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# THE STRATIGRAPHY OF THE FLORIDAN AQUIFER SYSTEM EAST AND NORTHEAST OF LAKE OKEECHOBEE, FLORIDA

BY

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Resource Planning Department
South Florida Water Management District
West Palm Beach, Florida    33402

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# PREFACE

Over the past several years, the South Florida Water Management District has funded applied research through the State University system in subject areas appropriate to it's responsibilities in water resources management.

This study was undertaken for several reasons. Based on preliminary studies, District staff recognized that the Floridan was not an aquifer (a rock formation that more or less uniformly yields water to wells throughout its thickness) but rather was composed of a system of rock units containing discrete, possibly hydrologically isolated water bearing formations, each of which had unique water quality and water yielding characteristics. It was further recognized that these formations and certain marker beds were areally very extensive and that they maintained their position in the vertical section relative to one another.

On the basis of these preliminary observations it was concluded that if the various stratigraphic and lithologic units were identified in detail by their mineralogical and physical make-up and correlated to a unique geophysical signal response from these formations, a series of maps and cross sections could be prepared which would define the location of all the water producing formations within the upper part of the Floridan aquifer, the depth to and thickness of these units, their essential identifying characteristics, the quantity of water that each are capable of producing, and the quality of water that may be expected from each of these formations. Thus, all of the uncertainty and mystery of drilling a Floridan aquifer well of suitable quality and adequate quantity for its intended use would be resolved.

Once the system has been thus dimensioned, predictive groundwater flow modeling can be undertaken and strategies and alternatives developed that would be designed to meet the increased demand that will be placed on this system in future years. At that point, functional groundwater resources management can become a relatively routine task.

This report documents the results of the underlying research that formed the basis for these more detailed and comprehensive hydrogeologic studies that were recently completed by District staff.

# ABSTRACT

The geologic formations comprising the Floridan aquifer in St. Lucie, Martin, and northern Palm Beach Counties have been studied through lithologic analysis of cuttings and analysis of the geophysical signatures of the formations. At least three units make up the Floridan aquifer in the study area: an unnamed grey calcilutite, the Ocala Limestone of the Upper Eocene Series, and the Avon Park Limestone of the Upper Middle Eocene Series.

The unnamed calcilutite is a grey calcilutite with varying amounts of quartz and phosphorite. Two members were observed in the Ocala Limestone. The upper member was a white coquina composed of foraminiferal tests such as _Lepidocyclina_. The lower member is a cream colored bioclastic calcarenite with smaller forams. The Avon Park Limestone was first recognized as a white chalky calcilutite which was accompanied by the presence of cone-shaped foraminifera such as _Dictyoconus cookei_. This unit was followed by alternating beds of dolomitic limestones and dolomites.

The formations show a south to southeasterly dip and indicate a slightly undulating surface. No real evidence of faults was observed in the study area. An erosional surface is recognized on top of the unnamed calcilutite. This surface may mark the erosion of an Oligocene unconformity.

The unnamed calcilutite was observed to be less than thirty feet thick throughout most of the study area with thicker pockets occurring in eastern and southwestern St. Lucie County, and, perhaps, also in the southwesternmost corner of the study area. The Ocala Limestone was seen to be thickest along a linear feature trending NW-SE through St. Lucie and Martin Counties.

Based on this reconnaissance work, it is recommended that further study be conducted in the eastern boundary of the study area and in Palm Beach

County, particularly for the interval containing the unnamed calcilutite. It was also recommended that in any such study care should be taken to check depth measurements on cutting samples against geophysical logs or some other more accurate means of depth determination.

# INTRODUCTION

## GENERAL STATEMENT

The term "Floridan aquifer" was originally defined to include the principal artesian aquifer which underlies the entire state. The Floridan aquifer was said to include "parts or all of the middle Eocene (Avon Park and Lake City Limestones), upper Eocene (Ocala Limestone), Oligocene (Suwannee Limestone), and Miocene (Tampa Limestone and permeable parts of the Hawthorn formation that are in hydrologic contact with the rest of the aquifer)" (Parker, et al., 1955, p. 189).

The purpose of the present study is to determine which formations make up the Floridan aquifer in St. Lucie, Martin and northern Palm Beach Counties, and to determine their general stratigraphic and structural relationships. The geophysical signatures of these formations are identified in an effort to establish a useful stratigraphic tool within the study area. By means of these signatures, the formations are mapped and their stratigraphic relationships interpreted. Refining the ages of the various formations is not included in the scope of this study. Instead, the study is intended to aid in the understanding of the Floridan aquifer system in southeastern Florida and to provide a starting point for more detailed stratigraphic studies in the future.

## STUDY AREA

The study area is comprised of St. Lucie and Martin Counties and the northern half of Palm Beach County, all of which are located in southeastern Florida. It covers approximately 1800 square miles (4662 square kilometers), the southern boundary of which is arbitrarily set by an imaginary line drawn

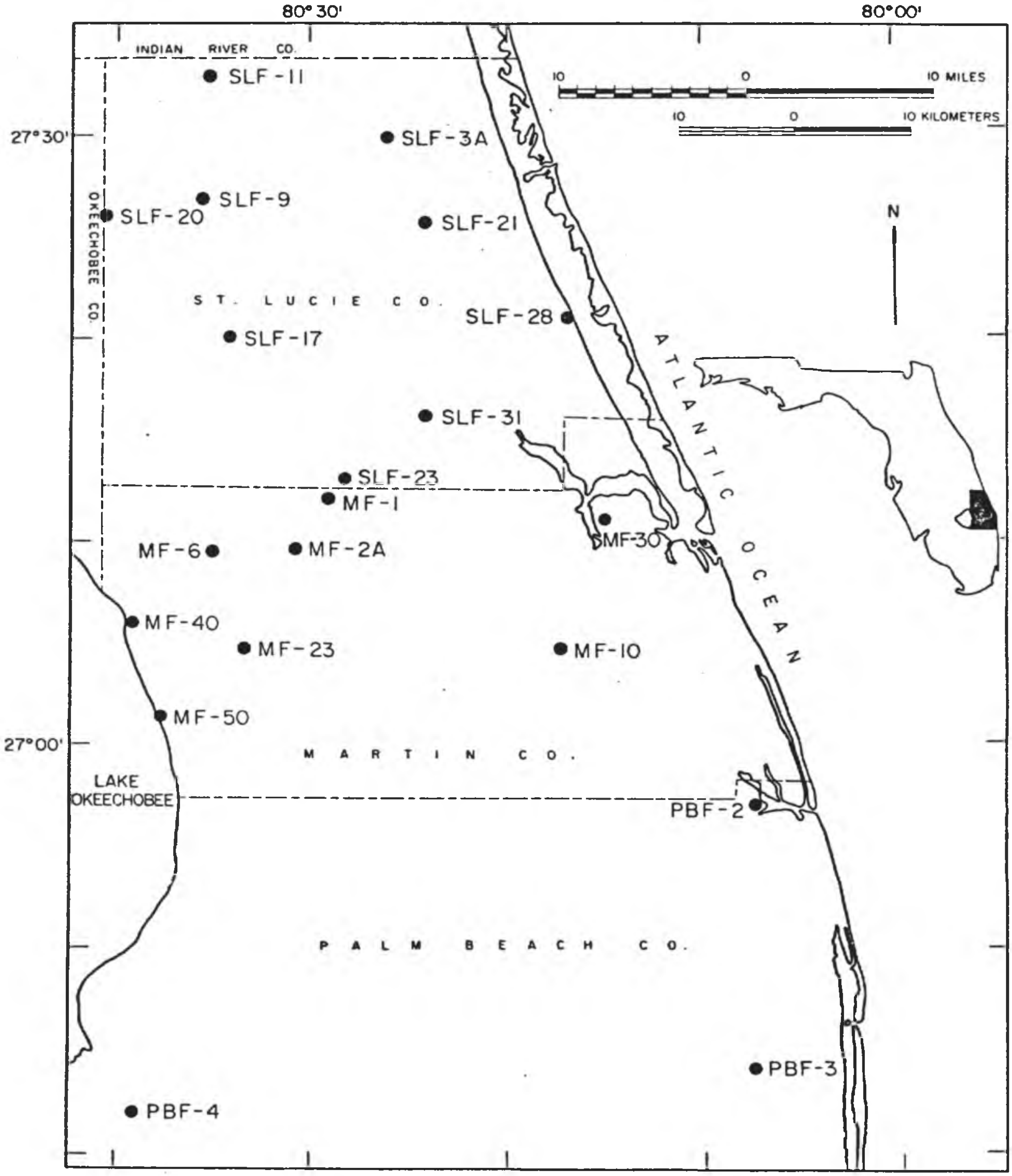


FIGURE 1. MAP OF STUDY AREA SHOWING WELL LOCATIONS

between the cities of Belle Glade and West Palm Beach. Figure 1 shows the exact geographic location of the study area and the locations of wells used in the study. Table I lists the latitudes, longitudes, and total depths below mean sea level (MSL) of the wells.

The study area can be subdivided into three physiographic provinces: (1) Atlantic Coastal Ridge, (2) Eastern Flatlands, and (3) Everglades (Davis, 1943, Fig. 1). The Coastal Ridge lies parallel to the coastline and extends approximately 5 miles inland. The Eastern Flatlands lie between the Coastal Ridge on the east and, in Martin and Palm Beach Counties, the Everglades and Lake Okeechobee on the west. In St. Lucie County, the Eastern Flatlands occupy all the land area west of the Coastal Ridge. The Everglades occupy the southwestern part of the study area and border Lake Okeechobee in Martin and Palm Beach Counties. Land surface elevations range from about 60 feet above sea level in western St. Lucie County to sea level along the coastline. The dominant surface drainage direction in the study area is eastward and southeastward towards the coast through artificial drainage canals. A shallow, non-artesian aquifer is used for domestic water supplies; whereas the deeper, artesian Floridan aquifer is used for irrigation purposes.

## METHODS

All of the wells used in this study were drilled by the hydraulic rotary drilling method. This method consists of cutting a borehole by means of a rotary bit. The cuttings are removed by continuous circulation of a drilling fluid as the bit penetrates the formations.

