-1670	-1970	S, Figure 3
M-0024	W-17565	292200	815100	91	90	47		20				G
M-0044	W-3889	291117	815405	58	199	40		-16	-45			T, H, JJ
M-0060	W-8415	291918	815754	68	674	65		38	-80			T, G

Well	Reference (FGS lithologic log, site name)	Lat.	Long.	Land Surf. Elev.	Total Depth bls	Elevation of top of Geological Units, msl						Cross Section or Figure
						HTRN	SWNN	OCAL	AVPK	OLDS	CDKY	
M-0068	W-15127, FGS core Harbison #1	285739	813951	112	210	1		-61				V
M-0090	W-11648	290511	815243	73	156	17		-65				T
M-0115	W-14315, FGS core Juniper #1	291051	814250	50	282	-30		-60	-80			U, H, V
M-0122	W-3688	291149	820526	70	135	59		-18				S, H
M-0139	W-892	291820	821102	102	193	82		38	-65			S, G
M-0310	W-11933	285821	815742	125	226	82		-15	-70			S, I
M-0410	Ocala National Forest 13	292817	814836	77	152	30		-54				Figure 18
N-0117	W-890	304001	812803	5	2109	-125		-545	-830			FF, LL
N-0131	W-13815	303746	815557	86	489	3		-410				A, U
N-0220	W-17155, Callahan	303543	814948	24	1072	-5		-345	-630			A, W
N-0221	W-17143, St. Mary	304658	815712	92	840	50		-373	-708			U, KK
N-0222	Humphreys Mining	304701	815710	90	1915							Figure 4
N-0237	W-17544, Cary State Forest	302409	815516	80	500	10		-340				B, U
N-0277	W-890, Rayonier #8	303835	812735	20	1811	-95		-550	-850			A
OK0003	W-6173, Fort Drum service plaza	273605	804925	53	764	-75		-395	-450			Z, R, DD
OR00004	W-6373	282240	811128	65	302	30		-167				O
OR0015	W-5128	282404	810505	74	514	10		-190	-220			O, KK
OR0110	W-15334	282925	805620	16	264	-72		-180	-235			CC, N
OR0121	W-6476	282141	812416	84	434	72		-95				O
OR0304	W-135	283253	812046	102	472	-10		-93	-158			N
OR0305	W-11902, Orange Co. High Point #2	283256	811311	74	426	-6		-108	-175			N, Y
OR0314	W-2177	283417	812411	101	380	35		-68	-75			N
OR0465	Lake Ivanhoe, Orlando	283339	812228	80	2186	40		-100	-170	-1755	-2015	Figure 9
OR0547	W-2608	284238	812757	70	640	37		-30	-95			L
OR0551	W-5836	283848	813103	112	425	50		-43	-120			M, V
OR0614	W-17303, Cocoa S	282530	810656	67	1110	-30		-175	-190			Z, Y
OR0618	W-17536	283135	810644	60	1140	-25		-130	-160			N
OR0652	W-17553, Rock Springs	284634	812619	35	636	-23		-115	-175			J
OS00005	W-16952	281036	810754	67	457	-90		-280	-295			Z, P
OS00006	W-11478, W-17021, W-10899	281952	813508	115	298	70		-89				O
OS00007	W-5236/12356	281935	812504	85	1194	45		-100	-250			V
OS00012	W-11420	280956	812654	65	397	50		-112	-140			P
OS00019	W-16952	274805	811154	50	850	-120		-220	-300			V, Q, JJ
OS0002	W-9124	274742	805853	71	877	-100		-179	-287			Z, Q
OS00021	W-17142	280821	812104	55	959	25		-100	-250			V, P
OS0005	W-9116	280928	805329	32	610	-80		-213	-290			KK
OS0041	W-13534	281703	805948	62	378	-60		-250	-270			Y
OS0068	W-17140	280538	810601	81	804	-100		-320	-360			Z
OS0220	W-13496, FGS core Osceola #2	281704	805430	35	412	-101		-250	-365			CC, DD

Well	Reference (FGS lithologic log, site name)	Lat.	Long.	Land Surf. Elev.	Total Depth bls	Elevation of top of Geological Units, msl						Cross Section or Figure
						HTRN	SWNN	OCAL	AVPK	OLDS	CDKY	
P-0172	W-5028, USGS test well	293932	813427	19	543	-16		-101	-228			W, Figure 10
P-0410	W-14180, SJRWMD core Crescent City	292218	813331	25	156	-18		-43	-85			X, G, KK
P-0418	W-5023	293759	813834	28	405	-57		-171	-310			KK
P-0463	W-8498, W-14376	293706	813747	16	248	-70		-187				F
P-0464	W-1727	293633	815945	95	242	52		-98				T, F, JJ
P-0473	W-5746, Ocala National Forest Johnson Field #1	292823	814433	10	144	-20		-124				U
P-0474	W-1496	293554	813425	61	226	10		-90				W, F, X
P-0493	W-14477, FGS core Bostwick #1	294552	813442	12	238	-92		-207				W
P-0510	W-1498	293733	814748	77	300	-8		-149				U, F
P-0593	W-14566, FGS core Atchison #1	293854	815246	90	226	12		-114				F
P-0619	W-6643, Hudson Pulp & Paper Co	294618	814734	57	1396	45		-93	-195	-875		U, Figure 6
P-0817	W-17173, Pomona Park	293206	813517	46	199	-3		-33	-97			X
PO0004	W-5473	281422	814223	145	440	75		50	0			S, P, JJ
PO0013	W-15653, SJRWMD core Thornhill	281202	813917	134	150	67		22				P
S-0028	W-15654, Cochran Forest	284322	810842	45	205	21	-15	-40	-100			CC
S-0042	W-15662, Kilbee Ranch	284232	810452	18	133	-46		-105				L
S-0063	W-12103	283838	811351	40	173	-17		-98				M
S-0080	W-5755	284702	811919	65	389	0		-20	-20			BB
S-0083	W-2792	284955	812019	20	167	-40		-115				K
S-0552	W-413	284800	811809	30	146	-4		-43				K
S-1200	Snow Hill Road at Econlockhatchee River	284051	810652	20	498	-25		-38	-165			CC, M
S-1216	W-16916	284047	812121	75	1505	26		-66	-140			Y
S-1224	W-17478, Geneva fire station.	284411	810711	75	866	50		-25	-50			L
S-1225	W-17381, Yankee Lake	284923	812348	45	1919	-15		-75	-180			X, J, K, Y
S-1348	W-359	284428	811444	9	134	0		-10	-45			L, KK
S-1351	Lake Mary	284413	812201	75	1082	40		-15	-115			L, Y
S-1399	SJRWMD unpublished file	284603	812301	45	513			-100	-175			Y
S-1402	W-17510	283812	811709	65	601	10		-110	-135			M, Y
SJ0025	W-12054, Ponte Vedra deep outpost well	301132	812257	5	1390	-81		-285	-545			FF, LL
SJ0128	W-13844, FGS core Faver-Dykes #1	294000	811527	6	174	-65		-147				FF
SJ0148	W-5013	294238	812656	28	592	-42		-144	-283			Figure 15
SJ0159	W-14413, FGS core Parker Farms #1	294751	812916	22	258	-45		-225				E
SJ0161	W-5014	294803	812709	29	912	-40		-180	-310			AA, LL
SJ0163	W-13765, FGS core Scott #3	295905	812723	25	242	-33		-210				AA, D
SJ0164	W-13744, FGS core Scott #1	295938	813008	29	252	-30		-211				D
SJ0177	W-13751, FGS core Scott #2	300514	812723	61	336	-41		-263				AA, Figure 16
SJ0178	W-11583	301424	812240	10	532	-70		-375				C
SJ0310	W-16535, St Joe Riverton Tract test well GCI-1	300249	813919	25	968	-95		-267	-470			W

