STATE OF FLORIDA
DEPARTMENT OF NATURAL RESOURCES
Tom Gardner, *Executive Director*

DIVISION OF RESOURCE MANAGEMENT
Jeremy A. Craft, *Director*

FLORIDA GEOLOGICAL SURVEY
Walter Schmidt, *State Geologist*

BULLETIN NO. 59

THE LITHOSTRATIGRAPHY OF THE HAWTHORN GROUP (MIOCENE) OF FLORIDA

By
Thomas M. Scott

Published for the
FLORIDA GEOLOGICAL SURVEY
TALLAHASSEE
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LETTER OF TRANSMITTAL

Bureau of Geology
August 1988

Governor Bob Martinez, Chairman
Florida Department of Natural Resources
Tallahassee, Florida 32301

Dear Governor Martinez:

The Florida Geological Survey, Bureau of Geology, Division of Resource Management, Department of Natural Resources, is publishing as its Bulletin No. 59, *The Lithostratigraphy of the Hawthorn Group (Miocene) of Florida.* This is the culmination of a study of the Hawthorn sediments which exist throughout much of Florida. The Hawthorn Group is of great importance to the state since it constitutes the confining unit over the Floridan aquifer system. It is also of economic importance to the state due to its inclusion of major phosphorite deposits. This publication will be an important reference for future geological investigations in Florida.

Respectfully yours,

Walter Schmidt, Chief
Florida Geological Survey

Printed for the
Florida Geological Survey

Tallahassee
1988

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ABSTRACT

The Hawthorn Formation has been a problematic unit for geologists since its inception by Dall and Harris (1892). It is a complex unit consisting of interbedded and intermixed carbonate and siliciclastic sediments containing varying percentages of phosphate grains. These sediments have been widely studied by geologists due to their economic and hydrologic importance in the southeastern United States. Economically, the Hawthorn sediments contain vast quantities of phosphate and clay and limited amounts of uranium. Hydrologically, the Hawthorn contains secondary artesian aquifers, provides an aquiclude for the Floridan aquifer system and, in some ares, makes up the upper portion of the Floridan aquifer system.

The Hawthorn Formation of previous investigators has been raised to group status in Georgia by Huddlestun (in press). The present investigation extends the formations recognized in southern Georgia into northern Florida with some modifications, and accepts Huddlestun's concept of the Hawthorn Group. The Hawthorn Group and its component formations in southern Florida represent a new lithostratigraphic nomenclature applied to these sediments. The elevation of the Hawthorn to group status in Florida is justified by the Hawthorn's complex nature and the presence of areally extensive, mappable lithologic units.

The Hawthorn Group in northern peninsular Florida consists of, in ascending order, the Penney Farms Formation, the Marks Head Formation and the Coosawhatchie Formation. The Coosawhatchie Formation grades laterally and, in a limited area, upwards into the Statenville Formation.

Lithologically, the Hawthorn Group in northern Florida is made up of a basal carbonate with interbedded siliciclastics (Penney Farms), a complexly interbedded siliciclastic-carbonate sequence (Marks Head), a siliciclastic unit with varying percentages of carbonate in both the matrix and individual beds (Coosawhatchie) and a crossbedded, predominantly siliciclastic unit (Statenville). Phosphate grains are present throughout these sediments, varying in percentage up to 50 percent of the rock.

Sediments of the Hawthorn Group in northern peninsular Florida range in age from Early Miocene (Aquitanian) to Middle Miocene (Serravalian). This represents a significant extension of the previously accepted Middle Miocene age.

In southern Florida, the group includes two formations, in ascending order, the Arcadia Formation and the Peace River Formation. The Tampa Formation or Limestone of former usage is included as a lower member of the Arcadia Formation due to the Tampa's limited areal extent, lithologic similarities, and lateral relationship with the undifferentiated Arcadia. Similarly, the Bone Valley Formation of former usage is incorporated as a member in the Peace River Formation.

Lithologically, the Arcadia Formation is composed of carbonate with varying amounts of included and interbedded siliciclastics. Siliciclastic sediments in the Arcadia are most prevalant in its basal Nocatee Member. The Peace River Formation is predominantly a siliciclastic unit with some interbedded carbonates. Phosphorite gravel is most common in the Bone Valley Member. Sand-sized phosphate grains are virtually ubiquitous in the southern Florida sediments with the exception of the Tampa Member where it is often absent.

The southern Florida Hawthorn sediments range in age from Early Miocene (Aquitanian) to Early Pliocene (Zanclian).

The Hawthorn Group in the eastern Florida panhandle is composed of the Torreya Formation and, in a few areas, a Middle (?) Miocene unnamed siliciclastic unit. Lithologically, the Torreya consists of a carbonate-rich basal section with interbedded clays and sands, and a dominantly siliciclastic, often massive, plastic clayey upper unit (Dogtown Member). Phosphate grains are noticeably less common in the Hawthorn of the panhandle.

Hawthorn Group sediments are characterized by the occurrence of an unusual suite of minerals. Apatite (phosphate grains) is virtually ubiquitous in the peninsular Hawthorn sediments. Palygorskite, sepiolite and dolomite occur throughout the group statewide.

Miocene sea level fluctuations were the primary controlling factor determining the extent of Hawthorn deposition in Florida. During the maximum Miocene transgression, sediments of the Hawthorn Group

were probably deposited over the entire Florida platform. Hawthorn sediments were subsequently removed from the crest of the Ocala Platform (Ocala Uplift) and the Sanford High by erosion.

The Hawthorn Group appears to have been deposited under shallow marine conditions. These conditions are suggested by the occurrence of molds of shallow water mollusks and a limited benthic foraminifera fauna. The deepest water conditions apparently existed in the Jacksonville and Okeechobee Basins.

The gamma-ray signature of the Hawthorn Group is quite distinctive, providing a useful tool for identification and correlation in areas of limited data. The Hawthorn signature consists of distinctly different patterns in northern and southern peninsular and eastern panhandle Florida.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of many individuals during the course of this study. The assistance of these individuals was invaluable in the successful completion of this investigation.

The author thanks C.W. "Bud" Hendry, Jr., former State Geologist of Florida, and Steve Windham, former Bureau Chief of the Florida Bureau of Geology for allowing the author to attend Florida State University under the state's job related courses program. Discussions and support from the staff of the Florida Geological Survey were greatly appreciated. Of particular assistance were Ken Campbell, Paulette Bond and Walt Schmidt, State Geologist. Justin Hodges, former driller for the Florida Geological Survey, was invaluable to this study. Mr. Hodges' expertise was responsible for the recovery of excellent quality cores, many of which were used in this research. Draftsmen Jim Jones and Ted Kiper spent many hours laboring over the figures for the text.

Thanks are due to a number of individuals around the state for their help during this project. These include: Jim Lavender, Tony Gilboy, Jim Clayton, John Decker, Greg Henderson and Kim Preedom of the Southwest Florida Water Management District who provided cores and geophysical data; Mike "50-50" Knapp from the South Florida Water Management District; Drs. Sam Upchurch and Richard Strom of the University of South Florida; and to Tom Missimer of Missimer and Associates.

Special thanks are due to Dr. Paul Huddlestun of the Georgia Geologic Survey for many hours of discussion and data sharing. Muriel Hunter also shared freely her knowledge of Florida stratigraphy.

The author is very appreciative of the very competent assistance of Cindy Collier, secretary from the Geological Investigations Section of the Florida Geological Survey. The final form of this manuscript would have been significantly more difficult to achieve without her assistance.

The author greatly appreciates the guidance and assistance of his faculty committee, Drs. Sherwood Wise (Chairman), William Parker, J.K. Osmond, Steve Winters, and William Burnett. Their time and effort assisted in an improved final draft. The author also appreciates the many hours of discussion and the assistance provided by former FSU graduate students and Florida Geological Survey graduate assistants Andy LeRoy and Barry Reik.

Reviews of this manuscript by a number of geologists aided the author in presenting this study in a more concise manner. This author greatly appreciates the efforts of the following reviewers: Walt Schmidt, Bill Yon, Ken Campbell, Ed Lane, Jackie Lloyd, Paulette Bond and Alison Lewis of the Florida Geological Survey; Drs. Wise, Parker, Osmond, Winters, and Burnett of Florida State University; Dr. Sam Upchurch of the University of South Florida; and Ms. Muriel Hunter, independent geologist.

Finally, and most importantly, are the thanks due to my family for their support during this endeavor. My wife of 17 years has lived with this research for more than one third of our married life. This research would not have been completed without her support.