Cutting samples were collected at uniform depth intervals, usually every ten or twenty feet, for many of the wells used in this study. These

# TABLE I

| Well # | Depth (feet below MSL) | Latitude | Longitude | γ-ray | Neutron | Electrical Resistivity |
|---|---|---|---|---|---|---|
| SLF-3A<br>(W-13850) | 1200 | 27°29'48" | 80°26'47" | X | X | X |
| SLF-9 | 1033 | 27°26'50" | 80°35'28" | X | X | X |
| SLF-11 | 921 | 27°32'12" | 80°35'11" | X | X | X |
| SLF-17 | 1260 | 27°19'34" | 80°34'18" | X | X | X |
| SLF-20 | 867 | 27°26'04" | 80°40'40" | X | X | X |
| SLF-21 | 686 | 27°25'37" | 80°24'09" | X | X | X |
| SLF-23 | 868 | 27°13'11" | 80°28'11" | X |  | X |
| SLF-28 | 852 | 27°20'28" | 80°16'35" | X |  |  |
| SLF-31 | 982 | 27°16'14" | 80°23'50" | X | X | X |
| MF-1 | 801 | 27°14'12" | 80°29'00" | X | X | X |
| MF-2A | 852 | 27°09'37"* | 80°30'39"* | X |  | X |
| MF-6 | 1017 | 27°09'39" | 80°35'00" | X | X | X |
| MF-10 | 970 | 27°04'32" | 80°17'23" | X | X |  |
| MF-23 | 1089 | 27°04'25" | 80°33'47" | X | X | X |
| MF-30<br>(W-12556) | 2990 | 27°11'46" | 80°15'02" | X |  |  |
| MF-40<br>(W-5441) | 992<br>992 | 27°05'58"* | 80°39'27"* | X |  | X |
| MF-50<br>(W-5442) | 997 | 27°01'22"* | 80°38'04"* | X |  | X |
| PBF-2 | 1337 | 26°56'42" | 80°07'23" | X |  |  |
| PBF-3<br>(W-13000) | 3314 | 26°44'21" | 80°07'32" | X |  |  |
| PBF-4<br>(W-8077) | 2063 | 26°42'20"* | 80°38'45"* | X |  |  |

*approximate values; accurate to the nearest minute wells are listed in the appendix along with their descriptions. The author examined these cuttings and described their lithology and the presence of certain key foraminifera. Key foraminifera were identified using Applin and Applin (1944), Applin and Jordan (1945), and Loeblich and Tappan (1964). Most of these cutting samples are on file with the Florida Bureau of Geology located in Tallahassee, Florida

Selected samples from the well cuttings were examined by x-ray diffraction techniques in order to gain more insight into the mineralogical composition of various units. These diffractograms were valuable in providing mineral identification and their approximate percentages.

Geophysical logs were obtained for all wells used in this study. Three types of geophysical logs were used: gamma-ray log, neutron log, and electrical resistivity log. The geophysical signatures of various formations were identified by comparing the cutting samples of the type well (SLF-3A) with its geophysical logs. SLF-3A was chosen for this purpose as the author aided in the collection of the cutting samples and felt confident as to the depths which the cutting samples represent. Geophysical logs and cuttings of other wells were examined to check these signatures. The various geophysical signatures are identified primarily on the gamma-ray logs, with the neutron and electrical resistivity logs reinforcing the identifications of the formations where possible. The geophysical logs used in this study are listed in Table I. These logs are also on file with the Florida Bureau of Geology.

The depths obtained from the geophysical logs were corrected to mean sea level (MSL). This information was then synthesized into cross-sections, structure contour maps and isopach maps.

## PREVIOUS STUDY

The stratigraphy and general geology of south Florida have been the subjects of debate since the first attempts were made to explain the geologic development of Florida's peninsula. Agassiz (1852) and LeCount (1857, 1878) hypothesized that much of the Florida peninsula was constructed of Recent coral reef debris. The peninsula was shown to be neither Recent in age nor formed of coral reef deposits by a study of fossil mollusks in south Florida (Heilprin, 1887).

Close similarities in the lithologies of Florida's limestones led early workers to subdivide these limestones into formations primarily on the basis of paleontological data. Initially, all of the older Tertiary rocks of the peninsula were included in the Vicksburg Limestone by Smith (1881). This included all limestones older than the greenish clay sequence presently regarded as the Hawthorn Formation. This Vicksburg Limestone was later divided by Dall and Harris (1892) on paleontological grounds. They distinguished a lower division which they called the Vicksburg Limestone, or Orbitoides Limestone, and an upper division which they named the Ocala Limestone. The Ocala Limestone was distinguished as a yellow, friable limestone with many foraminifera, especially in the form of "nummulitic beds".

The Tampa Limestone was also named by Dall and Harris (1892). It was described as a hard white, earthy limestone that underlies the town of Tampa. The Tampa Limestone is a controversial formation presently being restudied by King and Wright (1979). It is generally regarded as an impure limestone, usually in the form of a calcilutite. The quartz sand content of the Tampa as reported in the literature varies greatly. The range of lithologic characteristics attributed to the Tampa is sufficiently wide that almost any limestone could be regarded as Tampa Limestone using published criteria. The age of the Tampa is also debatable; however, most workers seem to feel that it is late Oligocene, early Miocene, or both.

Dall (1903) proposed the replacement of the name Vicksburg Limestone with the term Peninsular Limestone. The names Peninsular Limestone and Ocala Limestone were adopted by Matson and Clapp (1909) and later by Matson and Sanford (1913). They followed Dall in regarding the Ocala Limestone as younger than the Peninsular Limestone although they considered both limestones to be in the Vicksburg Stage (Oligocene).

Later it was found that much of the Peninsular Limestone was identical to the Ocala Limestone and that the fauna of the Ocala is of the Jackson Stage (upper Eocene) (Cooke, 1915). Cooke also suggested that the term "Peninsular Limestone" not be used until its relationship with the Ocala Limestone became better understood. He listed the formations older than the Ocala as being buried and presumably unworkable at the time. This view of south Florida's older limestones is again reflected in Stringfield's (1933) study of the ground water in the Lake Okeechobee area. He reported the Ocala Limestone in well cuttings from the area, but was uncertain as to the bottom of the Ocala. Stringfield, therefore, referred to all limestones from the top of the Ocala down to the bottom of the well as being part of the Ocala Limestone. In 1936 Stringfield states, "The lithology of the Ocala and the underlying Eocene rocks is similar, and it is therefore necessary to distinguish the two units on the basis of a study of fossils collected from the well cuttings. No diagnostic fossils have been reported near the contact and the lower limit of the Ocala has therefore not been definitely determined" (Stringfield, 1936, p. 125).

At that time it was believed that no representative of the Vicksburg Stage occurred in the Florida peninsula (Stringfield, 1936). However, within the same year, Cooke and Mansfield (1936, p. 71) proposed the name "Suwannee Limestone" for a yellowish limestone exposed along the Suwannee River in Florida. They felt that this limestone should be included in the upper Vicksburg Stage on the basis of its contained fossils. The Suwannee is presently described as being a rather pure limestone composed primarily of limy particles of organic origin. Small amounts of quartz sand (<10%) may be present (Cooke, 1945, p. 86).

Based on cuttings and data obtained from deep oil wells, Applin and Applin (1944) mapped and described the stratigraphy of the entire state of Florida as well as southern Georgia. Using lithologic and faunal differences, they were able to subdivide the subsurface limestones of south Florida and, in the process, they named several new formations. Thus, they succeeded in establishing Florida's first good subsurface stratigraphic column from the Vicksburg Stage of the Oligocene Series down to the lower Cretaceous. This study provided the framework for all future stratigraphic work in the state.

Applin and Applin (1944) were able to separate the Ocala Limestone into upper and lower members. The upper member is the typical Ocala consisting of a soft, white, foraminiferal coquina (Nummulitic beds). The lower member is a cream-colored calcarenite which is harder than the upper member and composed of molds of small miliolids. Unlike the upper member, the lower member contains very few large foraminifera. This concept of the Ocala is still used by the U. S. Geological Survey and can be recognized by the present author in the study area.

One of the new formations named by Applin and Applin (1944), the Avon Park Limestone, is recognized by the present author in the present study. The Avon Park Limestone is described as a cream-colored, highly fossiliferous, chalky limestone. It is also distinguished from the overlying Ocala Limestone by a difference in microfaunal characteristics. The Avon Park contains many cone-shaped foraminifera such as Coskinolina and Dictyoconus (Applin and Applin, 1944). Based on the fauna of the Avon Park, Applin and Applin listed its age as being Late Middle Eocene.

The formation that underlies the Avon Park in Florida's peninsula is the Lake City Limestone, also named by Applin and Applin (1944). However, as only three wells used in the present study are deep enough to penetrate the Lake City, and their geophysical logs are not of high quality, the Lake City Limestone is not discussed in this study.

The diagnostic foraminifera of the subsurface formations in Florida were discussed by Applin and Jordan (1945). Cooke (1945) synthesized preexisting literature in his broad compilation of the geology of Florida. Volumes of sediments were calculated and isopach maps were prepared of the various series within the Cenozoic for Florida and the Gulf Coastal Plain by Toulmin (1952). His work was based largely upon the formations as defined by Applin and Applin (1944).

The water resources of Palm Beach County were investigated by Schroeder, Milliken and Love (1954). They listed the formations comprising the principal artesian aquifer as the lower Hawthorn formations, Tampa, Suwannee, Ocala and Avon Park Limestones.

A comprehensive study of the water resources of southeastern Florida was prepared by Parker, et al. (1955). A great deal of information concerning the geology of south Florida is presented and correlated with the hydrology of the area. The name "Floridan aquifer" was proposed in that report for what had previously been known as the principal artesian aquifer.

The geology of Martin County was studied by Lichtler (1960) using well cuttings and electric logs. He listed the subsurface formations as well as their lithological and paleontological characteristics. He also postulated a major subsurface fault or fault zone having a displacement of 300 to 400 feet and a strike approximately parallel to and about five miles inland from the coastline. Movement along the fault was theorized to have started in late to post Oligocene time and to have continued during early Miocene time, when the Suwannee Limestone was exposed and eroded. The fault was considered a scissors-type fault with the greatest development at the southern end. Lichtler showed the fault extending from Martin County into adjacent St. Lucie and Palm Beach Counties.

A summary of the geology of Florida and a guidebook to the classic exposures was compiled by Puri and Vernon (1964). In this work a Florida stratigraphic nomenclature chart was presented as well as an extended discussion of the state of the art in Florida stratigraphy.

Primarily using electric logs, Chen (1965) described the lithostratigraphy of the Paleocene and Eocene rocks of Florida. He presented his findings in the form of numerous structure maps, isopach maps, and lithofacies maps. Chen's study was a broad regional study as is evidenced by the fact that only five wells (control points) are located in all of St. Lucie, Martin and Palm Beach Counties.

A paper on artesian water in Tertiary limestones in the southeastern states was prepared by Stringfield (1966). He showed a table which related the formations as described by Applin and Applin (1944) to the individual water-bearing properties of the formations.

Using hydrologic data, Vernon (1970, p.7) extended Lichtler's fault northward throughout most of St. Lucie County and southward through northern Palm Beach County. He showed the fault as intersecting the coastline somewhere near the city of West Palm Beach. Vernon used the top of the artesian aquifer as his measuring point rather than any particular geologic unit.

In 1975, Law Engineering Testing Company produced a study of Hutchinson Island (St. Lucie County) for the purpose of locating a nuclear power plant (Anonymous, 1975a). Many types of subsurface data were obtained in order to understand the geology of the area. Three deep geologic borings were drilled along a line west of the plant site in order to obtain data on both sides of Vernon's (1970) extension of Lichtler's (1960) fault. In addition, seismic surveys were conducted on the north fork of the St. Lucie River just north of the Martin County - St. Lucie County line. These surveys crossed the fault hypothesized by Lichtler (1960). Utilizing the data obtained, Law Engineering (1975) concluded that no fault was present but that warping (folding) was responsible for the offset in marker beds.