Well	Reference (FGS lithologic log, site name)	Lat.	Long.	Land Surf. Elev.	Total Depth bls	Elevation of top of Geological Units, msl						Cross Section or Figure
						HTRN	SWNN	OCAL	AVPK	OLDS	CDKY	
SJ0798	W-1376	295115	811608	10	223	-40		-155				E, FF
SL00042	W-14703	273057	801847	5	1062	-115	-600	-625	-780			HH, R, LL
V-0031	W-8458	290431	811448	43	303			-29	-40			EE
V-0068	W-14183, SJRWMD core Pierson	291458	812942	20	125	-35		-45	-89			X
V-0119	W-8455, USGS test well New Smyrna Beach	290251	810014	25	697	-57		-80	-130			GG, I
V-0183	W-183	290834	810738	43	817	-17		-48	-97			EE
V-0187	W-15995, Daytona Beach airport	291106	810341	24	818	-37		-74	-136			H
V-0200	W-4226	291030	805904	16	879	-33		-84	-138			H
V-0225	W-5743	291447	812749	62	1086	-25		-58	-120			H
V-0235	W-15290, FGS core Middleton #1	285051	810338	17	182	-4		-62	-90			K
V-0238	W-15290	285105	810701	27	257	15		-34	-60			K
V-0254	W-12386	285916	811749	70	344	38		8	8			I, EE, BB, CC, KK
V-0267	W-12795	290323	811720	76	337	52		11	-10			EE
V-0273	W-2865	290536	812011	100	286	55		-10	-10			BB
V-0304	W-3540	291024	810502	27	232	-30		-65	-130			EE
V-0307	W-7942	291100	812002	70	140	-16		-30	-30			BB
V-0375	W-8837	285146	811843	10	340			-25	-25			BB
V-0570	W-12786	285703	805650	23	203	-72		-88	-122			GG, K
V-0780	W-17315, Orange City fire tower	285439	811814	60	960	10		-20	-18			BB
V-0801	W-17527, Osteen	284840	811157	10	496	-48		-115	-115			K, CC
V-0810	W-17481, Snook Rd	285210	811315	35	604	-5		-55	-55			CC
V-0817	W-17531, Daytona Beach airport	291045	810344	30	972	-33		-70	-80			GG
V-0819	W-17529, Tiger Bay	290707	811016	40	488	-35		-45	-70			EE, LL
V-0831	W-17469, W-421, W-7942, W-17154	290930	811758	40	100			3				H
V-0842	W-12633	291926	810628	25	193	-22		-62	-125			GG

Geological Unit Abbreviations: **HTRN** = Hawthorn Group; **SWNN** = Suwannee Limestone; **OCAL** = Ocala Limestone; **AVPK** = Avon Park Formation; **OLDS** = Oldsmar Formation; **CDKY** = Cedar Keys Formation.

Appendix C. Annotated Bibliography of Published Geophysical Well Logs Within (or very near) the SJRWMD.

Prepared by Richard A. Johnson

A number of previous studies have illustrated geophysical logs or contain stratigraphic information from wells in the SJRWMD. A preliminary literature search was conducted at the outset of the current project to locate published logs and incorporate into the data used in this study any logs that were not already available in the SJRWMD database. A brief description of the publications' subjects and the well logs or data included in each were noted, and are included in the following bibliography.

Explanation of well identification formats used in various publications

The studies referenced in the following section use a variety of conventions to identify wells. Many wells are identified in publications simply by their latitude-longitude locations. These are presented as six-digit latitude, followed by a seven-digit longitude number. For example, a well at 28 degrees, 38 minutes, 20 seconds of latitude and 81 degrees, 13 minutes, and 28 seconds of longitude would be identified as 2838200811328. If the location was not recorded to the level of seconds, dashes are substituted for the missing numbers, e.g.: 2838—08113—.

A few wells are identified by their Township-Range-Section-quarter section location coordinates. For example, a well in Township 4 North, Range 25 east, in the northwest quarter of the southeast quarter of Section 36 would be expressed as T4N, R 25E, S36 NW/SE.

Some of the wells referenced in the studies are part of the Florida Geological Survey (FGS) well collection. FGS accession numbers are indicated by a "W" and a dash, followed by a one to six digit number, for example, W-16523. In cases where wells identified by other numbering formats correspond to FGS collection wells, the FGS number is shown in the bibliography text in parentheses.