THE LITHOSTRATIGRAPHY OF THE HAWTHORN GROUP (MIOCENE) OF FLORIDA

By
Thomas M. Scott

INTRODUCTION

The late Tertiary (Miocene-Pliocene) stratigraphy of the southeastern Coastal Plain provides geologists with many interesting and challenging problems. Much of the interest has been generated by the occurrence of scattered phosphorite from North Carolina to Florida. The existence of phosphate in the late Tertiary rocks of Florida was recognized in the late 1800's and provided an impetus to investigate these sediments. More recently, the hydrologic importance of these units has led to further investigations of the stratigraphy and lithology to determine their effectiveness as an aquiclude, aquitard and aquifer.

The Hawthorn Formation in Florida has long been a problematic unit. Geologists often disagree about the boundaries of the formation. The resulting inconsistencies have rendered accurate correlation between authors virtually impossible.

The biggest problem hindering the investigation of the Hawthorn strata has been a paucity of quality subsurface data. Since the mid-1960's, the Florida Geological Survey has been gathering core data from much of the state, providing a unique opportunity to investigate the extent of, and facies relationships in the Hawthorn of the subsurface.

This investigation is an attempt to provide an understanding of the Hawthorn Group, its lithologies, stratigraphy and relation to subjacent and suprajacent units. A greater understanding of the Hawthorn is imperative to deciphering the late Tertiary geologic history of Florida.

PURPOSE AND SCOPE

The purpose of this investigation is to provide a coherent lithostratigraphic framework facilitating a better understanding of the Hawthorn Group in Florida. The internal framework of the Hawthorn, its lateral continuity, and relation to subjacent and suprajacent units were investigated in order to provide this knowledge.

The area covered by this study extends from the Apalachicola River in the Florida Panhandle on the west to the Atlantic Coast on the east and from the Georgia-Florida border on the north, south to the Florida Keys (Figure 1). The study area encompasses all or portions of 56 counties. Data points outside the study area, particularly in Georgia, were used to assist in providing a more accurate picture within the study area boundaries.

The study area boundaries were chosen based on several criteria. In the past, the western limits of the Hawthorn were drawn at the Apalachicola River. The western boundary was chosen both to coincide with the historical boundary and to avoid overlap with the investigation of equivalent sediments in the Apalachicola Embayment by Schmidt (1984).

More than 100 cores provided the data base for the present study. The locations of cored data points are shown on Figure 2. Figure 3 delineates cross section transects.

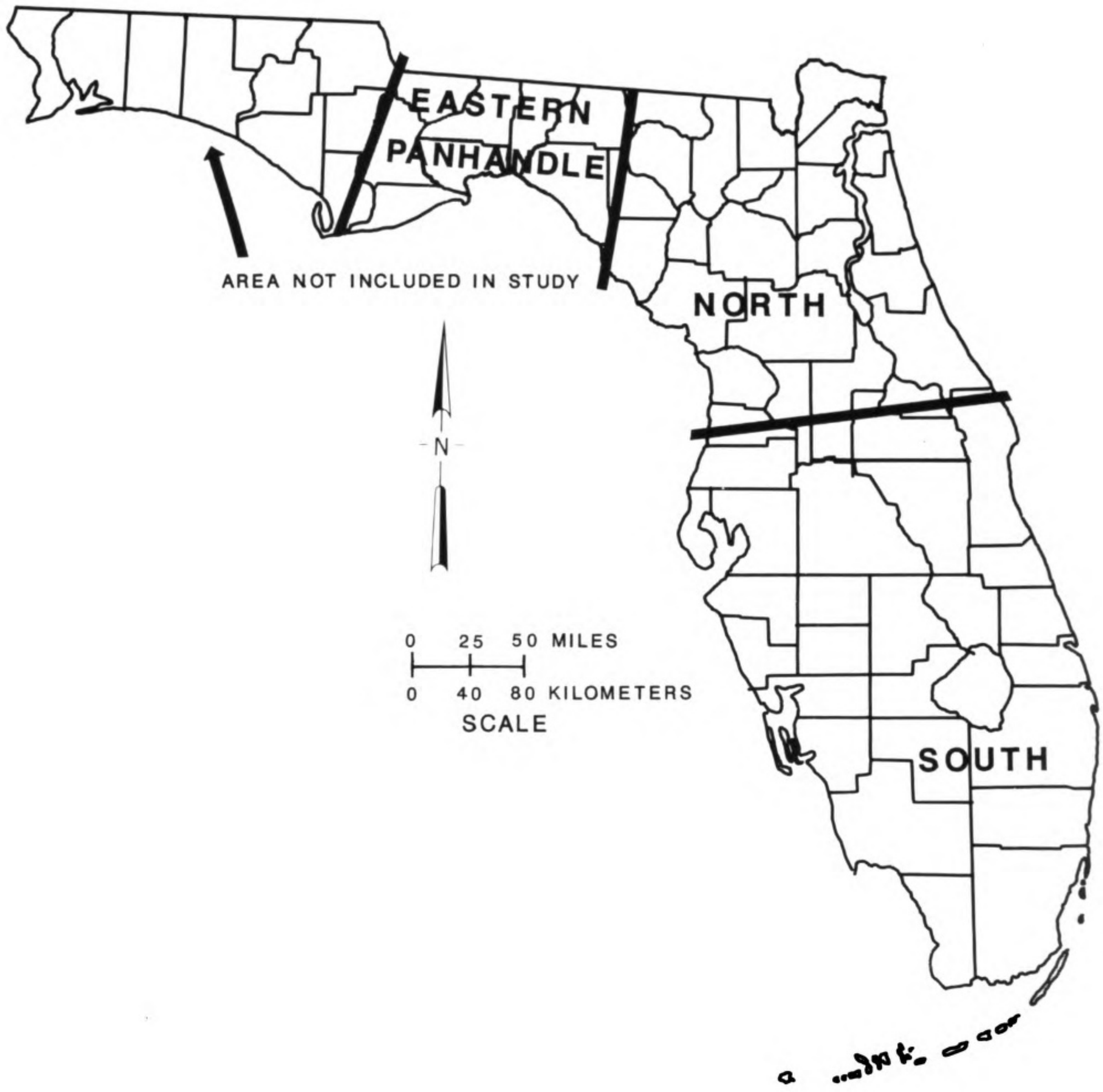


Figure 1. Study area and areas of discussion.