A report on the drilling and testing of deep disposal and monitoring wells for the city of Stuart in Martin County was produced by another engineering company, Black, Crow and Eidsness, Inc. (Anonymous, 1975b). They postulated another fault, parallel to and just west of Lichtler's (1960) fault. Their fault was based on the offset of key beds indicated in gamma-ray logs. The configuration and timing of movement along the fault are similar to those of Lichtler's (1960) fault. A brief description of the core of the Stuart disposal well is given in the appendix of Black, Crow, and Eidsness, Inc.'s (1975) report. The Stuart monitor well (W-12556) is used in the present study.

# STRATIGRAPHY

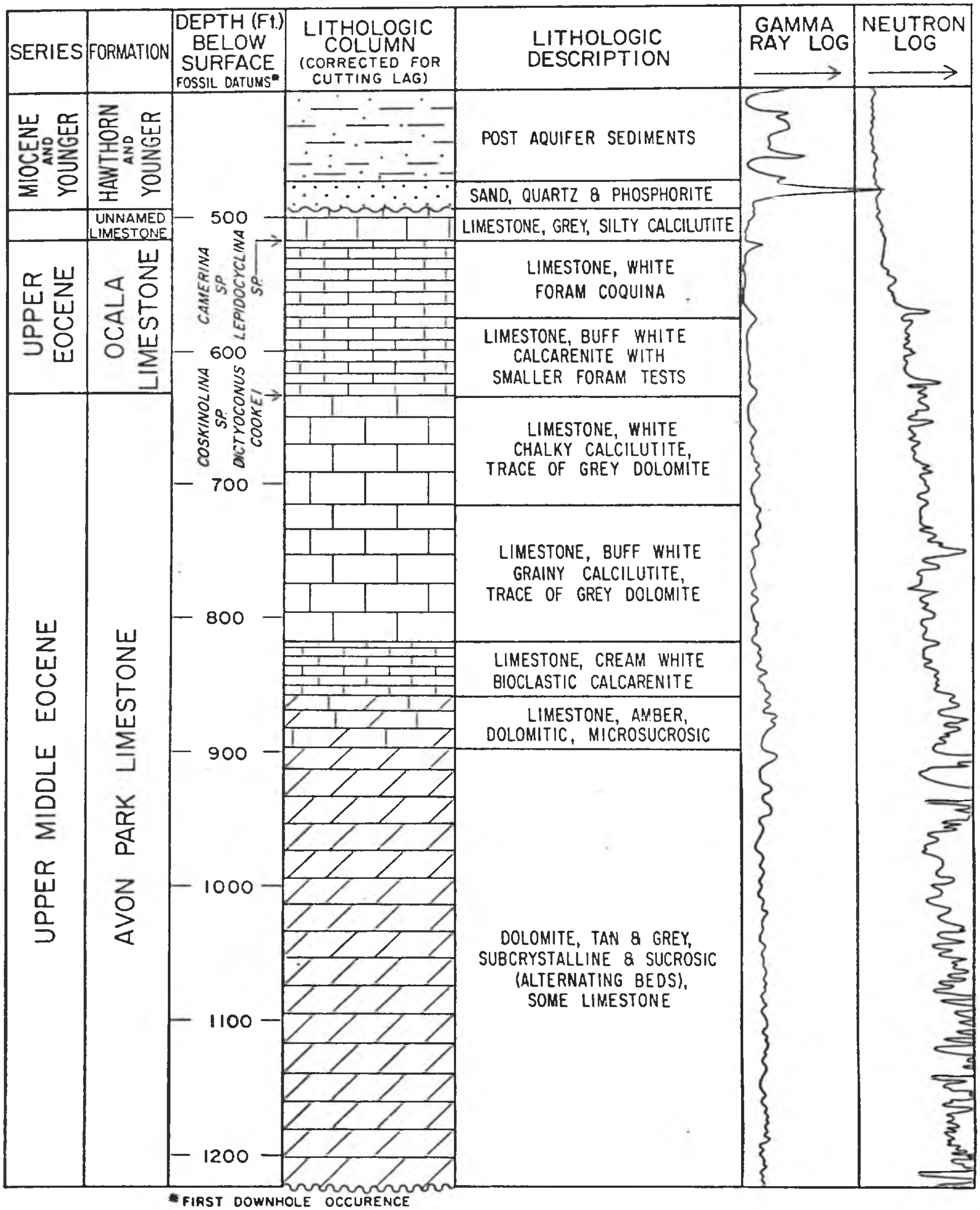
## LITHOSTRATIGRAPHY

As previously mentioned, SLF-3A was chosen as the primary reference well for the study area. The stratigraphic section in this well is characteristic for the area and is shown in Figure 2. A description follows.

The base of the Hawthorn formation occurs within the 483-503 foot (145-151 m) sample interval in SLF-3A, and is marked by a thin bed of unconsolidated sand. The sand is a mixture of phosphorite and quartz grains, and sand-sized fragments of chert and limestone. Traces of a dolomitic limestone are also present. The thickness of the sand bed is probably less than the twenty foot sample interval as evidenced by the amount of limestone present.

The next lithologic unit encountered downhole in SLF-3A is a grey calcilutite. This limestone is similar to that found in the sand unit above. This suggests a thickness greater than the twenty foot sample interval, probably about 20-30 feet (609 m) thick. Minor silt-sized phosphorite and traces of quartz sand are found with this limestone. No microfossils have been observed in this unit by the present author.

Below this calcilutite is a white foraminiferal coquina composed of large nummulitic genera such as Lepidocyclina. Some bryozoans and bioclastic debris are also found in this coquina along with other foraminifera such as Camerinids. This foraminiferal coquina is about 60 feet (18 m) thick.



*FIRST DOWNHOLE OCCURENCE

FIGURE 2. DETAILED STRATIGRAPHIC COLUMNAR SECTION OF WELL SLF-3A THIS IS THE REFERENCE SECTION FOR THE STUDY AREA

Below the foraminiferal coquina is a cream-colored bioclastic calcarenite or "grapestone" type of limestone. The larger foraminifera are absent except as small fragments; however, smaller forms such as the Camerinids are still present and seem to be more abundant. Traces of dolomitic limestone and recrystallized limestone are also present. This limestone is also about 60 feet (18 m) thick in SLF-3A.

The next lithologic unit encountered in SLF-3A is a white chalky calcilutite. Occurring with or very near this unit are cone-shaped foraminifera such as Coskinolina and Dictyoconus. Traces of dolomitic limestone also occur at the same depth intervals as this calcilutite. The thickness of this unit is about 80 feet (24 m).

Below the chalky calcilutite is a cream-colored grainy calcilutite. This calcilutite grades downward into a calcilutitic calcarenite which appears to be bioclastic in part. There seems to be an increase in the foraminifera diversity, but the forams are too abraded and recrystallized to be accurately identified. There is also some evidence of recrystallized limestone and dolomite. These two units combine to a thickness of about 140 feet (43 m).

Below these limestone units is a dolomitic limestone, amber in color and microsucrosic in texture. Below that are beds of dolomite. These consist of alternating layers of sucrosic textured amber dolomites and massive, subsrystalline, grey dolomites. SLF-3A was terminated in these dolomite beds.

These lithologic units in SLF-3A are representative of the stratigraphic sections in other wells where the cuttings were described (see cutting descriptions listed in the appendix). Most of these lithologic units can be traced throughout the study area although depths of occurrence and thicknesses may vary.

# FORMATIONS ENCOUNTERED

As previously mentioned, the base of the Hawthorn formation is readily recognized in the cutting samples. It corresponds to a sand unit with the highest concentration of phosphate found in the well. The sand is composed primarily of rounded, polished phosphorite and quartz grains. As stated above, in SLF-3A the base of the Hawthorn occurs between 483 and 503 feet (145-151 m) below land surface.

The next lithologic unit is the grey, sandy calcilutite between 503 and 523 feet (151-157 m). The formational name and age of this unit are not known, as no microfossils or other diagnostic criteria have been observed by the present author. This limestone fits neither the usual definitions for the Suwannee nor the Tampa Limestones, although it could be considered closer to the Tampa (due largely to the Tampa's vague definition).

The white, foraminiferal coquina below the grey calcilutite is almost certainly part of the Ocala Limestone. The forams are large nummulitic types and therefore correspond to Dall and Harris's (1892) "nummulitic beds". This unit also corresponds to the upper Ocala member described by Applin and Applin (1944).

The next unit down, the cream-colored, bioclastic calcarenite, or "grapestone" is probably the lower member of the Ocala as described by Applin and Applin (1944). In SLF-3A, the Ocala has a thickness of about 120 feet (36 m). The Ocala Limestone has been placed in the Jackson Stage of the Upper Eocene Series (Cooke, 1915).

Below the Ocala Limestone in SLF-3A is the white, chalky calcilutite, with associated cone-shaped foraminifera such as _Coskinolina_ and _Dictyoconus_. This fits precisely the Avon Park Limestone of Applin and Applin (1944). Based on the cutting samples, the top of this formation in SLF-3A is placed at 643 - 663 feet (196-202 m). SLF-3A apparently ends in the Avon Park Limestone; therefore, its thickness cannot be determined. Applin and Applin (1944) placed the Avon Park Limestone in the Claiborne Stage of the Upper Middle Eocene Series.

## COMPARISON OF FORMATIONS AND GEOPHYSICAL LOGS

The geophysical signatures of the formations discussed above were recognized by comparing the well cuttings and geophysical logs of Well SLF-3A. This comparison is shown in Figure 2. The lithologic log obtained from examination of the cuttings from SLF-3A was moved up by approximately 10 feet (3 m). This was done on the assumption that a consistent ten foot discrepancy in depth measurements (one-half the drill pipe length) was possible due to the time lag between the formation being drilled and its cuttings reaching the surface. After the lithologic column was corrected in this manner, the geophysical signatures of the various formations become evident. Before these geophysical signatures are described, a brief mention of the log types used is in order.

Three types of geophysical logs were used in this study: (1) gamma-ray log, (2) neutron log, and (3) electrical resistivity log. Table I shows which log types were used for each well.

The gamma-ray log is the log which gave the most satisfactory results and was primarily used in this study. The geophysical signatures are identified on the gamma-ray log whereas the other logs are used as a check. The gamma-ray log has historically been the best geophysical log for correlation purposes in Florida. Because of this, it is the only geophysical log that is common to all the wells used in the present study. The gamma-ray log basically is a measurement of the natural radioactivity of the various formations. Since phosphates in Florida contain uranium, the gamma-ray log effectively shows the presence of phosphate. To a lesser extent, it can also mark the presence of clay units and in some cases dolomites, depending on their concentrations of radioactive elements. The gamma-ray log can be run in cased holes. This is very useful when working old wells that have never been logged previously.

The neutron log delineates porous formations and can be used to determine the porosity of a formation. The neutron log responds inversely to the amount of hydrogen present in a formation. Thus, a formation with a lot of hydrogen shows a now neutron "kick" whereas a formation with little hydrogen shows a high neutron signature. In formations saturated with water ($H_2O$), such as most of those of Florida, it is easy to see how the neutron log would lead to an estimate of porosity. The neutron log is a useful check on units in the Floridan aquifer. It is especially useful in delineating the deeper dolomites, many of which are sub-crystalline in texture and therefore have little porosity. The neutron log can also be run in a cased hole.