Bibliography

Barraclough, J. T., 1962, Ground-water resources of Seminole County, Florida: Florida Geological Survey Report of Investigations 27, 91 p.

Data is presented concerning the ground-water resources of Seminole County. The study was designed to obtain basic hydrogeologic information about salt water contamination and declining water levels. Single-point-resistance electric logs from seven wells are shown with stratigraphic data. Wells cited in study: 2845—08117—, 2840—08107—, 2848—08116—, 2841—08110—, 2838200811328 (W-3195), 2842040811139 (W-3189), and 2847320811327 (W-1973).

Bermes, B. J., Leve, G .W., and Tarver, G. R., 1963, Geology and ground-water resources of Flagler, Putnam, and St. Johns Counties, Florida: Florida Geological Survey Report of Investigations 32, 97 p.

An investigation of the ground-water resources of the area in order to better define and understand the local problems of declining water levels and saltwater intrusion. Includes single-point-resistance electric logs of two U.S. Geological Survey test wells, with stratigraphy—later relogged by SJRWMD including gamma-ray and resistivity-electric: Putnam, 2939320813428

(W-5028); Flagler-St. Johns county line: 2937290812214 (W-4978).

Black, Crow and Eidsness, Inc., 1964, Hydrological investigations at the municipal water-supply well no. 6, city of Gainesville, Alachua County, Florida: Engineering Report, Project No. 110-64-R, Gainesville, Florida, 9 p. + plates.

The report summarizes findings concerning sources of pollution and possible remedial procedures in city of Gainesville (Alachua County) water supply well no. 6. Gamma ray and single point resistivity logs shown for well 2938130821852 (W-3790).

Black, Crow and Eidsness, Inc., 1968, Ground-water pollution survey for the Minute Maid Company (a division of the Coca-Cola Company), Plymouth, Florida: Engineering Report, Project No. 454-68-R1, 6-3 p.

Summarizes findings concerning sources of pollution (bacteria) and possible remedial procedures for Minute Maid production well #2, Orange County. Includes single point resistivity log for well #2 and Holts Lake drainage well; illustrates gamma-ray log* for well #2: 2841260813318* (W-1443), and 2841020813322 (W-4053).

Brown, D. P., 1980, Geologic and hydrologic data from a test-monitor well at Fernandina Beach, Florida: U.S. Geological Survey Open-File Report 80-347, 36 p.

Presents hydrologic and geologic data from the drilling of a deep observation well in northeastern Nassau County. Includes lithologic/drillers' logs and normal-resistivity/guard-electric, gamma ray, and neutron geophysical logs with an indication of general stratigraphy. Well was also logged by SJRWMD (gamma-ray, neutron and normal-resistivity-electric): well 3039580812804.

Brown, D. P., Johnson, R. A. and Baker, J. S., 1984, Hydrogeologic data from a test well at Kathryn Abbey Hannah Park, city of Jacksonville, Florida: U.S. Geological Survey Open-File Report 84-143, 41 p.

Presents drill-cutting interpretation and water-sample (chemistry) analyses, water-level measurements, and geophysical logs obtained from a deep test/observation well in eastern Duval County. Includes gamma ray, normal-resistivity- and focused-resistivity-electric, neutron logs; and lithologic log (also logged by SJRWMD): well 3022000812357.

Brown, D. P., Johnson, R. A. and Broxton, R. A., 1985, Hydrogeologic data from a test well in east-central Duval County, Florida: U.S. Geological Survey Open-File Report 84-802, 61 p.

Presents geologic, hydrologic and water-chemistry information obtained from the drilling of a deep test/observation well at Arlington east sewage facilities, Duval County. Illustrates gamma ray, normal-resistivity- and focused-resistivity-electric, neutron logs, and lithologic log (non-FGS partial well-cuttings description available). Also logged by SJRWMD (gamma-ray and normal-resistivity-electric logs): well 3020520813232

Brown, D. P., Miller, J. A. and Hayes, E. C., 1986, Hydrogeologic data from a test well near Ponte Vedra, northeast St. Johns County, Florida: U.S. Geological Survey Open-File Report 86-410W, 31 p.

Geologic hydrologic and water-chemistry data obtained during the drilling of a deep test/observation well near Ponte Vedra, St. Johns County. Includes gamma ray, normal-resistivity and focused-resistivity-electric, neutron logs, and lithologic log: well 3011280812258

Brown, D. W., Kenner, W. E., Crooks, J. W. and Foster, J. B., 1962, Water resources of Brevard County, Florida: Florida Geological Survey Report of Investigations 28, 104 p.

A summary of the then-available data concerning the quantity, quality and availability of water in Brevard County in order to prepare for rapid growth in population. Includes data from test well drilling. Single-point-resistance-electric log and formation contacts from one test well: 2822020805128 (W-3557).

Chen, C. S., 1965, The regional lithostratigraphic analysis of Paleocene and Eocene rocks of Florida: Florida Geological Survey Bulletin 45, 105 p.

A reconnaissance study of the stratigraphy of peninsular and panhandle Florida using well cuttings, cores and geophysical logs (electric). Commercial resistivity-electric logs from five oil-test wells with stratigraphic and general lithologic descriptions within or very near the SJRWMD (exact Lat/Long not available for 3): Baker - 3029090821845 (W-1500); Lake - 2823300814933 (W-275); Marion -T16S, R23E, S16 (W-1482); Nassau -T4N, R24E, S19 (W-336); and Osceola - T31S, R33E, S12 (W-1411).

Duncan, J. G., Evans, W. L., III, and Taylor, K. L., 1994, Geologic framework of the lower Floridan aquifer system, Brevard County, Florida: Florida Geological Survey Bulletin 64, 90 p. + plates.

Summarizes the geology, hydrogeology and ground-water chemistry of the lower Floridan aquifer system using well cuttings, cores, injection-well tests, borehole videos, geophysical logs, and monitor-well water chemistry data for use in planning future injection-disposal wells. Data was obtained from seven injection wells in Brevard County and one in Indian River County. Includes gamma ray and sonic logs and litho-stratigraphic column for seven deep wells, one cross section (seconds not available for one well in each county): Brevard - 2825330804222 (W-16226); 2807130803807 (W-30016); 2802050803550 (W-15944), 2804250803636 (W-16297), 2801300803603 (W-16133), 2804140803847 (W-15961), 28022608033— (W-15890); Indian River - 2735—08029— (W-14167).