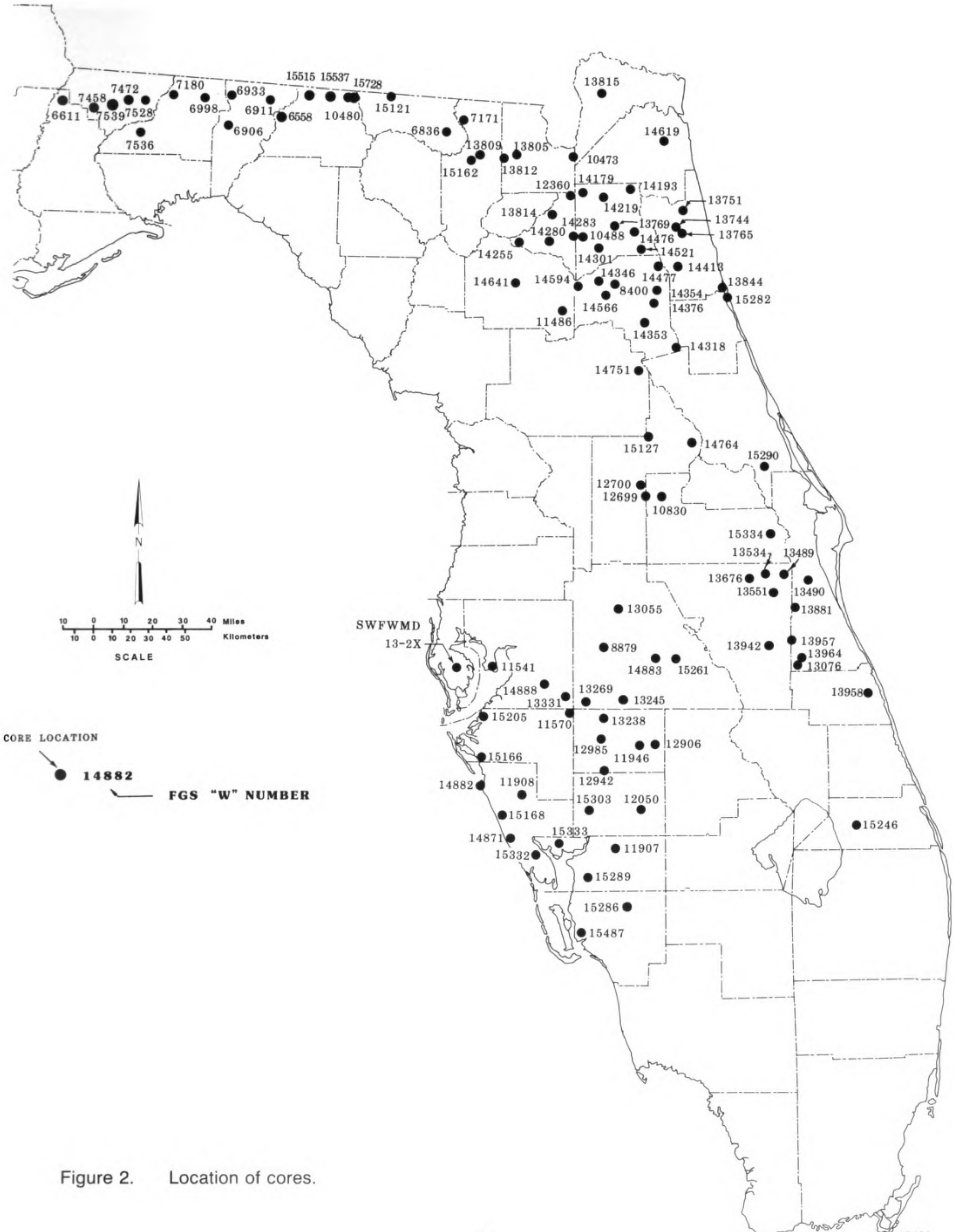


Figure 2. Location of cores.

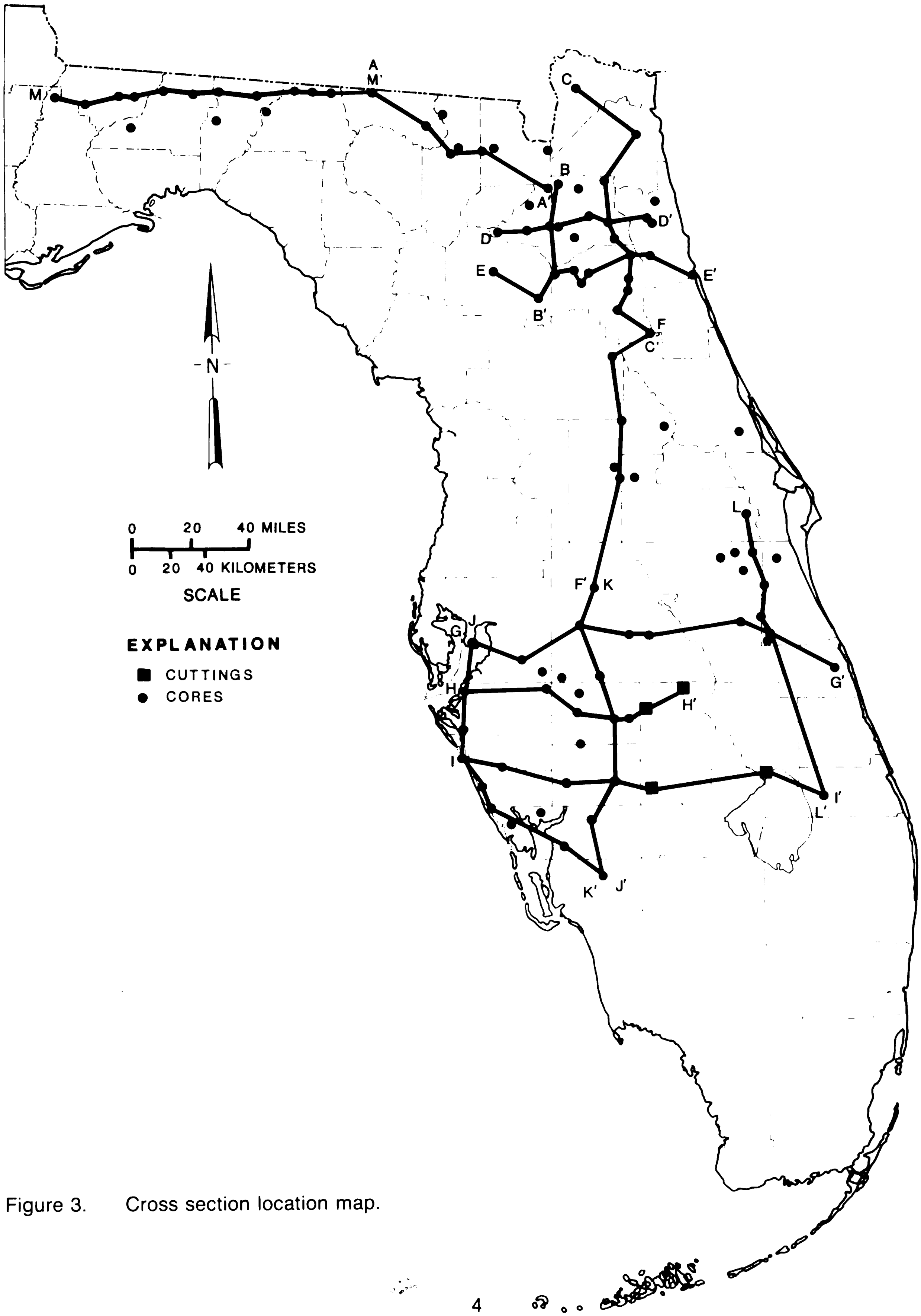


Figure 3. Cross section location map.

METHOD OF INVESTIGATION

The Hawthorn Group is predominantly a subsurface unit. As a result, the principal data sources for this study were the cores drilled by the Florida Geological Survey from 1964 through the present. The cores were obtained using a Failing 1500 Drillmaster with a capacity to drill in excess of 1000 feet (305 meters). Under most conditions, nearly continuous recovery of 1-¾ inch (4.5 cm) diameter cores was obtained. Losses in core recovery were minimized due to the expertise of driller Justin Hodges. The cores recovered were placed in boxes and are stored at the Geological Survey in Tallahassee. Additional cores were obtained from the Southwest Florida Water Management District and the St. Johns River Water Management District. All cores are available for inspection by the public.

Supplemental lithologic data sources included samples obtained from water wells drilled by private contractors who provide cuttings to the Geological Survey. Unfortunately, the cuttings do not necessarily provide accurate lithologic information. This circumstance is due to the loss of fine grained (clay, silt and very fine sand-sized), poorly consolidated to nonindurated sediments. The drilling method, sample collection, and subsequent removal of drill mud by washing facilitates the loss of this material. The net result is to skew the sediment types toward sands and more indurated materials. The use of cuttings does, however, allow the extrapolation of lithologies and contacts in areas of limited core control. Water-well cuttings were thus used only to supplement core data.

All cores and well cuttings were examined using a binocular microscope. Examinations were normally made at magnification of 10x to approximate the use of a hand lens in field indentification. Higher magnifications (up to 45x) were employed for the identification of the finer grained constituents of the sediments. Geologist's logs of the samples were recorded according to the Florida Geological Survey format which aids in producing a concise, standardized lithologic description. Coded lithologic data were stored on magnetic tape for later retrieval and use. These data were run through the Florida Geological Survey's FBGO1 program on the Florida State University computer which provided a full English printout of the lithologic information. The data were also run through the Stratlog program to provide a lithologic column of each core analyzed.

Samples collected for x-ray analysis were taken primarily from cores, although outcrops along the Suwannee and Alapaha Rivers were also sampled. Since clay minerals present in the sediments were of primary interest, samples were taken from the more clayey portions of the cores. Samples were mounted for x-ray analysis by standard techniques and analyzed with CuKαradiation.

Gamma-ray logs were run on most core holes. Numerous gamma-ray logs run in water wells are also available for correlation purposes. All geophysical logs are on permanent file at the Geological Survey and are open to the public.

PREVIOUS INVESTIGATIONS

Interest in the general stratigraphic framework of the southeastern Coastal Plain and the occurrence of phosphate in the sediments now assigned to the Hawthorn Group prompted geologists to investigate these sediments in Florida. Table 1 indicates the important nomenclatural changes that have occurred in relation to the Hawthorn Group.

The discovery of phosphatic rock in Florida first occurred in the late 1870's near the town of Hawthorne in Alachua County (Day, 1886). By 1883, Dr. C.A. Simmons quarried and ground the phosphatic rocks for fertilizer (Sellards, 1910). During the 1880's phosphate was also discovered in central Florida.