The third type of geophysical log used in this study is the electrical resistivity log. This log has been used where no neutron log was available. By passing an electrical current through the formations, the resistivity of the formations is measured. The electrical resistivity logs that are used are the 16 and 64 inch normals. These logs are highly dependent on the water (fresh or saline) contained in the formations, but seem to delineate the dolomites quite well. However, an electrical resistivity log cannot be run in a cased hole. An excellent discussion of these three log types as well as others is given by Schlumberger (1972).

The base of the Hawthorn formation is easily recognized on the gamma-ray log. It corresponds with the deepest, and usually biggest, sharp gamma-ray kick. This is due to the increase in rounded phosphorite grains which in SLF-3A occurs at about 488 feet (194 m).

Below the base of the Hawthorn, there is a 30-35 foot (9-11 m) interval before the next good gamma-ray kick. This 30-35 foot zone corresponds to the unnamed grey calcilutite that commonly contains some quartz and minor phosphorite.

The next noticeable unit on the gamma-ray log is an interval of relatively low gamma-ray intensity. This unit is approximately 100 feet (34 m) thick in SLF-3A and corresponds to the Ocala Limestone. On the gamma-ray log for SLF-3A there is a small kick in the middle of this limestone where cuttings indicate the contact between the upper and lower Ocala. This division, however, is not evident in all the other gamma-ray logs; therefore, the separation of the Ocala Limestone cannot be further dealt with here. The lower part of the Ocala, especially near the base, shows an increase in the neutron log intensity. This may reflect the harder and less porous characteristic of the lower Ocala.

Below the Ocala Limestone there is a noticeable increase in the background intensity of the gamma-ray log. This corresponds to the Avon Park Limestone. The increase in the gamma-ray background intensity may be due to the dolomitic character of the Avon Park Limestone. Deeper in the Avon Park Limestone, the dolomite beds can easily be recognized by the strong kick on the neutron log. A slight increase in the gamma-ray log is also noticeable at these depths. The electrical resistivity logs for other wells are also useful in delineating these dolomite beds.

# INTERPRETATION AND DISCUSSION

## STRATIGRAPHIC INTERPRETATION

As previously mentioned, the geophysical signatures of the formations comprising the Floridan aquifer were recognized in all wells used in this study. Table II lists the depths to the tops of these formations in the wells. Thickness for two units, the unnamed grey calcilutite and the Ocala Limestone, are also given in Table II. The data in Table II were used to construct structure contour maps for the base of the Hawthorn formation, the top of the Ocala Limestone, and the top of the Avon Park Limestone (Figs. 3, 4, and 5). Isopach maps for the unnamed grey calcilutite and the Ocala Limestone were constructed and are shown in Figures 6 and 7, respectively.

An examination of the structure contour maps in Figures 3, 4, and 5 shows a similarity between the tops of the unnamed calcilutite (bottom of Hawthorn), Ocala Limestone and Avon Park Limestone. These units exhibit a southerly or southeasterly general dip. In northern and central St. Lucie County, these three units show a regular, uniform surface. In southern St. Lucie County and Martin County, however, these surfaces seem to be less smooth and more irregular. A small, high area is present in east central Martin County on all three maps. The existence of this high area is probably the source of most of the faults proposed in this area. It is the present author's opinion, however, that this high is probably not caused by faulting but instead by some other means. This high area may be an erosional feature, or it may be due to slight tectonic activity such as warping, as suggested in the Law Engineering report (Anonymous, 1975a).

## TABLE II*

| Well # | Base of Hawthorn | Top of Ocala | Top of Avon Park | Unnamed ls. thickness | Ocala thickness |
|---|---|---|---|---|---|
| SLF-3A (W-13850) | 465 | 501 | 609 | 36 | 108 |
| SLF-9 | 446 | 477 | 556 | 31 | 79 |
| SLF-11 | 392 | 412 | 504 | 20 | 92 |
| SLF-17 | 564 | 598 | 742 | 34 | 144 |
| SLF-20 | 484 | 515 | 627 | 31 | 112 |
| SLF-21 | 443 | 510 | 634 | 67 | 124 |
| SLF-23 | 602 | 625 | 734 | 23 | 109 |
| SLF-28 | 575 | 743 | 794 | 168 | 51 |
| SLF-31 | 697 | 702 | 773 | 5 | 71 |
| MF-1 | 637 | 671 | 757 | 34 | 86 |
| MF-2A | 601 | 633 | 718 | 32 | 85 |
| MF-6 | 671 | 697 | 748 | 26 | 51 |
| MF-10 | 628 | 645 | 779 | 17 | 135 |
| MF-23 | 729 | 741 | 835 | 12 | 94 |
| MF-30 (W-12556) | 772 | 784 | 814 | 12 | 30 |
| MF-40 (W-5441) | 685 | 698 | 760 | 13 | 62 |
| MF-50 (W-5442) | 698 | 724 | 759 | 26 | 35 |
| PBF-2 | 1079 | 1085 | 1197 | 6 | 112 |
| PBF-3 (W-13000) | 772 | - | - | - | - |
| PBF-4 (W-8077) | 801 | 831 | 933 | 30 | 102 |

*(Depths in feet below MSL)