Fairchild, R. W., 1972, The shallow aquifer system in Duval County, Florida: Florida Geological Survey Report of Investigations 59, 50 p.

This investigation studies the geologic and hydrologic characteristics of the shallow-rock aquifer system in Jacksonville, Duval County, to determine the potential of the interval as a primary or secondary source of potable water for the area. One gamma-ray log with associated stratigraphy and lithology: 3029150814215.

Fairchild, R. W., 1977, Availability of water in the Floridan aquifer in southern Duval and northern Clay and St. Johns Counties, Florida: U.S. Geological Survey Water-Resources Investigations 76-98, 53 p.

An investigation of the geology and hydrology of the Floridan aquifer in the Jacksonville area, including test wells. Includes single-point-resistance electric and gamma-ray logs for test well in Clay County with formation contacts and general lithology: well 3006560814634 (W-11940).

Frazee, J. M. and McClaugherty, D. R., 1979, Investigation of ground water resources and salt water intrusion in the coastal areas of northeast Florida: St. Johns River Water Management District Technical Publication SJ 80-4, 136 p. + appendices.

Evaluates ground water resources and salt water intrusion in coastal areas of northeastern Florida. Cross sections as well as a fence diagram are constructed using geophysical logs and drillers' logs. Lists tops of formations for 35 geophysically-logged wells in tabular form (logs not shown); 8 cross sections; fence diagram: Flagler - 2926030810624, 2934020811110, 2940020811252, 2925230812347, 2926030810825, 2926480811206 (W-15096), 2926470811820, 2933140811324, 2933130811352, 2932560811720, 2935040811837, and 2935290811917; St. Johns – 2943000811417, 2949240811616, 2950470811603, 2952000811623, 2939430812842, 2941200812920, 2949470813022, 2937290812214, 2946120812534, 3002030812027, 2937160812926; Duval – 3013270812657, 3020580812442, 3025370812531, 2958170813046, 3015120813311, 3020310813922, 3023050812941 (W-10359), 3023010812950, 3023420813152; Nassau – 3040440812702, 3041130812720, 3042080812710.

Gillespie, D. P., 1976, Hydrogeology of the Austin Cary control dome in Alachua County, Florida: University of Florida masters thesis, 127 p.

Investigates the hydrology and geology of and possible groundwater contamination in a cypress dome, Alachua County, in order to determine if safe Floridan-aquifer system recharge is possible through these domes in this area. Seven gamma-ray logs from test wells with general lithology: 2945100821204, 2945020821223, 2945300821220, 2944200821309, 2946150821249, 2946120821238, and 2946130821234.

Grubb, H. F., Chappelear, J. W. and Miller, J. A., 1978, Lithologic and borehole geophysical data, Green Swamp area, Florida: U.S. Geological Survey Open-File Report 78-574, 270 p.

Presents detailed lithologic descriptions as well as gamma-ray and single-point-resistance logs obtained from continuous-core tests located in Lake, Pasco, Polk, and Sumter Counties, in and near the Green Swamp. Includes gamma-ray and single-point-resistance logs from 31 wells within or very near the SJRWMD: Lake County (*gamma-ray only) 2832070814921*, 2830240814533, 2827220814844 (W-15572), 2828400814816 (W-15574), 2824550814837 (W-15576), 2825220814443 (W-15578), 2833310815540, 2824250815605, 2834040815317*, 2832010815450*, 2832070814921*, 2830540814938, 2830410814700, 2825580815617, 2825080815720, 2827260815616, 2828440815305, 2827220814844, 2825290815135, 2823140815112, 2821570815258, 2828400814816, 2828060815014, 2824550814837, 2823180815440, 2832470815154, and 2824350815423; Polk – 2818090814651,

2816290814620, 2818360814053*, and 2820310814321.

Hampson, P. S., 1984, Effects of hydraulic borehole mining on ground water at a test site in northeastern St. Johns County, Florida: U.S. Geological Survey Water-Resources Investigations Report 83-4149, 29 p.

Presents results of an experimental single-borehole phosphate mining project (in northern St. Johns County) conducted by the U.S. Geological Survey. in cooperation with the U.S. Bureau of Mines. Gamma-ray logs from five small-diameter test/observation wells: 300309081234401, 300309081234402, 300309081234403, 300309081234404, and 300309081234405.

Johnson, R. A., 1979, Geology of the Oklawaha basin: St. Johns River Water Management District Technical Publication SJ 79-2, 23 p. + appendix.

Electric-normal-resistivity, gamma ray and drillers' logs are used to delineate lithology, stratigraphy and structure of portions of Lake, Marion, Orange and Polk Counties. Stratigraphic contacts for 50 geophysically-logged wells listed in tabular form (logs not shown); two cross sections: Lake - 2851530814017, 2850580813816 (W-13800), 2847400813440, 2847380813527, 2824560814449, 2849470814137 (W-13862), 2849050814638, 2851370815147, 2850130815332, 2850140815514 (W-14090), 2841360815214, 2939220814608 (W-13853), 2838410814352, 2838150814643 (W-13855), 2838030815057 (W-13872), 2837030815308 (W-13854), 2834040815426, 2832510815249, 2832540814633 (W-12874), 2834510814437, 2830280814552, 2828490814547, 2827270814815, 2827060814937, 2824560814449, 2845250815310, 2851040814048, 2850380814032 (W-14023), and 2850270815446; Marion - 2920210820829, 2913240820901, 2913020820813, 291222082110101 (W-8405), 291222082110102 (W-8406), 2911010820655, 2910180820752, 2910270820340, 2912190815448, 2905490820731, 2904210815935, and 2858530815229; Orange – 2846290813832, 2945550813601, 2843370813552, 2843080813439, 2843040813835 (W-13913), and 2842330813903 (W-13919); Polk – 2818190813954, 2814230814223, and 281453081420.