Smith (1881) noted the phosphatic rocks exposed along the Suwannee River from the Okefenokee Swamp downstream and placed them in the Vicksburg Stage. Hawes (1882), in discussing the "phosphatic sandstones from Hawthorne," described them as containing sharks' teeth and bones belonging to the Tertiary Age. Smith (1885) and Johnson (1885) discussed the stratigraphy and occurrence of the phosphatic rocks of Florida. Johnson (1885) applied the name Fort Harlee marl to the phosphatic sediments at Waldo in Alachua County. He mentioned the occurrence of *Ostrea* and silicified corals within the sediments. Johnson also mentioned that those rocks are rather widespread in the state.

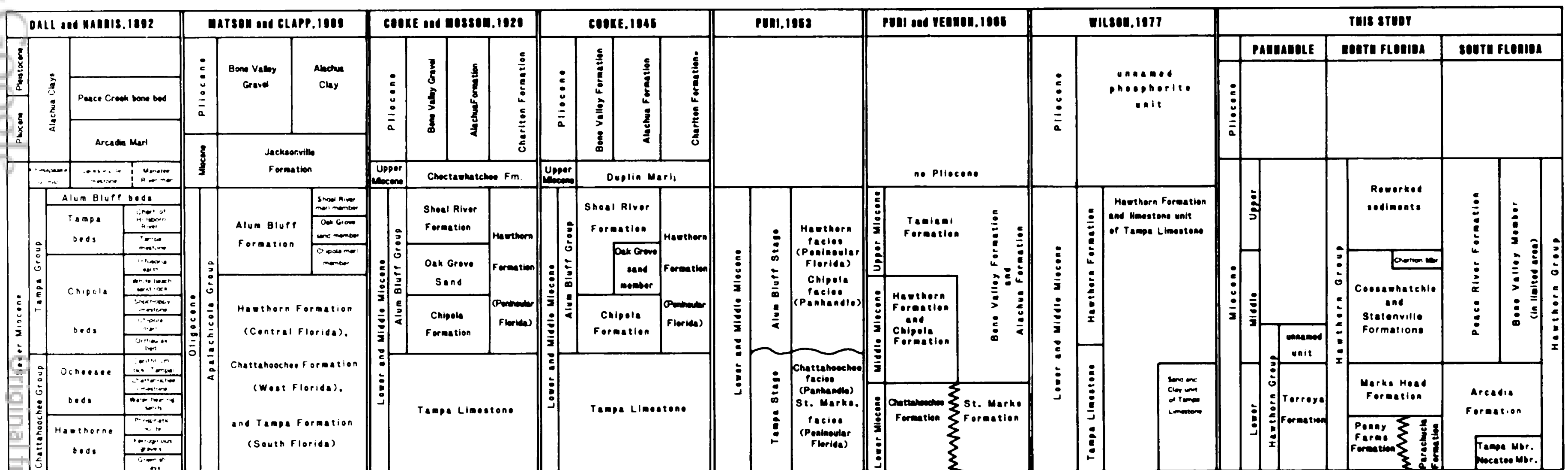


Table 1. Nomenclatural changes that have occurred in relation to the Hawthorn Group.

Smith (1885) examined samples sent to him by L.C. Johnson and thought the phosphatic limestone at Hawthorne was Eocene or Oligocene, as was the rest of the limestone in the peninsula. However, fossiliferous samples from the Waldo area indicated to Smith that the rocks were Miocene. He considered the rocks near Waldo to be the same as those exposed at Rock Springs in Orange County. Kost (1887), in the first report of the Florida Geological Survey, mentioned the recognition of phosphatic rocks in several locations throughout the state. Penrose (1888) briefly discussed the phosphatic sediments of Alachua County. Johnson (1888) named the Waldo Formation for the phosphatic sediments exposed in eastern Alachua County.

The first major contribution to the understanding of the Miocene phosphatic sediments of Flordia was published by Dall and Harris (1892). Relying upon unpublished data from L.C. Johnson and their own field information, Dall and Harris applied the name "Hawthorne beds" for the phosphatic sediments exposed and quarried near Hawthorne, Alachua County. They reproduced sections and descriptions obtained from Johnson. Dall and Harris placed the "Hawthorne beds" in the "newer" Miocene. Johnson's Waldo Formation was thought to be in the "older" Miocene although Dall and Harris state (p. 111), "Old Miocene phosphatic deposits - These rocks were among those referred by Johnson to his Waldo formation, though typical exposures at Waldo belong to the newer or Chesapeake Miocene." Dall and Harris placed the "Hawthorne beds" in their "Chattahoochee group" which overlies the Vicksburg Group and underlies the "Tampa group" (including their "Tampa limestone" which they felt was younger than the "Hawthorne beds").

The name "Jacksonville limestone" was applied by Dall and Harris (1892) to a "porous, slightly phosphatic, yellowish rock" first recognized by Smith (1885). They thought the "Jacksonville limestone" covered a large area from Duval County to at least Rock Springs in Orange County and included it in the "newer Miocene" above the "Hawthorne beds."

Dall and Harris (1892) examined the sediments in the phosphate mining area on the Peace River and referred to the phosphate-producing horizon as the "Peace Creek bone bed." Underlying the producing zone was a "yellowish sandy marl" containing phosphate grains and mollusk molds which they named the "Arcadia marl." Both units were considered to be Pliocene in age.

Dall and Harris also named the "Alachua clays" stating these clays "occur in sinks, gullies, and other depressions... ." They assigned the Alachua clays to the Pliocene based on vertebrate remains.

Matson and Clapp (1909) considered the Hawthorn to be Oligocene following Dall (1896) who began referring to the "older Miocene" as Oligocene. They considered the Hawthorn to be contemporaneous with the Chattahoochee Formation of west Florida and the Tampa Formation of south Florida. The Hawthorn was referred to as a formation rather than "beds" without formally making the change or designating a type section. Matson and Clapp placed the Hawthorn in their "Apalachicola group." Chert belonging to the "Suwannee limestone" was also included in the Hawthorn Formation at this time.

Matson and Clapp (1909) named the "Bone Valley gravel," replacing the "Peace Creek bone bed" of Dall and Harris (1892). They believed, as did Dall and Harris, that this unit was Pliocene. Matson and Clapp thought that the Bone Valley was predominantly of fluviatile origin and was derived from preexisting formations, especially the "Hawthorn formation." The Bone Valley gravels were believed to be younger than Dall and Harris' "Arcadia marl," older than the Caloosahatchee marl and in part contemporaneous with the "Alachua clays."

Veatch and Stephenson (1911) did not use the term "Hawthorn formation" in describing the sediments in Georgia. Instead the sediments were included in the "Alum Bluff formation" and described as strata lying between the top of the Chattahoochee formation and the base of the Miocene. Overlying their "Alum Bluff" sediments was an argillaceous sand that was in places a friable phosphatic sand which Veatch and Stephenson named the Marks Head marl. The Duplin marl, a coarse phosphatic sand with shells, overlies the Marks Head or the Alum Bluff when the Marks Head is absent.

Sellards (1910, 1913, 1914, 1915) discussed the lithology of the sediments associated with hard rock and pebble phosphate deposits. He presented a review of the origins of the phosphate and their relation to older formations. Sellards (1915) published the section exposed at Brooks Sink in a discussion of the incorporated pebble phosphates.

Matson and Sanford (1913) dropped the "e" from the end of Hawthorne (as Dall and Harris had used it). They state (p. 64), "The name of this formation is printed on the map as Hawthorne, the spelling used in some previously published reports, but as the geographic name from which it is derived is spelled Hawthorn, the final "e" has been dropped in the text." This began a debate of minor importance that continues to the present. Currently the Florida Geological Survey accepts the name without the "e."

Vaughan and Cooke (1914) established that the Hawthorn is not equivalent to or contemporaneous with, any part of the Chattahoochee Formation but is essentially equivalent to the "Alum Bluff formation." They suppressed the name Hawthorn and recommended the use of the name "Alum Bluff formation" and retained the Oligocene age.

Matson (1915) believed that the "Alum Bluff" (Hawthorn) phosphatic limestones formed the bed rock beneath the pebble phosphates of central Florida. This unit had previously been called the "Arcadia marl" (Dall and Harris, 1892). Matson added the sands of the "Big Scrub" in what is now the Ocala National Forest and the sands of the ridge west of Kissimmee (Lake Wales Ridge) to the "Alum Bluff formation." He thought also that the sequence of sediments called the "Jacksonville formation" (formerly the "Jacksonville limestone" of Dall and Harris, 1892) contained units equivalent to the "Alum Bluff formation." Matson thought that the "Bone Valley gravel" and "Alachua clays" were Miocene. He based this on the belief that the elevation of the "Bone Valley gravel" was too high to be Pliocene.