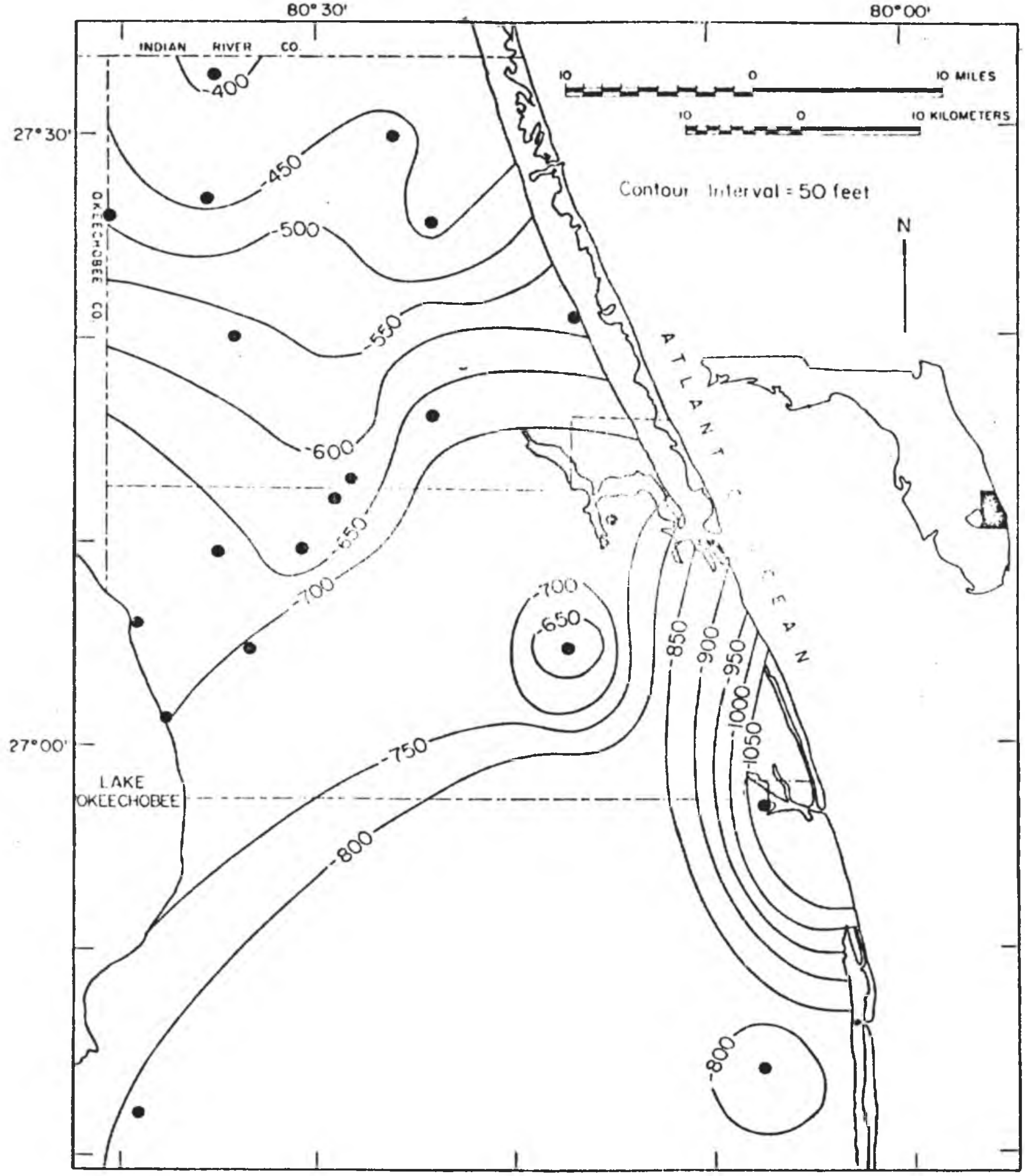


FIGURE 3. STRUCTURAL CONTOUR MAP OF THE BASE OF THE HAWTHORN FORMATION

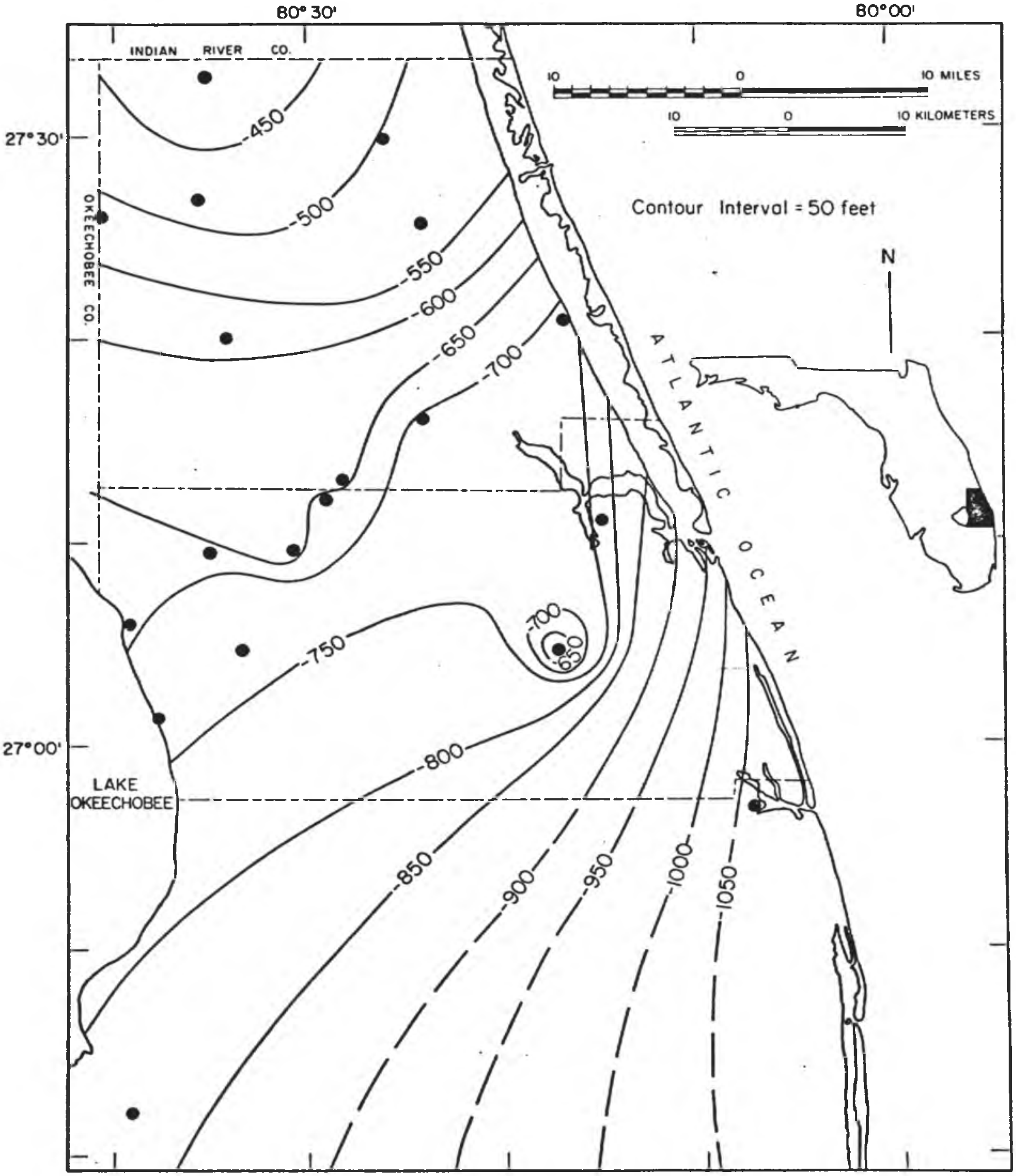


FIGURE 4. STRUCTURAL CONTOUR MAP OF THE TOP OF THE OCALA LIMESTONE

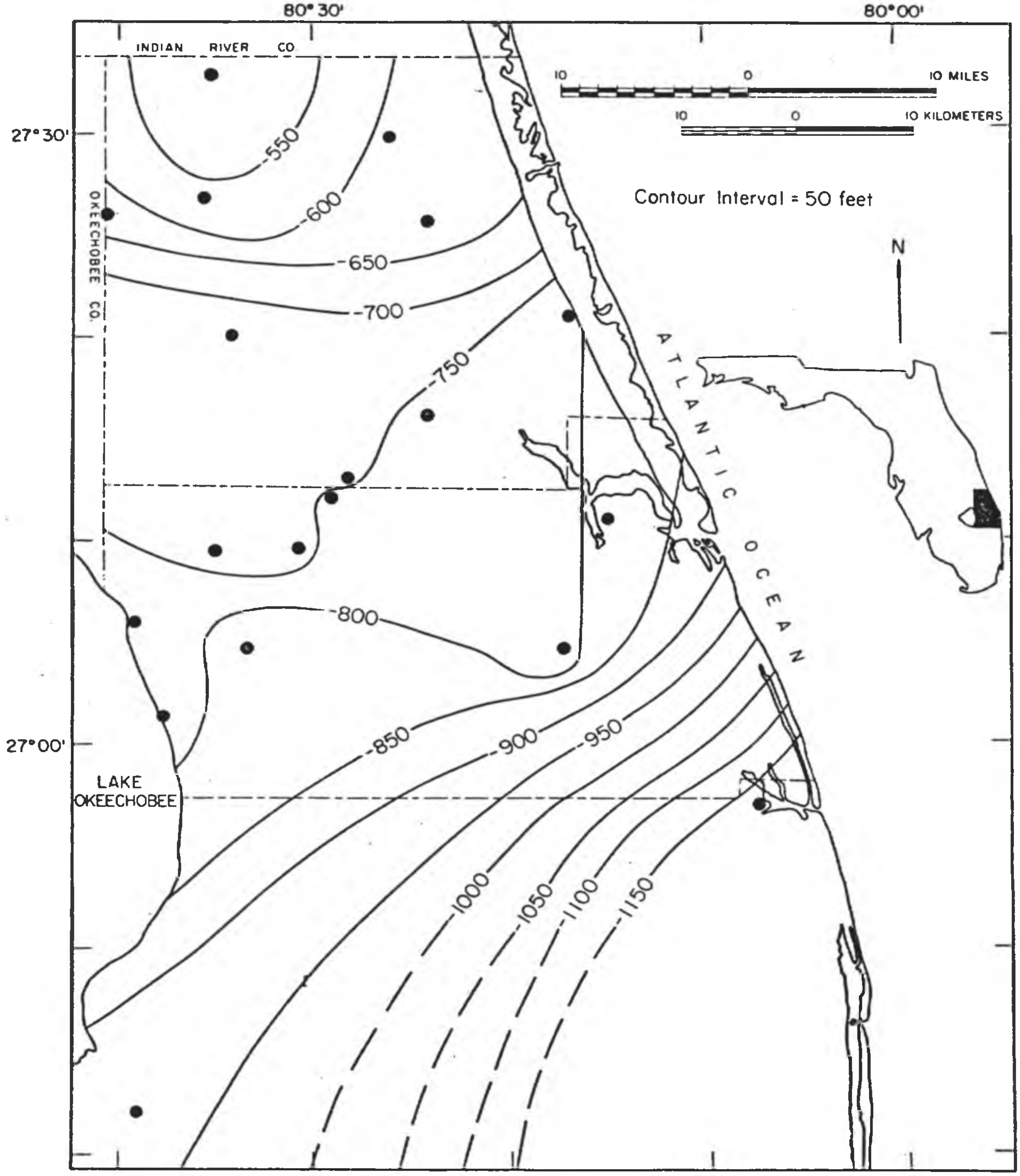


FIGURE 5. STRUCTURAL CONTOUR MAP OF THE TOP OF THE AVON PARK LIMESTONE

One noticeably dissimilar feature is the low seen in southeastern Martin and northeastern Palm Beach Counties on the structure contour map for the base of the Hawthorn (Fig. 3). This low is not present for the top of the Ocala (Fig. 4) or the top of the Avon Park (Fig. 5). This interpretation may be correct, but more probably, this difference is caused by the lack of data for PBF-3 in Figures 4 and 5. The gamma-ray log for PBF-3 (W-13000) is very poor below the strong kick which represents the base of the Hawthorn. A notation is made on the gamma log that the poor quality of the log at this point is due to the effects of the cement grout.

The thickness of the unnamed grey calcilutite can be plotted in two categories, those greater than thirty feet and those less than thirty feet (Fig. 6). The areas where the thickness is greater than thirty feet are located in eastern and southwestern St. Lucie County. Another area may be present in the southwesternmost corner of the study area, but more data is needed to confirm this. Therefore, other than the two areas in St. Lucie County, the thickness of the unit in the rest of the study area is less than thirty feet.

The identity of the unnamed calcilutite has not yet been established although several possibilities exist. Minor phosphorite in the limestone suggests that it may be a lower unit of the Hawthorn formation. If this is true, then the phosphorite sand used in the present study to mark the base of the Hawthorn will have to be moved up into the middle of the Hawthorn rather than marking its base. This would also place the Hawthorn formation directly over the Ocala Limestone.

Another possibility is that the calcilutite is part of the Tampa Limestone. This alternative would be favorable if one were to attribute the phosphorite in the limestone to downhole contamination. Although the

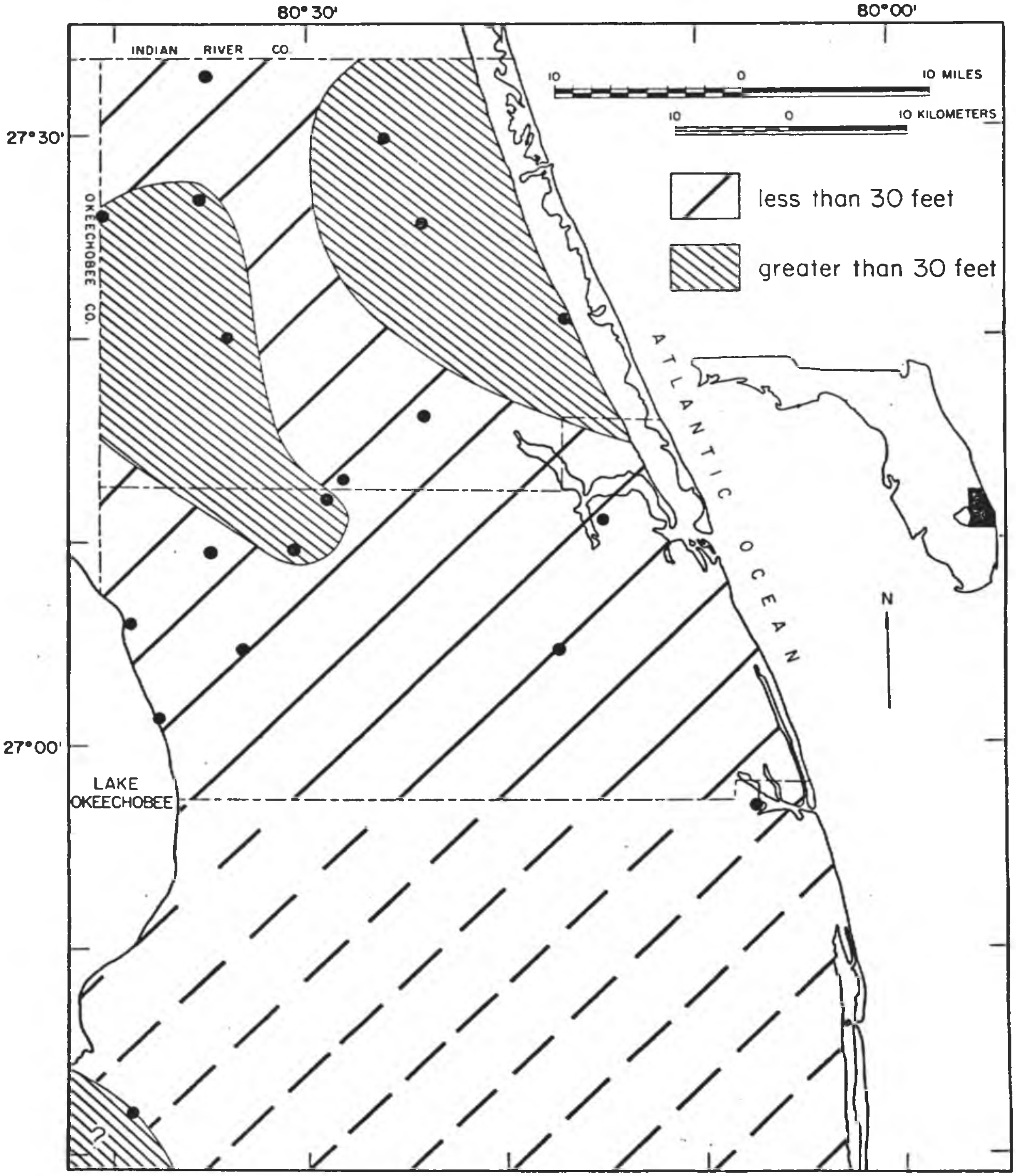


FIGURE 6. ISOPACH MAP OF THE UNNAMED CALCILUTITE

calcilutite does not closely resemble the Tampa Limestone found at the type locality, it would be similar if the phosphorite were not present (K. C. King, 1979, personal communication).