Johnson, R. A., 1981, Structural geologic features and their relationship to salt water intrusion in west Volusia, north Seminole, and northeast Lake Counties: St. Johns River Water Management District Technical Publication SJ 81-1, 32 p + appendices.

Geophysical logs (gamma-ray, electric normal-resistivity), cores and Florida Geological Survey lithologic printouts were used to delineate stratigraphy of the study area in order to identify subsurface faults that may have caused local saltwater intrusion. Stratigraphic contacts for 40 geophysical-logged wells are listed in tabular form. Logs shown for two of these wells; five cross sections; three short-core lithologic descriptions: Volusia - 2920120813210, 2918230812808, 2915200812654, 2915230812437, 2915010812858, 2914570812853, 2914580812942, 2915020813032, 2914400812715, 2914310812630, 2912160812155, 2910350811800, 2908160811912, 2915580812152, 2903540812138, 2906470812137, 2905100812136, 2903540811957, 2905340811750, 2901380812032, 2859430811810, 2859160811749, 2859030811747, 2858050811642 (W-14419), 285641081200401, 285641081200402, 2855370811108, 2905530812007, 2854380811836, 2953020811817, 2851530811442, 2851030811158, 2851050810720, and 2851380810706 (W-15666); Lake – 2909460813210, 2906420813142 (W-11929), and 2904150813122 (near W-12891), Seminole – 2947020811920, and 2946540811920; Marion - 2910070813832.

Johnson, R. A., 1984, Stratigraphic analysis of geophysical logs from water wells in peninsular Florida: St. Johns River Water Management District Technical Publication SJ 84-16, 57 p. + appendices.

General geophysical (gamma-ray and electric normal-resistivity) characteristics for the nine Cenozoic formations of peninsular Florida are described and figured. Stratigraphic contacts for 21 deep geophysically-logged wells within SJRWMD (logs not shown): Baker - 3026200821735 (W-6500), Duval - 3024160815226 (W-8881), 3022290814008, 3020070813547 (W-5459), 3022000812357; Indian River – 2736070803103, 2742060802255, (W-10348), and 2746250802421; Lake – 2848260815133; Marion – 2910510820812; Nassau – 3040000812805; Okeechobee – 2734510805148; Orange - 2841270812810 (W-14765); Osceola – 2747420805853; Polk – 2814230814223; Putnam – 2937380813516, and 2946180824734 (W-6643); St. Johns – 2948030812710; Seminole - 2841510812608 (W-14436); Volusia - 2901030805519 (W-924).

Leve, G. W., 1968, Reconnaissance of the ground-water resources of Baker County, Florida: Florida Geological Survey Report of Investigations 52, 24 p.

A preliminary investigation of the groundwater resources, including geology, of Baker County utilizing well inventories, Includes driller and Florida Geological Survey data, and two test wells in the county. One gamma ray* and two single-point-resistance-electric logs from the test wells: 3015350821620 (W-6502) and 3026200821735* (W-6500).

McGurk, B., Bond, P. and Mehan, D., 1989, Hydrogeologic and lithologic characteristics of the surficial sediments in Volusia County, Florida: St. Johns River Water Management District Technical Publication SJ 89-7, 38 p. + appendices.

Lithologic and hydrostratigraphic data on the sediments superjacent to the Floridan aquifer system are presented. Depths to top of formations are listed in tabular form for 124 wells geophysically logged in Volusia County: 2850280811931, 850320810622, 2850510810338, 2850520810408, 2851030811158, 2851050810702, 2851260811401, 2851370805218, 2851380810706 (W-15666), 2851460811843, 2851530811442, 285206081072201, 285206081072202, 285206081072203, 2853020811817, 2854110805148, 285419081041001 2854380811836, 2854420811814, 2855370811108, and 2856350811954 (W-10445), 2856350811957, 285636081104901 (W-14502), 285636081104902 (W-15140), 285641081200401, 285641081200402, 2856490805304, 2857560811742 2858050811642 (W-14419), 2859030811747, 2859160811749, 2859430811810 2859490805802 (W–12951), 2859530805759, 290038081043101, 290038081043102 2900380810454, 2901030805519 (W –924), 2901210811858, 2901380812032 2901510805503 (W–14710), 2902380810906, 2902510810014 (W–8455), 2902520805901, 2903080805901, 2903110805902, 2903230811721, 2903540811957, 2903540812138, 2903540812138, 2904410811829, 2905100812136, 2905130812147, 290534081175002, 2905370812012, 2905390812006, 2905400812145, 2905480812126, (W-15729), 2905530812007, 2905580812152, 2906350810102, 2906460812137, 2907080812333, 2907500810612, 2907520812209, 2908020811856, 2908110810832, 2908120810831, 2908130810832, 2908160811912, 2908170810822, 2908200810812, 2908200810823, 2908200810836, 2908240810802, 2908290810840, 2908300810518, 290834081073801, 290834081073802, (W-15994), 2908380810844, 2908470810149 (W-14625), 2908470810154 (W-14624), 2908470810200, (W-14623,) 2908470810312, 2909440810313, 2909450813048, 2909560805848,

2910240810503, 2910310805904 (W-2171), 2910350811800, 2911000810537, 2911010812002, 2911070810342 (W-15995), 2911130810501, 2911170812513, 2911210810427 (W-4231), 2911400810321, 2911400810356, 2911520810237, 2912060810307, 2912070810305, 2912080810302 (W-5260), 2912080810305, 2912080810308 (W-5784), 2912090810300 (W-5223), 2912090810305, 2912110810302, 2912160812155 (W-14182), 2912160812156, 2912370810241, 2912400810050, 2912460810352, 2912480810707, 2914090812550, 2914310812631, 291433081284102, 2914480812749, 2914570812709, 2914580812942 (W-14183), 2915080813028, 2915550810458, 2918210810315, 2918230812808 (W –14181), and 2919410812942.

Miller, J. A., 1978, Geologic and geophysical data from Osceola National Forest, Florida: U.S. Geological Survey Open-File Report 78-799, 101 p.