Sellards (1919) considered the "Alum Bluff" to be Miocene rather than Oligocene based on the vertebrate and invertebrate faunas. He stated (p. 294): "In the southern part of the state the deposits which are believed to represent the equivalent of the Alum Bluff formation are distinctly phosphatic." He felt that the deposits referred to the "Jacksonville formation" are lithologically similar to the "Alum Bluff" sediments as developed in south Florida and contain similar phosphatic pebbles. According to Sellards (1919), phosphate first appears in the Miocene "Alum Bluff" rocks, and the "Bone Valley gravels" and the "Alachua clays" represent the accumulation of reworked Miocene sediments.

Mossom (1925, p. 86) first referred the "Alum Bluff" to group status citing "The Alum Bluff is now considered by Miss Gardner as a group... ." Gardner did not publish this until 1926. Gardner (1926), in raising the Alum Bluff to a group, also raised the three members, Shoal River, Oak Grove, and Chipola, to formational status. Mossom (1926) felt the Chipola Formation was the most important and widespread subdivision of the group. He included the fuller's earth beds in north Florida and the phosphatic sands throughout the state in this formation. However, the phosphatic sands were generally referred simply to the Alum Bluff Group. Mossom also believed that the red, sandy clay sediments forming the hills in north Florida belonged in the Chipola Formation.

The Hawthorn Formation was reinstated by Cooke and Mossom (1929), since Gardner (1926) had raised the Alum Bluff to group status. Cooke and Mossom (1929) defined the Hawthorn Formation to include the original Hawthorn "beds" of Dall and Harris (1892) excluding the "*Cassidulus*-bearing limestones" and chert which Matson and Clapp (1909) had placed in the unit. Cooke and Mossom believed the "*Cassidulus*-bearing limestones" and the chert should be placed in the Tampa Limestone (which at that time included strata now assigned to the Suwannee Limestone). They included the "Jacksonville limestone" and the "Manatee River marl" (Dall and Harris, 1892) in the Hawthorn even though they felt the faunas may be slightly younger than typical Hawthorn. They also included Dall and Harris' "Sopchoppy limestone" in the Hawthorn. Cooke and Mossom felt that a white to cream-colored, sandy limestone with brown phosphate grains was the most persistent component of this unit.

Stringfield (1933) provided one of the first, although brief, descriptions of the Hawthorn Formation in central-southern Florida. He noted that the Hawthorn contained more limestone in the lower portion toward the southern part of his study area.

Cooke (1936) extended the Hawthorn Formation as far northeastward as Berkeley County, South Carolina. Cooke (1943, p. 90) states, "The Hawthorn Formation underlies an enormous area that stretches from near Arcadia, Florida, to the vicinity of Charleston, South Carolina." Cooke (1945) discussed the Hawthorn and its occurrence in Florida. The only change suggested by Cooke (1945, p. 192) was to tentatively include the Jacksonville Formation of Dall and Harris (1892) into the Duplin Marl rather than in the Hawthorn as Cooke and Mossom (1929) had done. Cooke (1945) also believed that the Apalachicola

River was the western boundary of the Hawthorn.

Parker and Cooke (1944) investigated the surface and shallow subsurface geology of southernmost Florida. The plates accompanying their report showed the Hawthorn Formation ranging from -10 feet MSL (-3 meters) to -120 feet MSL (-37 meters) overlain by the Tamiami Formation, Caloosahatchee Marl, and Buckingham Marl. Parker (1951) reassigned the upper sequence of Hawthorn sediments to the Tamiami Formation based on his belief that the fauna was Late Miocene rather than Middle Miocene. This significantly altered the concept of Mansfield's (1939) Tamiami Limestone and of the Hawthorn in southern Florida. Parker et al. (1955) continued this concept of the formations.

Cathcart (1950) and Cathcart and Davidson (1952) described the Hawthorn phosphates, their relationship to the enclosing sediments and the lithostratigraphy. Also mentioned is the variation in lithologies and thickness of the Hawthorn within the land pebble district. An excellent description of the Bone Valley Formation was presented by Cathcart (1950).

Vernon (1951) published a very informative discussion of the Miocene sediments and associated problems. Beyond providing data on the limited area of Citrus and Levy Counties, Vernon provided a proposed geologic history of Miocene events. He believed that the Alachua Formation was a terrestrial facies of the Hawthorn and also was, in part, younger than Hawthorn.

Puri (1953) in his study of the Flordia panhandle Miocene referred to the Middle Miocene as the Alum Bluff Stage. He considered the Hawthorn to be one of the four lithofacies of the Alum Bluff Stage.

Yon (1953) investigated the Hawthorn between Chattahoochee in the panhandle and Ellaville on the Suwannee River. Yon included in the Hawthorn the sand and clay unit that was later formally placed in the Miccosukee by Hendry and Yon (1967).

Bishop (1956), in a study of the groundwater and geology of Highlands County, Florida, concluded that the "Citronelle" sands which overlie the Hawthorn graded downward into the Hawthorn. He suggested that these sands be included in the Hawthorn as a non-marine, continental facies deposited as a delta to a large river which existed in Florida during the Miocene.

Pirkle (1956 a, 1956 b, 1957) discussed the sediments of the Hawthorn Formation from Alachua County, Florida. He considered the Hawthorn as a unit of highly variable marine sediments which locally contained important amounts of phosphate. He also regarded the sediments of the Alachua Formation as terrestrial reworked sediments ranging from Lower Miocene to Pleistocene. Later studies by Pirkle, Yoho, and Allen (1965) and Pirkle, Yoho, and Webb (1967) characterized the sediments of the Hawthorn and Bone Valley Formations.

The interest of the United States Geological Survey in the Hawthorn and Bone Valley Formations for their economic deposits of phosphate and related uranium concentrations resulted in a number of publications including Bergendal (1956), Espenshade (1958), Carr and Alverson (1959), Cathcart and McGreevy (1959), Ketner and McGreevy (1959), Cathcart (1963 a, b; 1964; 1966), Espenshade and Spencer (1963), and Altschuler, Cathcart, and Young (1964). With the exception of Espenshade (1958) and Espenshade and Spencer (1963), the studies investigated the strata in the Central Florida Phosphate District and adjacent areas. Espenshade (1958) and Espenshade and Spencer (1963) conducted investigations in north Florida.

Goodell and Yon (1960) provide a discussion of the lithostratigraphy of the post-Eocene rocks from much of the state. They provide a regional lithostratigraphic view of the Miocene sediments in Florida.

The occurrence of magnesian (Mg) rich clays (palygorskite) within the Hawthorn Formation has been investigated by several authors. McClellan (1964) studied the petrology and occurrence of the palygorskite (attapulgite). Gremillion (1965) investigated the origin of the clays. Ogden (1978) suggested depositional environments and the mode of formation of the clays.

Puri and Vernon (1964) summarized the geology of the Hawthorn. They discussed the status of the knowledge of the Hawthorn but added very little new information.

Brooks (1966, 1967) suggested that the Hawthorn should be raised to group status in the future. He further discussed the existence of the Hawthorn across the Ocala Uplift and its subsequent erosional removal. Brooks believed Middle Miocene strata were absent from the Ocala Uplift but were present downdip from the arch. He felt that Lower Miocene beds were present on the arch.

Sever, Cathcart, and Patterson (1967) investigated the phosphate resources and the associated stratigraphy of the Hawthorn Formation in northern Florida and southern Georgia.

Riggs (1967) suggested raising the Hawthorn Formation to group status based on his research in the phosphate district. The rocks of Riggs' "Hawthorn group" were related by containing greater than one percent phosphate grains. The Bone Valley Formation was included as the uppermost unit of the group. Riggs and Freas (1965) and Freas and Riggs (1968) also discussed the stratigraphy of the central Florida phosphate district and its relation to phosphorite genesis.

The geology and geochemistry of the northern peninsular Florida phosphate deposits were investigated by Williams (1971). Clark (1972) investigated the stratigraphy, genesis and economic potential of the phosphorites in the southern extension of the Central Florida Phosphate District.

Weaver and Beck (1977) published a wide ranging discussion of the Coastal Plain Miocene sediments in the southeast. Emphasis was placed on the depositional environments and the resulting sediments, particularly the clays.

Wilson (1977) mapped the Hawthorn and part of the Tampa together. He separated the upper Tampa, termed the Tampa Limestone unit, from the lower "sand and clay" unit of the Tampa Limestone.