A remote possibility is that the calcilutite is a facies to be included in the Suwannee Limestone. This possibility is unlikely as the calcilutite in no way resembles the Suwannee as originally described by Cooke and Mansfield (1936).

A fourth alternative is that the unnamed calcilutite does not belong to any of the above formations, but represents a new formation in itself. If this is indeed the case, then it needs to be formally named, described, and mapped. Examination of this unit in existing cores, restricted and unavailable to the present author, would be very important. New cores within the study area should also be taken in an effort to better understand this unit and to establish a publicly accessible type section.

If one assumes that the phosphorite sand (called the base of the Hawthorn in this paper) marks the well-known Oligocene unconformity (Vail, 1978), then the resolution of the unnamed calcilutite problem could have some interesting consequences. For example, if the unnamed calcilutite is found to be a lower member of the Hawthorn formation, then the presumed Oligocene unconformity formed after the initial deposition of the Hawthorn. Assuming that the Miocene age of the Hawthorn is correct, this leads to the conclusion that the presumed Oligocene unconformity actually formed during Miocene time in the study area.

On the other hand, if the Oligocene unconformity is marked by the phosphorite sand and the unnamed calcilutite is shown to be pre-Miocene in age, then other interesting conclusions are possible. The unnamed calcilutite can then be thought of as representing the youngest rock that survived the erosion of the unconformity. This means that with the exception of two areas, less than 30 feet of post-Ocala rock survived the Oligocene erosion in the study area (Fig. 6). The Oligocene section here is generally much thinner than that in other parts of the state (Puri and Vernon, 1964). When one realizes, however, that this area is very close to the Atlantic continental slope, this view coincides nicely with the contention of Shipley, et al. (1978) that the erosion of the Oligocene unconformity was greater to the east than to the west. Although their data are based on seismic evidence along the continental margin and Black Plateau, it may also be applied to the present study area inasmuch as the study area is located close to the continental slope.

The isopach map of the Ocala Limestone (Fig. 7) is interesting in that it is the opposite of the isopach map for the unnamed calcilutite (Fig. 6). Two relatively thin areas ( <50 feet) are found in western and northeastern Martin County. The rest of the map shows a thicker section. This thicker section seems to trend NW-SE through the study area with the thinner patches located on either side of the axis.

This suggests that a trough or some other low area ran NW-SE through the area. This low area could have come about in many ways. More detailed study of the area is necessary before the actual cause of this low can be determined.

Three lines of cross-sections are shown in Figure 8. Cross-sections A-A' and B-B' (Figs. 9 and 10) are more or less north-south cross-sections and show the dip of the formations. In these cross-sections, as well as C-C' (Fig. 11), unit 1 refers to the interval on the geophysical logs that corresponds with the grey unnamed calcilutite in SLF-3A. Unit 2 refers to the interval that corresponds with the Ocala Limestone. Below unit 2 is