A study conducted to assess hydrologic impact of possible phosphate mining in the Osceola National Forest. Lithologic information, microfaunal lists, and gamma-ray logs are given for 10 test coreholes. Includes gamma-ray logs for two existing wells* and seven test wells in Baker County in or very near the SJRWMD: 302115082232201 (W-13805), 302115082232202, 302251082194901 (W-13813), 302251082194902, 301702082271501 (W-13812), 301635082234001 (W-13811), 301635082234002, 302620082173501* (W-6500), and 301535082162001* (W-6502).

Miller, J. A., 1986, Hydrogeologic framework of the Floridan aquifer system in Florida and parts of Georgia, Alabama, and South Carolina: U.S. Geological Survey Professional Paper 1403-B, 91 p. + plates.

Analyzes the regional geology and hydrology of the Floridan aquifer system. Illustrates 11 deep electric logs in the SJRWMD with stratigraphic contacts on plates (six with general cuttings lithology*): Alachua - T9S, R21E, S24* (W-1472); Baker - T1N, R20E, S21* (W-1500); Bradford - T4S, R22E, S24 (W-3150?); Flagler - T11S R25E S8* (W-1473); Marion - T15S, R26E, S6 (W-15281); Okeechobee - T36S, R34E, S5* (W-3739); Orange - T23S, R31E, S21* (W-3673), T23S, R33E, S20, and T20S, R28E, S6 (W-4053); Osceola - T31S, R33E, S12* (W-1411); Putnam - T11S R26E S27 (W-1838).

Motz, L. H. and Heaney, J. P., 1992, Upper Etonia Creek hydrologic study; Phase II, Final Report: St. Johns River Water Management District Special Publication SJ 92-SP18,177 p. + appendices.

Investigates the relationship between lake levels and the surface water and groundwater systems in portions of Alachua, Bradford, Clay and Putnam Counties, including hydrogeologic data, gamma-ray logs and lithologic descriptions (by SJRWMD). Presents gamma-ray logs for five wells in Clay County: 2949370820145 (W-16980), 2951160820058, 2947280820109, 2949110815726, and 2948460815520.

Munch, D. A., 1979, Test drilling report of northwest Volusia County: St. Johns River Water Management District Technical Publication SJ 79-3, unpaginated.

Presents geophysical logs and construction information for five observation wells in Volusia County drilled by the SJRWMD for the U.S. Geological Survey. Includes gamma-ray and electric logs with construction information and stratigraphy for five wells, one cross section, three

Florida Geological Survey lithologic descriptions of cores, five lithologic descriptions of cores and well cuttings: 2918230812808 (W-14181), 2915020813032, 2914580812942 (W-14183), 2914310812630, and 2912160812155 (W-14182).

Phelps, G. G., 1990, Geology, hydrology, and water quality of the surficial aquifer system in Volusia County, Florida: U.S. Geological Survey Water-Resources Investigations Report 90-4069, 67 p.

Presents and interprets data gathered during a hydrological study of the surficial aquifer system in Volusia County, including the lithology and thickness thereof using geologic sections, geophysical (gamma-ray) logs and test drilling. Includes 11 gamma-ray logs with hydrologic and (generalized) geologic units, and seven cross sections: 285129080510501, 285152080520902, 285343081140402, 285625080525202, 285630081174702, 290025081185002, 290243081175302, 290508081200602, 290554081160802, 290947081232902, and 291806081284302.

Phelps, G. G., 1994, Hydrogeology, water quality, and potential for contamination of the upper Floridan aquifer in the Silver Springs ground-water basin, central Marion County, Florida: U.S. Geological Survey Water-Resources Investigations Report 92-4159, 69 p. + plates.

The hydrogeology, water quality, and potential for contamination of the Silver Springs groundwater basin in Marion County are described. Includes one gamma-ray log with general lithologic description for well 291225082042801 (W-16799).

Phelps, G. G. and Roher, K. P., 1986, Hydrogeology in the area of a freshwater lens in the Floridan aquifer system, northeast Seminole County, Florida: U. S. Geological Survey Water-Resources Investigations Report 86-4078, 74 p.

Discusses the hydrogeology of a freshwater lens in the Geneva area (Seminole County), including the rate of recharge of the Floridan aquifer, well construction data, gamma-ray logs, and stratigraphy of nine test wells, with three cross sections: 2842070811116, 2842170810230, 2842330810452 (W-15655), 2842470810708, 2843220810843 (W-15654), 2843250810927, 2844280810726 (W-15665), 2844420810524, and 2846260810518 (W-15656).

Reese, D. E., Belles, R. and Brown, M. P., 1984, Hydrogeologic data collected from the Kissimmee Planning Area: South Florida Water Management District, Technical Publication 84-2, 191 p.

Presents data (including geophysical logs) concerning the Floridan aquifer system obtained from all or parts of Orange, Osceola, Polk, Okeechobee, Highlands, Glades and Martin Counties, including two wells within or very near the SJRWMD. Illustrates gamma-ray, resistivity-electric and neutron logs (no stratigraphic nor lithologic interpretation) for Okeechobee –2732380804242; and Osceola – 2744000800431.

Reik, B. A., 1981, The Tertiary stratigraphy of Clay County, Florida with emphasis on the Hawthorn Formation: Florida State University masters thesis, 165 p.

Provides a detailed subdivision of the subsurface stratigraphy of the Hawthorn unit in Clay

County by means of cores, cuttings and geophysical (gamma- ray) logs. Also considers "Lake City", Avon Park, and Ocala stratigraphy, lithologies and structures. Illustrates eight gamma-ray logs with Hawthorn-unit stratigraphy shown and detailed lithologic descriptions: Clay - 2959020815003 (W-13769), 3008550820026 (W-14179), 3009060814537 (W-14193), 2952040815516 (W-14301), 958580814325 (W-14476), 2950290813948 (W-14521); Putnam - 2943020820159 (W-14594).

Ross, F. W. and Munch, D. A., 1980, Hydrologic investigation of the potentiometric high centered about the Crescent City Ridge, Putnam County, Florida: St. Johns River Water Management District Technical Report 5, 75 p. + appendix.