Missimer (1978) discussed the Tamiami-Hawthorn contact in southwest Florida and the inherent problems with the current stratigraphic nomenclature. Peck et al. (1979) believed that the definition of the Tamiami by Parker et al. (1955) added to the previously existing stratigraphic problems. Hunter and Wise (1980 a, 1980 b) also addressed this problem suggesting a restriction and redefinition of the Tamiami Formation.

King and Wright (1979) in an effort to alleviate some of the stratigraphic problems associated with the Tampa and Hawthorn formations redefined the Tampa and erected a type section from a core at Ballast Point. Their redefinition restricted the Tampa to the quartz sandy carbonates with greater than 10 percent quartz sand and less than 1 percent phosphate grains. King (1979) presented a discussion of the previous investigations of the Tampa to which the reader is referred. The discussion is not repeated here.

Riggs (1979 a, 1979 b; 1980) described the phosphorites of the Hawthorn and their mode of deposition. Riggs (1979 a) suggested a model for phosphorite sedimentation in the Hawthorn of Florida.

Scott and MacGill (1981) discussed the Hawthorn Formation in the Central Florida Phosphate District and its southern extension. Scott (1983) provided a lithostratigraphic description of the Hawthorn in northeast Florida. Both studies were in cooperation with the United States Bureau of Mines.

T.M. Scott (1981) suggested the Hawthorn Formation had covered much of the Ocala Arch and was subsequently removed by erosion. Scott (1982) designated reference cores for the Hawthorn Formation and compared these to the reference localities previously designated. Scott's (1982) discussion was limited to the northeastern part of the state.

Cyclic sedimentation in the sediments of the Hawthorn was proposed by Missimer and Banks (1982). Their study suggested that reoccurring sediment groups occurred within the formation in Lee County. Also Missimer and Banks followed the suggestions of Hunter and Wise (1980 a, 1980 b) in restricting the definition of the Tamiami. This is also the case in Wedderburn et al. (1982).

Hall (1983) presented a description of the general geology and stratigraphy of the Hawthorn and adjacent sediments in the southern extension of the Central Florida Phosphate District. An excellent discussion of the stratigraphy and vertebrate paleontology of this area was provided by Webb and Crissinger (1983).

Silicification of the Miocene sediments in Florida has been the focus of a number of studies. Strom, Upchurch and Rosenweig (1981), Upchurch, Strom and Nuckles (1982), and McFadden, Upchurch, and Strom (1983) discussed the origin and occurrence of the opaline cherts in Florida. Related to the cherts are palygorskite clays that were also discussed in these papers and by Strom and Upchurch (1983, 1985).

There have been a number of theses completed on various aspects of the Hawthorn Group. These include McClellan (1962), Reynolds (1962), Isphording (1963), Mitchell (1965), Assefa (1969), Huang (1977), Liu (1978), King (1979), Reik (1980), Leroy (1981), Peacock (1981), and McFadden (1982).

Many water resource investigations include a section on the Hawthorn Formation but do not add new geologic or stratigraphic data. These are not included here.

GEOLOGIC STRUCTURE

The geologic structures of peninsular Florida have played an important role in the geologic history of the Hawthorn Group. These features affected the depositional environments and the post-depositional occurrence of the Hawthorn sediments. Due to the nature of the Tertiary sediments in peninsular Florida, it is difficult to ascertain a true structural origin for some of these features. Depositional and erosional processes may have played a role in their development.

The most prominent of the structures in peninsular Florida is the Ocala Platform (often referred to as Ocala Arch or Uplift) (Figure 4). The term platform rather than uplift or arch is preferred here since it does not have a structural connotation.

Originally named the Ocala Uplift by O.B. Hopkins in a 1920 U.S. Geological Survey press release, this feature was formally described by Vernon in 1951. Vernon described it as a gentle flexure developed in Tertiary sediments with a northwest-southeast trending crest. He believed that the crest of the platform has been flattened by faulting. Vernon (1951) dated the formation of the uplift as being Early Miocene based on the involvement of basal Miocene sediments in the faulting and the wedging out of younger Miocene sediments against the flanks of the platform. Cooke (1945) thought that warping began prior to the Late Eocene and continued into the Late Miocene or later. Ketner and McGreevy (1959) suggested that the platform formed prior to Late Miocene since undeformed beds of Late Miocene overlie warped beds of the Ocala Platform. Cooke (1945), Espenshade and Spencer (1963) and T.M. Scott (1981) believed that the Hawthorn once covered most or all of the Ocala Platform. Vernon (1951) believed the Platform was an island area throughout much of the Miocene and the Hawthorn sediments did not extend across the structure. Brooks (1966) believed the feature formed prior to the early Late Miocene. He also agrees with Pirkle (1956 b) that the Hawthorn once extended across the platform.

Riggs (1979 a, b) stated that the Ocala Upland (his term for the Ocala Platform) was a major structural feature controlling the formation and deposition of the phosphorites in the Florida Miocene.

The Sanford High is another important positive feature in the northern half of peninsular Florida (Figure 4). Vernon (1951) proposed the name for a feature located in Seminole and Volusia Counties, Florida. He describes the feature as "a closed fold that has been faulted, the Sanford High being located on the upthrown side." The Hawthorn Group and the Ocala Group are missing from the crest of the Sanford High. The Avon Park Formation lies immediately below post-Hawthorn sediments. The missing section presumably was removed by erosion. Meisburger and Field (1976), using high-resolution seismic reflection profiling, identified a structural high offshore from Daytona Beach in Volusia County and suggested that this feature may be an offshore extension of the Sanford High. Meisburger and Field believed that the seismic evidence indicated uplift that ended prior to Pliocene time. Vernon (1951) believed the feature to be a pre-Miocene structure. Riggs (1979 a, b) considered the Sanford High the "other positive element of extreme importance" in relation to phosphorite deposition.

Extending from the Sanford High are the St. Johns Platform to the north and the Brevard Platform to the south (Figure 4). Both are low, broad ridges or platforms expressed on the erosional surface of the Ocala Group. The St. Johns Platform plunges gently to the north-northwest towards the Jacksonville Basin. The Brevard Platform plunges gently to the south-southeast and southeast. The names of both features were introduced by Riggs (1979 a, b).

The Jacksonville Basin, located in northwest Florida, is the most prominent low in the northern half of the peninsula. In the deepest part of the basin the Hawthorn Group sediments exceed 500 feet (150 meters) in thickness. The name Jacksonville Basin was first used by Goodell and Yon (1960). Leve (1965) believed the basin was at least in part fault controlled.

Previously, many authors included the Jacksonville Basin in the Southeast Georgia Embayment. As more data became available it became apparent that an eastward dipping positive feature, informally named the Nassau Nose (Scott, 1983), separated the Jacksonville Basin from the rest of the Southeast Georgia Embayment. The Jacksonville Basin should still be considered as a subbasin of the larger embayment. The Southeast Georgia Embayment was named by Toulmin (1955) and appears to have been active from Middle Eocene through Miocene time (Herrick and Vorhis, 1963).