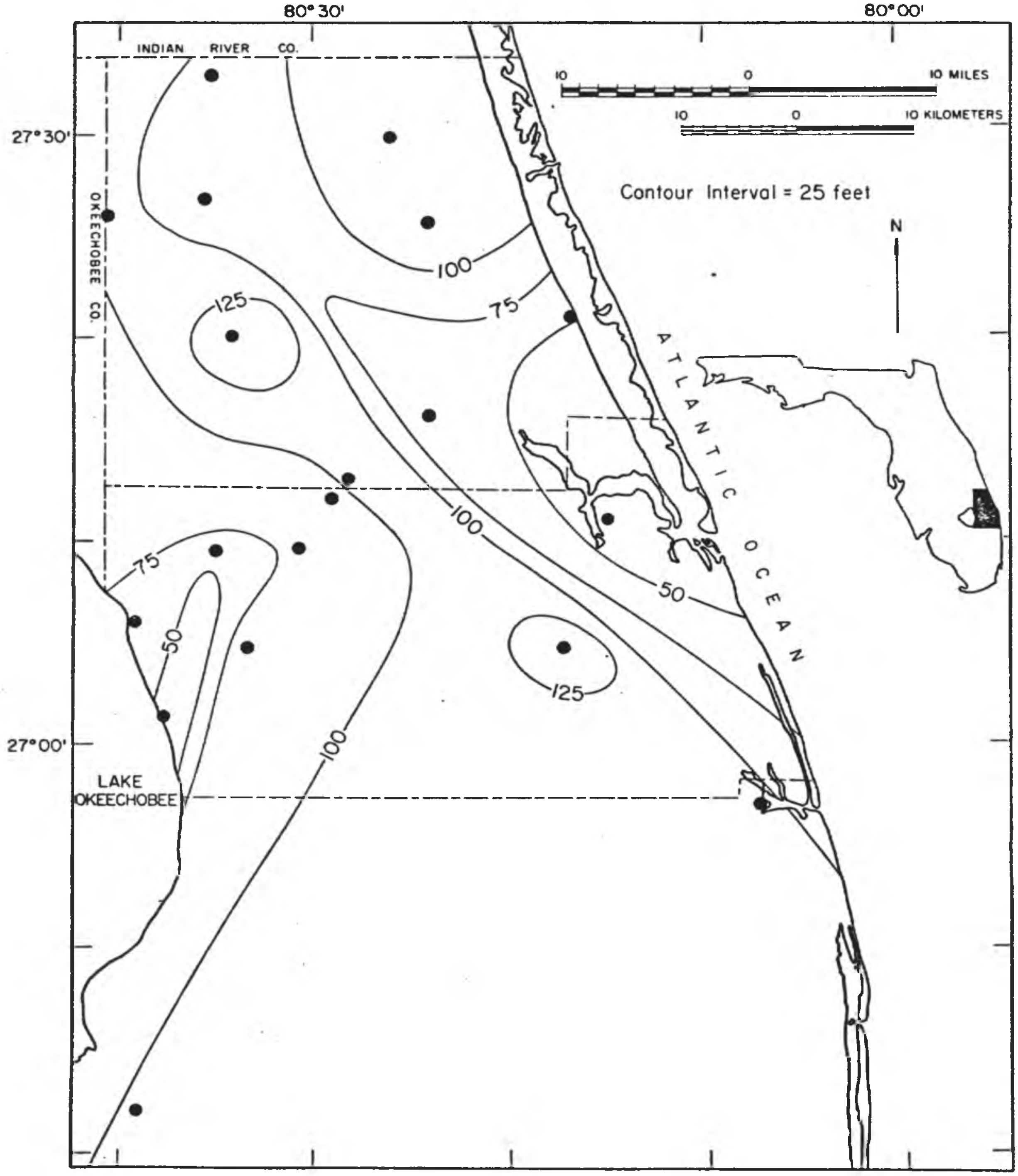


FIGURE 7. ISOPACH MAP OF THE OCALA LIMESTONE

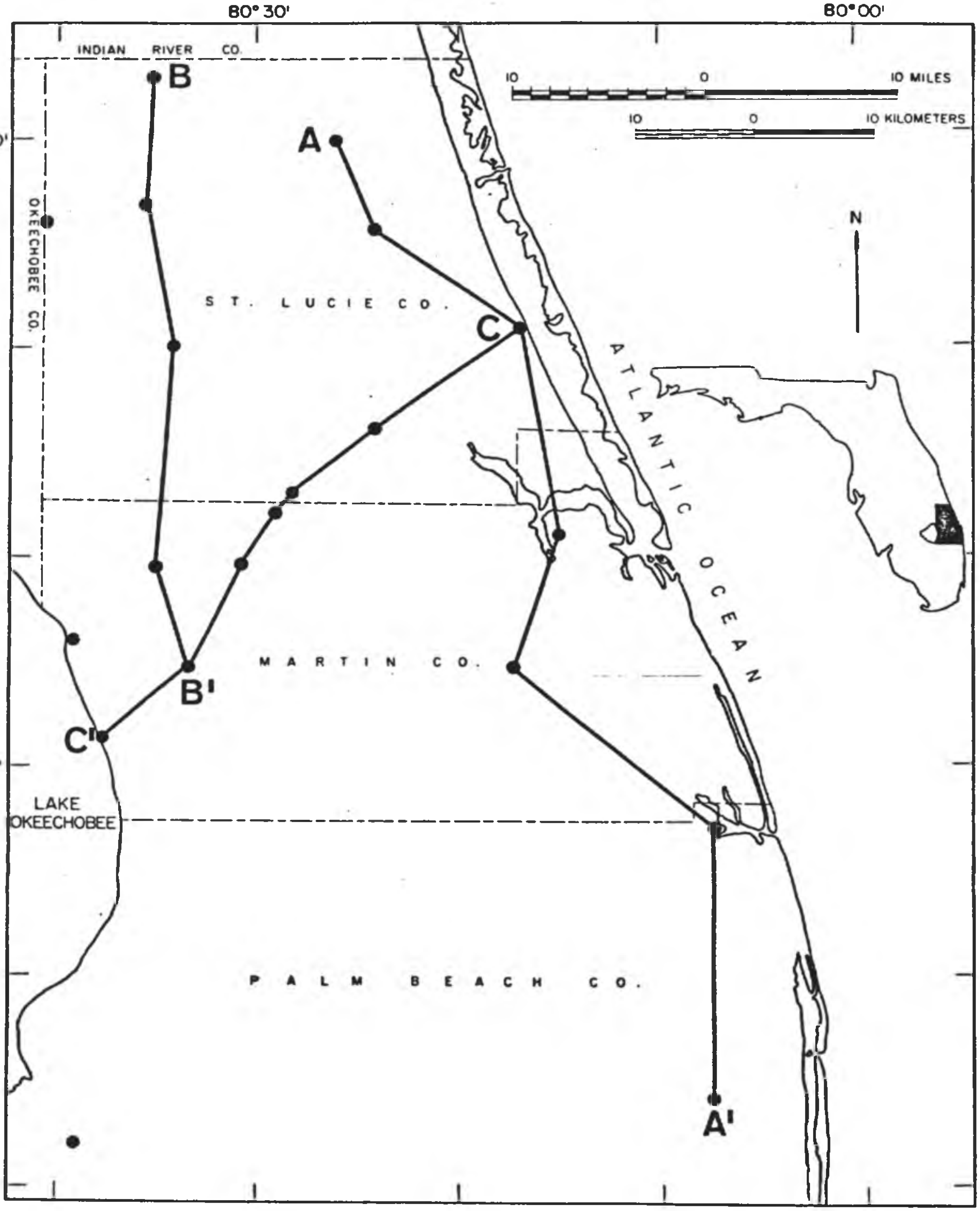


FIGURE 8. MAP OF STUDY AREA SHOWING LINES OF CROSS-SECTIONS

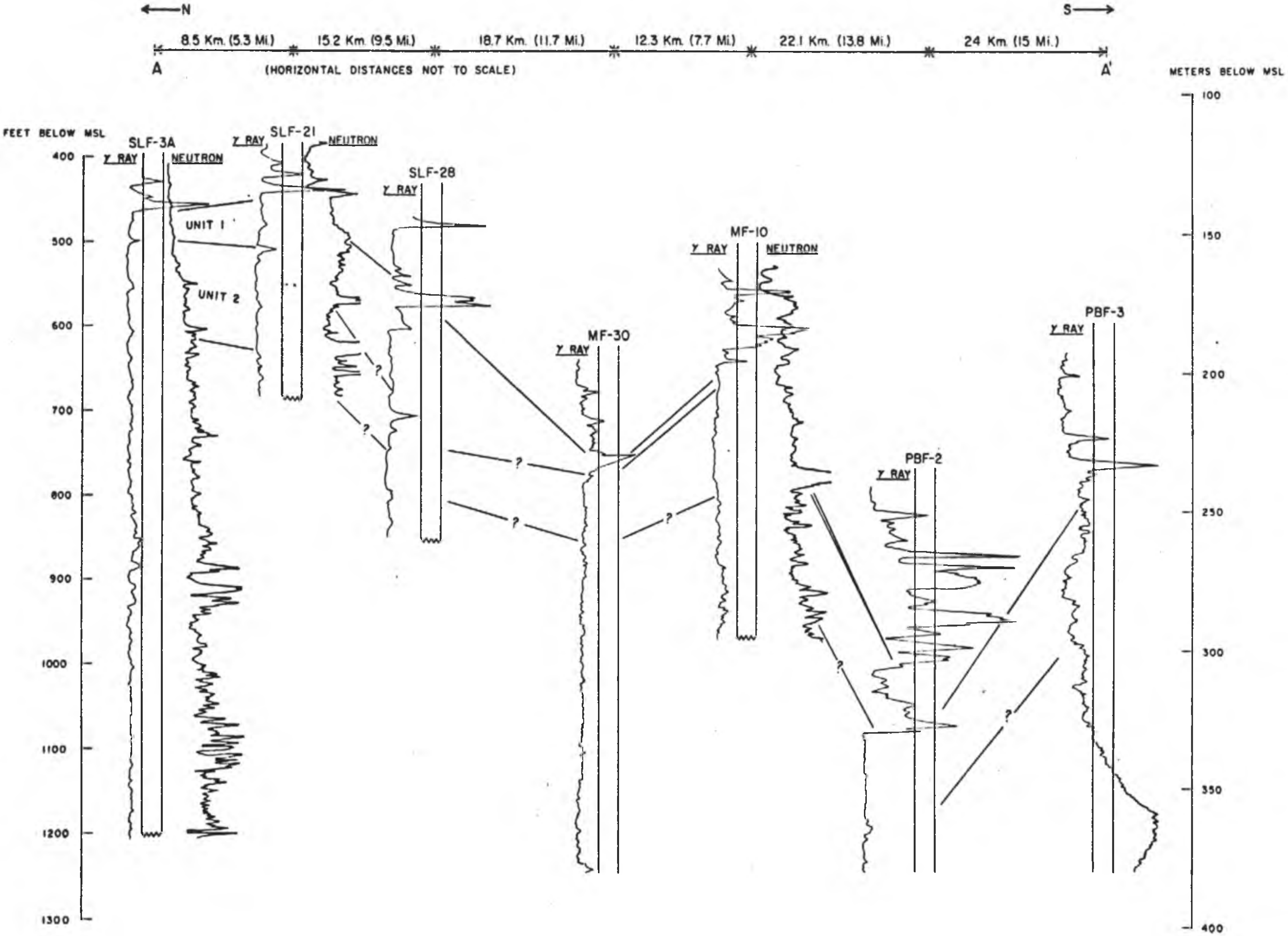


FIGURE 9. STRATIGRAPHIC CROSS-SECTION A-A'

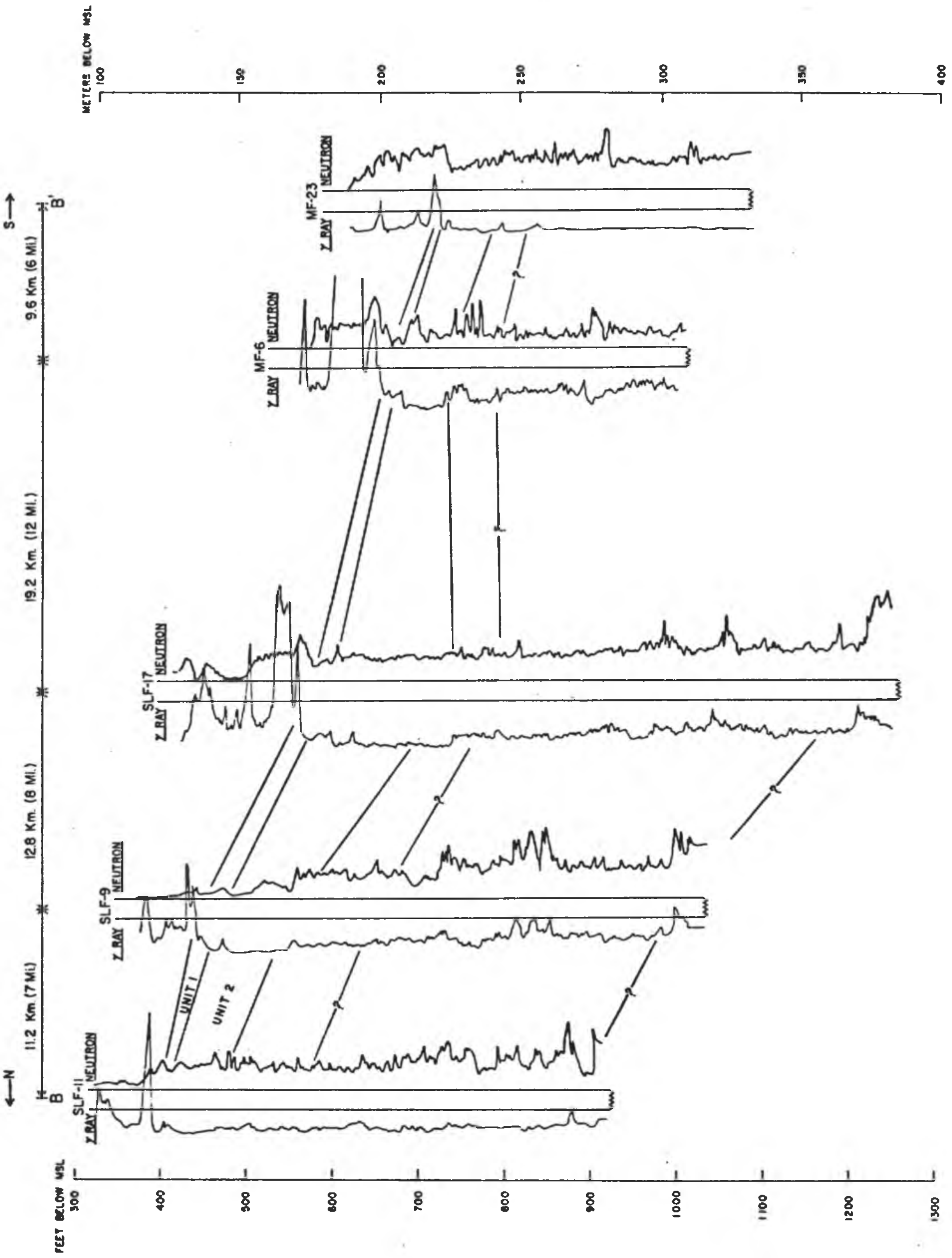


FIGURE 10. STRATIGRAPHIC CROSS-SECTION B-B'

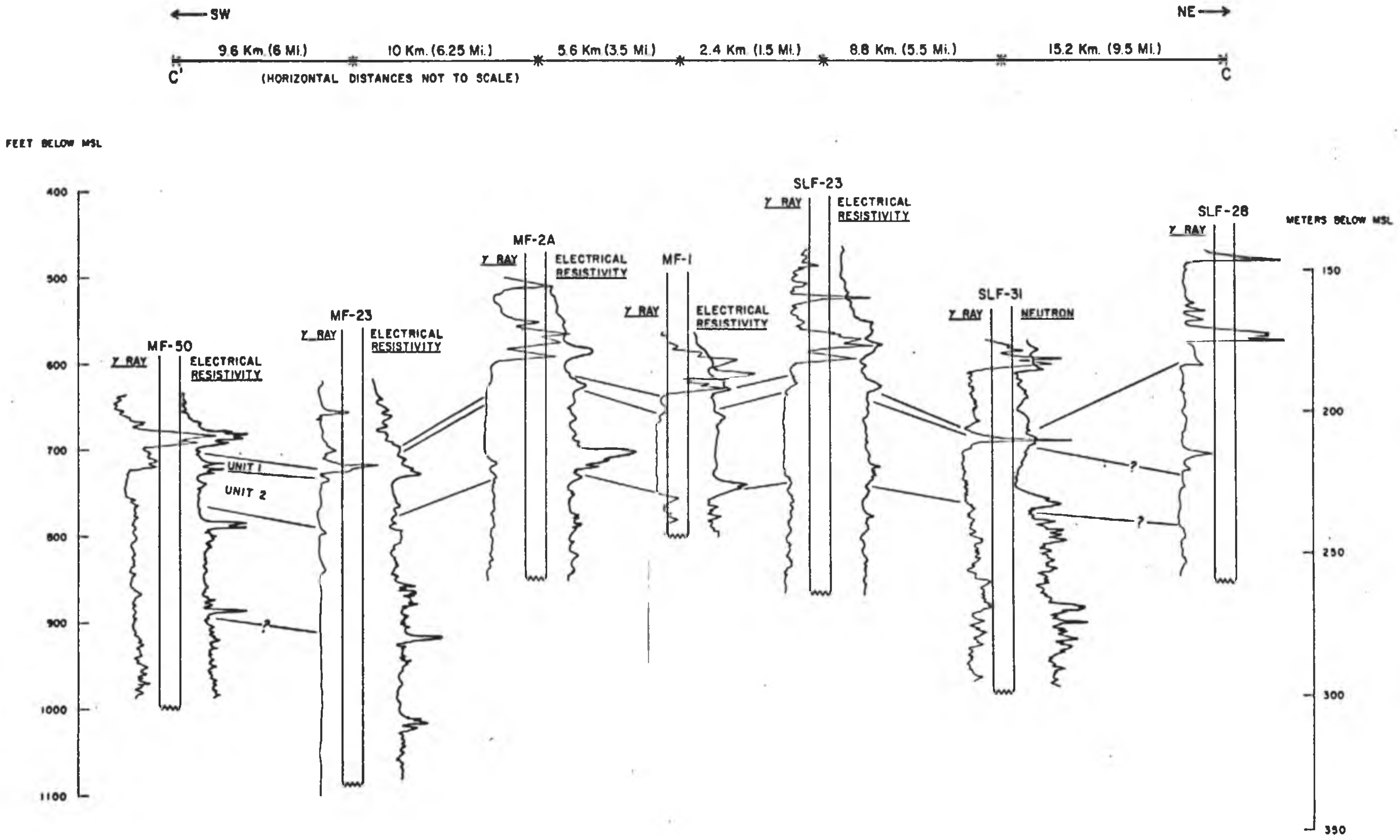


FIGURE 11. STRATIGRAPHIC CROSS-SECTION C-C'

the Avon Park Limestone. While the author believes that all of the geophysical logs as shown end in the Avon Park Limestone, correlations between beds within the Avon Park (primarily dolomite beds) have been proposed where possible. Due to the poor quality of the geophysical logs for MF-30, PBF-2 and PBF-3, correlations involving these wells in cross-section A-A' (Fig. 9) are very speculative.