A detailed investigation of the geology, structure, aquifer characteristics, water budget, and water quality of the Crescent City Ridge area. Includes a table of formation contacts for 26 geophysically-logged wells: Putnam - 2922180813331 (W-14180), 2922470812843, 2922510812818, 2922540812814, 292257081353201, 292257081353202, 292257081353203, 2924240813136, 2924520813113, 2925050813113, 2925080813027, 2925110813050, 2925240813553, 2926210813751, 2926280813733, 2926480813137, 2927340813146, 2928030814050, 2928070813308, 2928170813345, 2928240813415, 2932130813522, 2933200813945, 2932340814241, and 2934190814156; Volusia - 2920120813210.

Rutledge, A. T., 1982, Hydrology of the Floridan aquifer in northwest Volusia County, Florida: U.S. Geological Survey Water Resources Investigations Open File Report 82-108,116 p. + plate.

Investigates the ground water hydrology of northwestern Volusia County with regard to the area's primary agriculture: fern growing. The relationships between pumping for freeze protection during the winter and salt water intrusion as well as sinkhole development are investigated. Provides gamma-ray log with general stratigraphy and lithology for one well: 2914330812715

Rutledge, A. T., 1985, Use of double-mass curves to determine drawdown in a long-term aquifer test in north-central Volusia County: U.S. Geological Survey Water-Resources Investigations Report 84-4309, 29 p.

Determines long-term drawdown in surficial and Floridan aquifer systems in Volusia County using a long-term aquifer test. Gamma-ray and lithologic logs of one well (15 feet northeast of pumped well): 2910040811014.

Sacks, L. A., Lee, T. M. and Tihansky, A. B., 1992, Hydrogeologic setting and preliminary data analysis for the hydrologic-budget assessment of Lake Barco, an acidic seepage lake in Putnam County, Florida: U.S. Geological Survey Water-Resources Investigations Report 91-4180, 28 p.

Describes the hydrogeologic setting of a Putnam-County lake (surficial aquifer system) as well as a preliminary analysis of the hydrologic budget. Includes gamma-ray logs from three shallow observation wells: 2940420820029, 2940270820025, and 2940310820041.

Schiffer, D. M., 1996, Hydrology of the Wolf Branch sinkhole basin, Lake County, east-central Florida: U.S. Geological Survey Open-File Report 96-143, 29 p.

Describes the hydraulic characteristics of the connection between Wolf Sink and the Upper Floridan aquifer system and the general relationship of the sink to the ground-water hydrology. Illustrates gamma-ray logs from six wells in Lake County: 2847200813700, 2847210813657, 2847230813719, 2847250813619, 2848000813553, and 2847380813527.

Schiner, G. R. and German, E. R., 1983, Effects of recharge from drainage wells on quality of water in the Floridan aquifer in the Orlando area, central Florida: U.S. Geological Survey Water-Resources Investigations Report 82-4094, 124 p.

Describes the quality of ground water in the injection zones of drainage wells and the effects of those wells on supply wells. Includes the gamma-ray log and stratigraphy from one drainage well in Orange County: 2831540812207 (W-139).

Schiner, G. R., Laughlin, C. P. and Toth, D. J., 1988, Geohydrology of Indian River County, Florida: U.S. Geological Survey Water-Resources Investigations Report 88-4073, 110 p.

Delineates the hydrologic and geologic characteristics of surficial and Floridan aquifer systems in Indian River County utilizing 53 geophysical-log sets and 25 test wells. Includes the gamma-ray log and stratigraphy for one well (2736070803103), and five cross sections (35 wells) with approximate stratigraphic contacts (logs not shown): 2749480802916, 2745170802618, 2744530802638, 2744140802650 (W-15668), 2742400802532, 2739550802455, 2739320802419, 2739050802409, 2737450802346, 2746030803457 (W-15669), 2740020802619, 2737320802410, 2736070802328, 2733480801930, 2746230805032 (W-3783), 2746070804930, 2745020803958, 2744480803732, 2745570803430, 2745220803043, 2744530802637, 2745340802511, 2745320802418, 2750570802923, 2748370802935, 2743090802653, 2739050802411 (W-14268), 2735360802402 (W-14908), 2736160804705, 2736490804527 (W-3021), 2734160804030 (W-15664), 2736330803510, 2736070803103, 2736150802835, and 2734300801953.

Scott, T. M., 1983, The geology of the Hawthorn Formation of northeast Florida: Florida Geological Survey Report of Investigations 94, Part I, 90 p.

Provides data concerning the geologic framework of the Hawthorn unit in Nassau, Duval, Baker, Union, Clay, St. Johns, Putnam, Alachua and Flagler Counties. One gamma-ray log with formation contacts* figured; plus a tabular list of 26 cores with gamma-ray logs and formation contacts: Alachua - 2942300822343 (W-14641 - very near SJRWMD); Bradford - 2957150820328 (W-14283); Clay - T6S, 23E, S31, SE/NE/SE (W-10488), 3006550815257 (W-14219), T6S, R25E, S7, SW/SE (W-13769), 2952020815513 (W-14301), T4S, R23E, S16, NW/SE (W-14179), 2958580814325 (W-14476*), 3009060814537 (W-14193), 2950290813948 (W-14521); Duval - 3023330813347 (W-14619); Nassau - 3037460815557, (W-13815); Putnam - T9S, R25E, S18, SW/NW (W-8400), 2937060813647 (W-14376), 2923070813057 (W-14318), 2945590813442 (W-14477), 2943480815337 (W-14346), 2938550815247 (W-14566), 2930540813943 (W-14353), 2943020820159 (W-14594), and 2939590813532 (W-14354); St. Johns – 2959390813008 (W-13744), 2940000811527 (W-13844), 3005150812723 (W-13751); 2947510812916 (W-14413), and 2959060812724 (W-13765).

Scott, T. M., 1987, The lithostratigraphy of Nassau County in relation to the superconducting super collider site investigation: Florida Geological Survey Open File Report 15, 56 p.