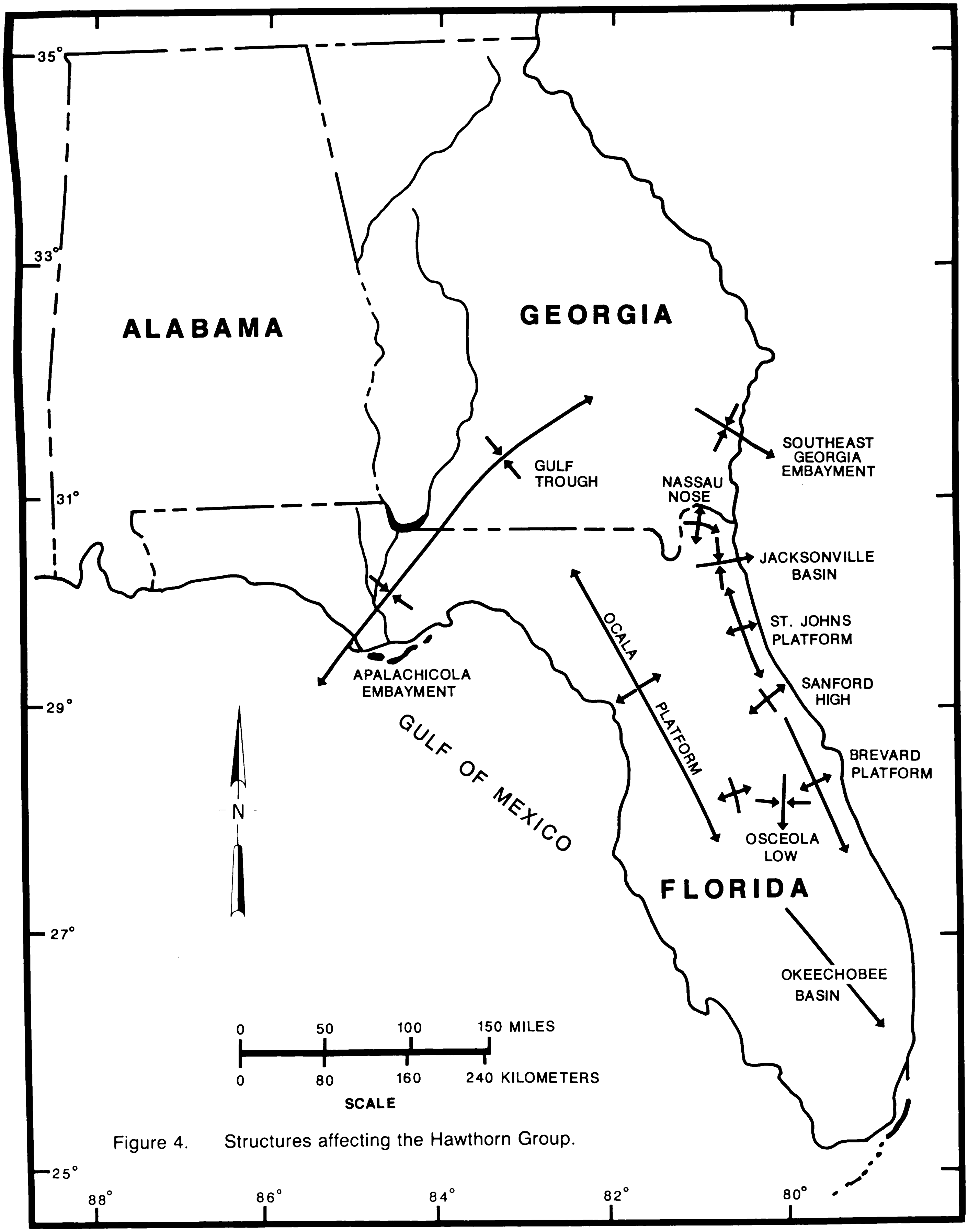


Figure 4. Structures affecting the Hawthorn Group.

The Gulf Trough or Channel extends from the Southeast Georgia Embayment to the Apalachicola Embayment (Figure 4). It is the Miocene expression of the older Suwannee Straits. The Suwannee Straits effectively separated the siliciclastic facies to the north from the carbonate facies to the south during the Early Cretaceous. The Gulf Trough was nearly full of sediments by the Late Oligocene and Early Miocene time, allowing increasing amounts of siliciclastic material to invade the carbonate environments of the peninsular area. Schmidt (1984) provided an excellent discussion of the history of both the Suwannee Strait and the Apalachicola Embayment.

In central peninsular Florida between the southern end of the Ocala Platform and the Brevard Platform are two important features in relation to the Hawthorn Group. The Osceola Low and the Kissimmee Faulted Flexture (Figure 4) were both named by Vernon (1951). Vernon considered the Kissimmee Faulted Flexure to be "a fault-bounded, tilted, and rotated block" with "many small folds, faults, and structural irregularities." His "flexure" is actually a high on the Avon Park surface with the Ocala and Hawthorn Groups absent over part of it due to erosion.

The Osceola Low, as described by Vernon (1951), is a fault-bounded low with as much as 350 feet (106 meters) of Miocene sediments. This author has investigated the Osceola Low using cores, well cuttings and geophysical data (Florida Geological Survey, unpublished data). The data does not indicate the presence of a discrete fault. They do suggest a possible flexure or perhaps a zone of displacement with "up" on the east, "down" on the west. This zone also appears to be the site of increased frequency of karst features developed in the Ocala Group limestone. Scott and Hajishafie (1980) indicated that the Osceola Low trends from north-south to northeast-southwest.

The Okeechobee Basin as named by Riggs (1979 a, 1979 b) encompasses most of southern Florida (Figure 4). It is an area where the strata generally gently dips to the south and southeast. Pressler (1947) referred to this area as the South Florida Embayment stating that its synclinal axis plunged towards the Gulf (to the southwest and/or west). Since this differs significantly from the Okeechobee Basin, the term Okeechobee Basin is preferred and utilized in this study. Within the basin there have been postulated episodes of faulting (Sproul et al., 1972) and folding (Missimer and Gardner, 1976).

INTRODUCTION TO LITHOSTRATIGRAPHY

The Hawthorn Group has long been considered a very complex unit. Puri and Vernon (1964) declared the Hawthorn "the most misunderstood formational unit in the southeastern United States." They further considered it as "a dumping ground for alluvial, terrestrial, marine, deltaic, and pro-deltaic beds of diverse lithologic units... ." Pirkle (1956b) found the dominant sediments to be quite variable stating, "The proportions of these materials vary from bed to bed and, in cases, even within a few feet both horizontally and vertically in individual strata."

HAWTHORN FORMATION TO GROUP STATUS: JUSTIFICATION, RECOGNITION AND SUBDIVISION IN FLORIDA

Formational status has been applied to the Hawthorn since Dall and Harris named the "Hawthorne beds" in 1892. As is evident from the Previous Investigations section, there has been much confusion concerning this unit. The complex nature of the Hawthorn caused many authors to suggest that the Hawthorn Formation should be raised to group status although none formally did so (Pirkle, 1956b; Espenshade and Spencer, 1963; Brooks, 1966, 1967; Riggs, 1967). The Hawthorn was referred to as a group in Georgia for several years on an informal basis until Huddlestun (in press) formalized the status change in the southeastern United States, recognizing its component formations in Georgia. The recognition of formations within the Hawthorn Group in Florida is warranted due to the lithologic complexity of the sediments previously referred to as the Hawthorn Formation. The extension of several Georgia units into Florida and the creation of new Florida units is based on the expectation that Huddlestun will validly publish the status change from formation to group. If he fails to do so, this text will be amended to validate the necessary changes in the proper manner according to the North American Code of Stratigraphic Nomenclature (1983).

An original type locality for the Hawthorn Group was not defined within the limits of our present stratigraphic code. However, it appears that Dall and Harris' (1892) intention was to use the old Simmons pits near Hawthorne in Alachua County as the type locality (holostratotype). The other sections referred to by Dall and Harris (1892) at Devil's Millhopper, Newnansville well, and White Springs were reference sections. The old Simmons pit is no longer accessible indicating the need for a new type locality (neostratotype). The Hawthorne #1 core W-11486, located in Alachua County drilled in the vicinity of the old Simmons pit should fill this gap. As such the Hawthorne #1 core is designated as a neostratotype or replacement (accessible) type section for the Hawthorn Group.

Although many authors have agreed that the Hawthorn deserves group status, questions remain. What should be included in the group and what should be the stratigraphic status of the units (i.e., formations with or without members)? The approach used in this study has been to identify lithostratigraphic units within the study area, determine their areal extent and thickness and, based on these findings, assign a formational status where appropriate. Having done that, as detailed subsequently in this report, the Hawthorn Formation of Florida is herein raised to group status. Its formations are described and type sections or cores are designated in accordance with the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature (NACSN), 1983). Utilizing the group concept will enable geologists to better understand the framework of the Miocene sediments in Florida and much of the southeastern Coastal Plain.

The sediments placed in the Hawthorn Group are related by the occurrence of phosphate, a palygorskite-sepiolite-smectite clay mineral suite and the mixed carbonate-siliciclastic nature of the entire sequence. Color, particularly in the siliciclastic portions, is often distinctive in the sediments of this group. In some regions and in specific intervals, lithologic heterogeneity provides a diagnostic trait of the Hawthorn Group.

The component formations of the Hawthorn Group vary from region to region within the State. The variation is the result of the depositional and environmental controls exerted on the Hawthorn sediments by features such as the Ocala Platform, the Sanford High, the St. Johns Platform, and the Brevard Platform. The variation in component formations of a group is discussed in and accepted by the North American Commission on Stratigraphic Nomenclature (Article 28b, North American Stratigraphic Code, 1983).

The name Hawthorn is retained for the group since the group represents a series of units that had been recognized as the Hawthorn Formation. Only a few changes (additions) are proposed in this report that alter the overall boundaries of the former Hawthorn Formation. Due to its wide use and acceptance, dropping the term Hawthorn and providing a new group name would cause unnecessary confusion.