Cross-section C-C' (Fig. 11) runs NE-SW through Martin and St. Lucie Counties and generally shows the strike of the formations. The surfaces of the formations are depicted as slightly undulating surfaces which may indicate slight warping in the area.

As previously mentioned, this slight warping is also seen in the structure contour maps (Figs. 3, 4, and 5) and may be the cause for many of the postulated faults paralleling the coastline in this area. It should be noted that in section C-C' (Fig. 11), the Ocala and Avon Park Limestones become deeper in depth from SLF-31 to SLF-28. This line crosses two proposed faults which both predict that the formation depths should become deeper to the east (the downthrown block). This deepening of the previously mentioned formations in SLF-28 is accompanied by a thickening of the unnamed calcilutite. More work is needed in this area in order that this thickening, as well as the general geology of the area, becomes better understood.

# DISCUSSION

As previously mentioned, this study is based primarily on geophysical logs because of apparent inconsistencies in well cutting samples. From observations made in the present study, the author is led to the conclusion that deep well studies based only on well cutting data have a large margin for error. These errors can appear as contamination from up the borehole and especially as errors in depth estimates. By conscientious observation of the cuttings, the contamination problem can be minimized. The problem of proper depths, however, can only be dealt with when the cutting samples are compared with more reliable depth measurements, such as those on geophysical logs. It is the author's opinion that in any deep well studies, cutting samples should be studied with geophysical logs close at hand. This would result in better and more consistent depth data.

In this study, St. Lucie and Martin Counties had good data coverage, whereas only a few wells were located in northern Palm Beach County. The wells there were great distances apart and had poor geophysical logs. Because of this, no real geologic conclusions can be made for that area. Closer examinations of the well cuttings from the entire study area may produce useful biostratigraphic data, but as stated above, cutting depths should be checked carefully against geophysical logs. It is hoped that this reconnaissance study of St. Lucie and Martin Counties will provide a starting point, and perhaps background for future, more detailed studies of the area.

# APPENDIX

## GEOLOGIC LOGS

## SLF-3A
## (W-13850)

| Depth (feet) | Description |
|---|---|
| 0-483 | Post aquifer sediments. |
| 483-503 | Sand, rounded phosphorite and quartz, also freshly broken pieces of chert, some white limestone with minor included phosphorite; some microsucrosic dolomitic limestone. |
| 503-523 | Limestone, light grey, hard calcilutite; pieces of olive chert. |
| 523-583 | Limestone, white, a "micro-coquina" foraminiferal calcarenite composed of *Lepidocyclina* and *Camerina* tests; bryozoa. |
| 583-603 | Limestone, white, grainy calcilutite; some resinous dolomitic limestone. |
| 603-643 | Limestone, light grey, calcilutitic calcarenite; *Camerina*, some *Lepidocyclina*, bryozoa. |
| 643-723 | Limestone, white, hard, chalky, calcilutite; *Dictyoconus cookei* - numerous; trace of a very light grey subcrystalline limestone. |
| 723-783 | Limestone, cream, grainy calcilutite; traces of grey dolomite. |
| 783-823 | Limestone, cream, grainy calcilutite; traces of grey dolomite and traces of a white, chalky calcilutite; seems to be an increase in foram diversity. |
| 823-863 | Limestone, cream, calcilutitic calcarenite (bioclastic?); some evidence of recrystallization (dolomite?) and abraded forams. |
| 863-903 | Limestone, dolomitic, tan, in part microsucrosic, a calcilutite with a few carbonate clasts; trace of white chalky calcilutite; some shell fragments. |
| 903-923 | Dolomite, calcitic, tan to greyish tan, sucrosic to subcrystalline; some limestone from above; forams - *Dictyoconus*. |
| 923-963 | In part calcitic dolomite as above; ~933 dolomite, dolomite, dark grey to tan, subcrystalline; also an orange sucrosic dolomite (very pretty). |
| 963-1103 | Dolomite, calcitic, tan to orange, microsucrosic to sucrosic; trace of white limestone. |

SLF-3A (W-18350) Cont'd.

| Depth (feet) | Description |
|---|---|
| 1103-1123 | Dolomite, tan to grey, subcrystalline; traces of sucrosic dolomite and white limestone. |
| 1123-1143 | Dolomite, orange-brown, sucrosic; trace of white limestone and subcrystalline dolomite. |
| 1143-1163 | Dolomite, calcitic, grey, tan and white, microsucrosic and subcrystalline; trace of a white calcitic clay. |
| 1163-1223 | Dolomite, calcitic, tan, microsucrosic; trace of white calcitic clay. |

## SLF-23

| Depth (feet) | Description |
|---|---|
| 0-567 | Post aquifer sediments. |
| 567-588 | Clay, silty, grey; rounded sand-sized phosphorite and quartz grains; traces of a white limestone. |
| 588-609 | Limestone, white, hard, grainy, calcilutite, some minor, very fine quartz and phosphorite inclusions; ~15% dolomitic limestone, amber color, microsucrosic; minor phosphorite and quartz sand. |
| 609-630 | Limestone, white, hard calcilutite (micrite). |
| 630-672 | Limestone, white, loosely cemented calcarenite; minor, fine quartz and phosphorite sand; trace of olive chert. |
| 672-735 | Limestone, white, loosely cemented foraminiferal calcarenite; *Lepidocyclina sp.*, *Camerina ? sp.*, pelecypod fragments, bryozoa. |
| 735-756 | Limestone, white, hard calcilutic calcarenite. |
| 756-777 | Limestone; white, soft calcilutite; trace of some amber sub-crystalline, resinous dolomite?; *Dictyoconus cookei*. |
| 777-819 | Limestone, white, well cemented calcilutite; some resinous dolomite?; *Dictyoconus cookei*. |
| 819-840 | Limestone, white, loosely cemented calcarenite; minor phosphorite and quartz (contamination?); *Lepidocyclina* fragments, *Camerina*, *Dictyoconus*. |
| 840-861 | Limestone, white, loose bioclastic? calcarenite. |
| 861-903 | Limestone, white, mixture of bioclastic calcarenite as above and a calcilutite; trace of amber, microsucrosic, dolomitic limestone; *Dictyoconus*. |

## MF-40
## (W-5441)

| Depth (feet) | Description |
|---|---|
| 0-649 | Post aquifer sediments. |
| 649-691 | Limestone, buff white to grey, calcilutite, quartz and phosphorite grains, some calcite grains; shell fragments. |
| 691-712 | Limestone, buff white, hard calcilutite broken into sand size fragments; shell fragments. |
| 712-723 | Limestone, buff white, hard calcilutite with lots of shell fragments. |
| 723-754 | Limestone, buff white, calcarenite (bioclastic), lots of forams (almost a subcoquina); *Lepidocyclina*,*Camerina*, *Operculinoides*. |
| 754-764 | Limestone, buff, calcarenite, fewer large forams; *Camerina*. |
| 764-796 | Limestone as in 723-754 (definitely a coquina). |
| 796-817 | Limestone, buff, calcarenite with fewer large forams; *Camerina*. |
| 827-838 | Limestone, white calcilutite as above, also some calcite crystals and calcarenite; large echinoids, some calcite crystals. |
| 838-859 | Limestone, white calcilutite as above, also some calcite crystals and calcarenite; large echinoids, *Dictyoconus*. |
| 859-869 | Limestone, buff white, unconsolidated calcarenite, *Dictyoconus*. |
| 869-890 | Limestone, white to buff, mixture of white calcilutite and calcarenite grains; large echinoids. |
| 890-901 | Limestone, white calcilutite; *Dictyoconus*. |
| 901-953 | Limestone, white, grainy calcilutite; *Dictyoconus*; some calcite crystals. |
| 953-985 | Limestone, buff, calcarenite, lots of forams; *Dictyoconus*. |
| 985-1007 | Limestone, white, grainy calcilutite; *Dictyoconus*. |

## MF-50
## (W-5442)

| Depth (feet) | Description |
|---|---|
| 0-650 | Post aquifer sediments. |
| 650-690 | Limestone, yellow grey, calcilutite, some fine phosphorite and quartz grains; few shell fragments. |
| 690-730 | Limestone, buff to grey, largely calcilutite as above, beginning of a vitreous calcite and consolidated calcilutite. |
| 730-760 | Limestone, cream, calcarenite; *Operculinoides*, broken *Lepidocyclina*, *Camerina*; some calcite crystals. |
| 760-770 | Limestone, buff white, calcarenite; few large forams. |
| 770-800 | Limestone as in 730-760 (Lep. coquina). |
| 800-810 | Limestone, dolomitic, cream to tan, calcilutitic calcarenite, smaller forams. |
| 810-840 | Limestone, cream, calcilutitic calcarenite; trace of a white chalky calcilutite, *Dictyoconus cookei*. |
| 840-850 | Limestone, cream, calcarenite; *Dictyoconus*. |
| 850-900 | Limestone, buff white, grainy calcilutite; some amber calcitic dolomite crystals. |
| 900-920 | Limestone, buff, calcarenite. |
| 920-1013 | Limestone, buff white, calcilutite (grainy); few layers of calcarenite. |

### PBF-3
### (W-13000)

| Depth (feet) | Description |
|---|---|
| 0-750 | Post aquifer sediments. |
| 750-880 | Limestone, light grey, poorly consolidated calcilutite; loose polished and rounded phosphorite grains; shell fragments. |
| 880-920 | Limestone, white, chalky calcilutite; phosphorite, embedded in limestone; lots of contamination from above; lots of loose phosphorite grains, shell fragments. |
| 920-1010 | Limestone, light grey, poorly consolidated calcilutite; shell fragments. |
| 1010-1070 | Limestone, buff, foram coquina with a calcilutite matrix; *Lepidocyclina*. |
| 1070-1270 | Limestone, white, bioclastic calcarenite with lots of smaller foram tests. |
| 1270-1330 | Limestone, white, grainy calcilutite; *Dictyoconus cookei*. |
| 1330-1340 | Limestone as above; also a light grey subcrystalline dolomite. |
| 1340-1350 | Limestone, buff to tan, bioclastic calcarenite; *Dictyoconus cookei*. |
| 1350-1420 | Limestone, white, chalky calcilutite. |
| 1420-1460 | Limestone, buff, calcarenite (bioclastic in part). |
| 1460-1517 | Dolomite, buff, microsucrosic. |
| 1517-1537 | Dolomite, amber, sucrosic. |
| 1537-1590 | Limestone, white, chalky calcilutite. |
| 1590-1620 | Dolomite, light grey, subcrystalline. |
| 1620-1660 | Limestone, white, chalky calcilutite. |
| 1660-1670 | Dolomite, amber, microsucrosic. |
| 1670-1690 | Limestone, buff, fossiliferous calcarenite; *Dictyoconus*. |

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