Presents the shallow stratigraphy of the site considered for location of the Superconducting Supercollider in Nassau County, Florida, utilizing the then-existing data base of geologic information at the Florida Geological Survey: cores, cuttings and geophysical logs. Includes a gamma-ray log from one FGS core in Clay County; and a table of formation contacts for 16 geophysical well logs in Nassau County: Clay - 3006550815257 (W-14219); Nassau - T3N, R28E, S30 (W-890), T3N, R28E, S8 (W-391), T3N, R28E, S24, T3N, R28E, S5, 3037460815557 (W-13815), 3032520814633, 3040440812702, 3040000812805, 3041130812720, 3041080812708, 3037570812803, 3044150815936 (W-15662), T2N, R28E, S8 (W-6265), 3039300812745, 3039480812752, and 3033480814943.

Scott, T. M., 1988, The lithostratigraphy of the Hawthorn Group (Miocene) of Florida: Florida Geological Survey Bulletin 59, 148 p.

Presents the detailed stratigraphy, lithofacies and occurrence of the Hawthorn Group utilizing 100+ continuous cores and well cuttings from peninsular and eastern-panhandle Florida. Illustrates three gamma-ray logs within the SJRWMD with formation contacts marked (emphasis on intra-Hawthorn Group formations): Clay - 3006550815257 (W-14219); Indian River - 2741520802614 (W-13958); and Osceola - 2816520805947 (W-13534).

Spechler, R .M., 1994, Saltwater intrusion and quality of water in the Floridan aquifer system, northeastern Florida: U.S.Geological Survey Water-Resources Investigations Report 92-4174, 76 p.

Describes the hydrogeological framework of the Floridan aquifer system in Duval, Nassau and St. Johns Counties and considers the existence, sources and mechanisms of saltwater intrusion in the study area. Illustrates four geologic cross sections utilizing 16 wells with SJRWMD geophysical logs (logs not shown): Duval - 3009440813626, 3016140812342 (W-15214), 3024160815226 (W-8881), 3020230813613, 3020520813232, 3021340812848, and 3021590812356; Nassau - 3044090815938 (W-15662), 3037460815557 (W-13815), 3033480814943, and 3040010812803; St. Johns - 2952000811623, 2949470813022, 2943340812708, 3043000811417, 2953400812637, and 3011320812258.

State of Florida, 1987, Site proposal, superconducting super collider: State of Florida, Volumes 1-8 with appendix.

A detailed report submitted by the governor to the U.S. Department of Energy proposing that the superconducting super collider be constructed in Nassau County, northeastern Florida. Includes lithologs, stratigraphic contacts, and gamma-ray logs from 36 shallow test borings in Nassau County (data in appendix): T3N, R26E, S7 (W-16330), T2N, R23E, S3 (W-16331), T4N, R24E, S19 (W-16332), T1N, R25E, S10 (W-16333), T3N, R24E, S— (W-16334), T4N, R24E, S2 (W-16335), T4N, R24E, S24 (W-16336), T4N, R25E, S7 (W-16337), T4N, R25E, S20 (W-16338), T4N, R25E, S40 (W-16339), T4N, R25E, S22 (W-16340), T4N, R25E, S36 (W-16341), T3N, R25E, S48 (W-16344), T2N, R26E, S4 (W-16345), T2N, R25E, S12 (W-16346), T2N, R25E, S24 (W-16347), T2N, R25E, S46 (W-16348), T1N, R24E, S1 (W-16350), T1N, R24E, S10 (W-16351), T2N, R23E, S14 (W-16352), T2N, R24E, S6 (W-16353), T3N, R23E, S23 (W-16355), T3N, R23E, S3 (W-16356), T4N, R23E, S14 (W-16357), T4N, R24E, S16 (W-

16358), T4N, R24E, S10 (W-16359), T3N, R26E, S18 (W-16360), T3N, R26E, S29 (W-16361), T1N, R24E, S5 (W-16362), T2N, R23E, S35 (W-16363), T2N, R23E, S25 (W-16364), T3N, R23E, S11 (W-16365), T2N, R26E, S11 (W-16366), and T3N, R26E, S9 (W-16367).

Toth, D. J., 1985, Test drilling report for observation wells at Sebastian Inlet State Park, Brevard County, Florida: St. Johns River Water Management District Technical Publication SJ 85-6, 22 p.

Presents hydrologic and geologic data collected during the drilling of three observation wells at a site in southeastern Brevard County. Includes gamma-ray and neutron logs and stratigraphy of 1 well (deepest) using composite well cuttings: 2752100802722

Weedman, S. D., Scott, T. M., Edwards, L. E., Brewster-Wingard, G. L. and Libarkin, J., 1995, Preliminary analysis of integrated stratigraphic data from the Phred #1 corehole, Indian River County, Florida: U.S. Geological Survey Open-File Report 95-824, 63 p.

Provides lithostratigraphic, biostratigraphic and diagenetic analyses of Florida Geological Survey core in Indian River County in order to interpret the age, and depositional and diagenetic history of subsurface units in south Florida. Includes core hole gamma-ray log for 2741500802609 (W-13958).

Wyrick, G. G., 1960, The ground-water resources of Volusia County, Florida: Florida Geological Survey Report of Investigations 22, 65 p.

A detailed study of the ground-water resources of Volusia County (including test wells) with emphasis on salt-water intrusion problems. Provides single- point-resistance electric logs from six test and public supply wells with stratigraphic and lithologic data (seconds and W # not available in one well): 2905410811329 (W-3527), 2909480810602 (W-3476), 2911200810438 (W-3477), 2911—08103—, and 2914410810220 (W-3701).

Zellars-Williams, Inc., 1978, Metallurgical evaluation of Hawthorn phosphate from Florida East Coast: Final Report for U.S. Bureau of Mines, 10 p. + appendices.

Results of a U.S. Bureau of Mines project to analyze phosphorite ore from selected sites in northeastern Florida (within SJRWMD). Presents gamma-ray logs from eight Florida Geological Survey core holes, one* with resistivity log: Brevard - 2808100805052 (W-13881); Clay - 2959020815003 (W-13769); Indian River - 2741500802609 (W-13958); Nassau - 3038100815605 (W-13815); St. Johns - 2959390813003 (W-13744), 2940090811532 (W-13844), 3005150812723 (W-13751*), and 2959060812724 (W-13765).

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