Once the lithostratigraphic units were determined, names were selected for the respective sections. These are listed in Table 1 along with reference to the original author. When possible, names currently in use, or proposed in a bordering State (Georgia), were used in Florida. Examples of these are the Marks Head, Coosawhatchie and Statenville Formations currently recommended for use in Georgia (Huddlestun, in press). Where a sediment package exhibited significant variation in Florida from the equivalent unit in Georgia, a new name is proposed (i.e., the Penney Farms Formation).

In the eastern panhandle the name Torreya Formation is used since it is already in the literature (Banks and Hunter, 1973; Huddlestun and Hunter, 1982; Hunter and Huddlestun, 1982; Huddlestun, in press) and there is insufficient evidence to suggest any changes. Future research, however, may suggest further changes.

The names of the formational units of the Hawthorn Group in southern Florida were selected based on historical perspective and current usage. The name Arcadia Formation is reintroduced for the Hawthorn carbonate unit. The use of Arcadia is similar to the use suggested by Riggs (1967). Two members are named in the Arcadia, the Tampa Member and the Nocatee Member. These members do not comprise the entire Arcadia but only represent the lower Arcadia where they are identifiable.

The Tampa Member represents a reduction in status for the Tampa from formation to member. Since this reduction represents only a minor alteration of the Tampa definition and since the name Tampa is widely used and recognized, a new name is not suggested for this member. The most prominent reasons for reducing the Tampa to member status is the limited area of recognition and its lithologic affinities with the rest of the Arcadia Formation of the Hawthorn Group.

A new name, the Peace River Formation, is proposed for the upper Hawthorn siliciclastic section, including the Bone Valley Formation of former usage. The Bone Valley Formation is reduced to member status and the name is retained for the same reasons discussed for the Tampa Member. There has been some discussion and disagreement concerning including the entire Bone Valley in the Hawthorn Group due to the presence of a major, Late Miocene unconformity. This unconformity separates the upper gravel bed of the Bone Valley from the remainder of the unit and often is recognizable only on a biostratigraphic basis using vertebrate faunas. The unconformity is generally not recognized on a lithostratigraphic basis. The North American Stratigraphic Code (NACSN, 1983) recognizes this problem. Article 23d states "...a sequence of similar rocks may include an obscure unconformity so that separation into two units may be desirable but impractical. If no lithic distinction adequate to define a widely recognizable boundary can be made, only one unit should be recognized, even though it may include rock that accumulated in different epochs, periods or eras (NACSN, 1983)."

The formations of the Hawthorn Group are similar yet different in northern and southern Florida and in the eastern panhandle. Also, within southern Florida, the group varies from east to west. As a result the discussion of the Hawthorn will be presented separately for northern and southern Florida and the eastern Florida panhandle (Figure 1).

PRESENT OCCURRENCE

The Hawthorn Group underlies much of peninsular Florida (Figures 5 and 6). It is absent from most of the Ocala Platform and Sanford High due to erosion. Outliers of Hawthorn sediments and residuum occur scattered along the platform in lows and in some karst features. The Hawthorn Group sediments are also absent from part of Vernon's (1951) Kissimmee Faulted Flexure in Osceola County presumably due to erosion.

The Hawthorn Group dips gently away from the Ocala Platform and Sanford High at generally less than 6 feet per mile (1.1 meters per kilometer) (Figure 5). In north Florida, the Hawthorn dips generally to the east and northeast towards the Jacksonville Basin and the east coast. Locally the dip may become greater and may reverse in some areas. This is due to postdepositional movement related to karst activity, subsidence, possible faulting, and tilting of the platform. Scott (1983) indicated this on structure maps of the Ocala Group (p. 29) and the Hawthorn Formation (p. 32).

In central and south Florida the Hawthorn Group dips gently to the south and southeast with local variations (Figure 5). Generally, further south in the state the dip is more southeasterly. The strata dip to the west and southwest along the western edge of the state from Pasco County south to Lee County.

The Hawthorn Group ranges in thickness from a feather edge along the positive features to greater than 500 feet (160 meters) in the Jacksonville Basin and greater than 700 feet (210 meters) in the Okeechobee Basin (Figures 4 and 6). The Hawthorn generally thickens to the northeast in north Florida toward the Jacksonville Basin and southward into the Okeechobee Basin (Figure 6).

NORTH FLORIDA

INTRODUCTION

The Hawthorn Group in Florida, north of Orange County and west through Hamilton County, has distinct affinities to the Hawthorn in Georgia. The sediments of the upper two-thirds of the group are very similar to those in Georgia, facilitating the use of the same terminology in both states. The basal one-third of the group changes significantly into Florida and, therefore, a new formational name is proposed.

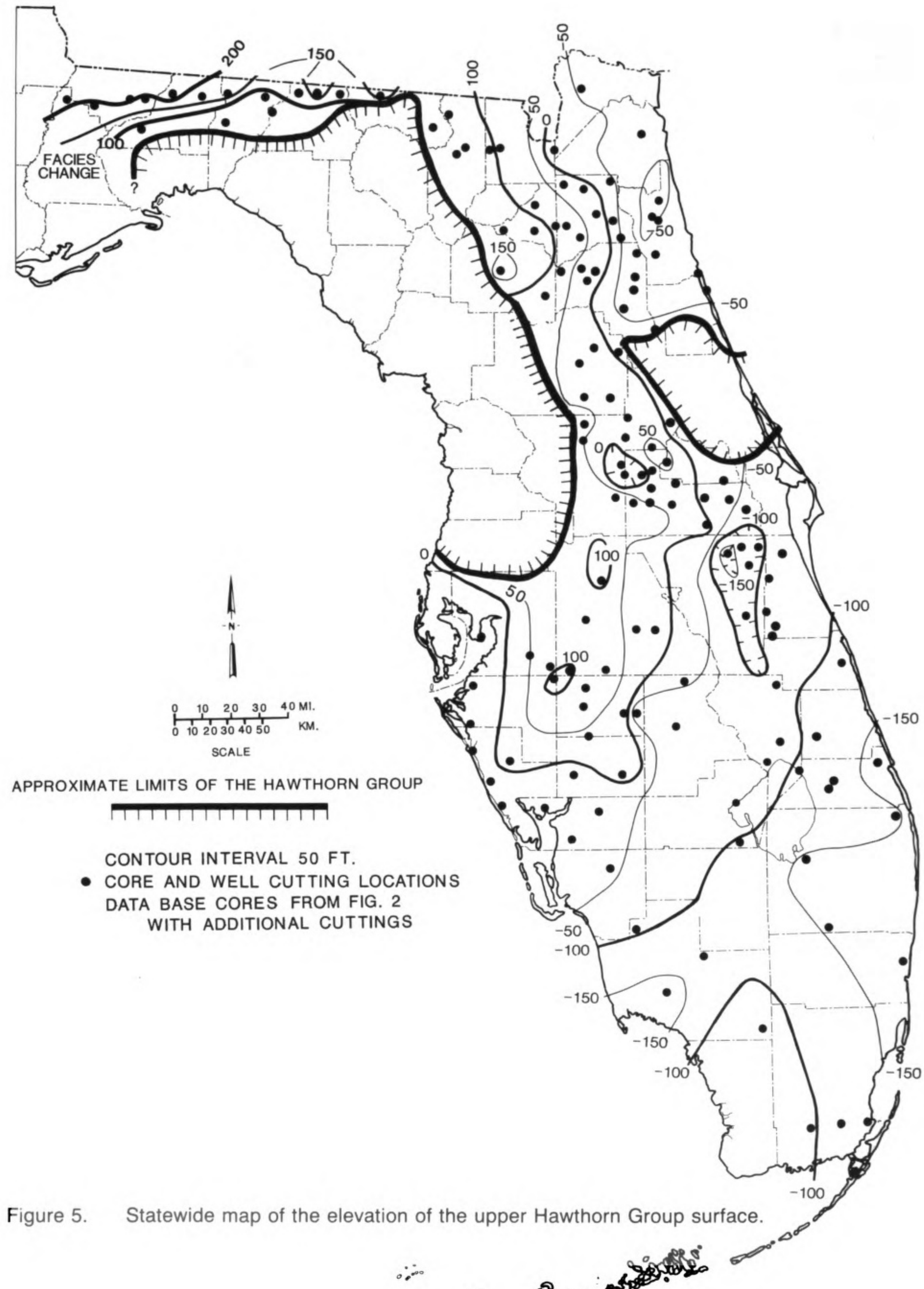


Figure 5. Statewide map of the elevation of the upper Hawthorn Group surface.

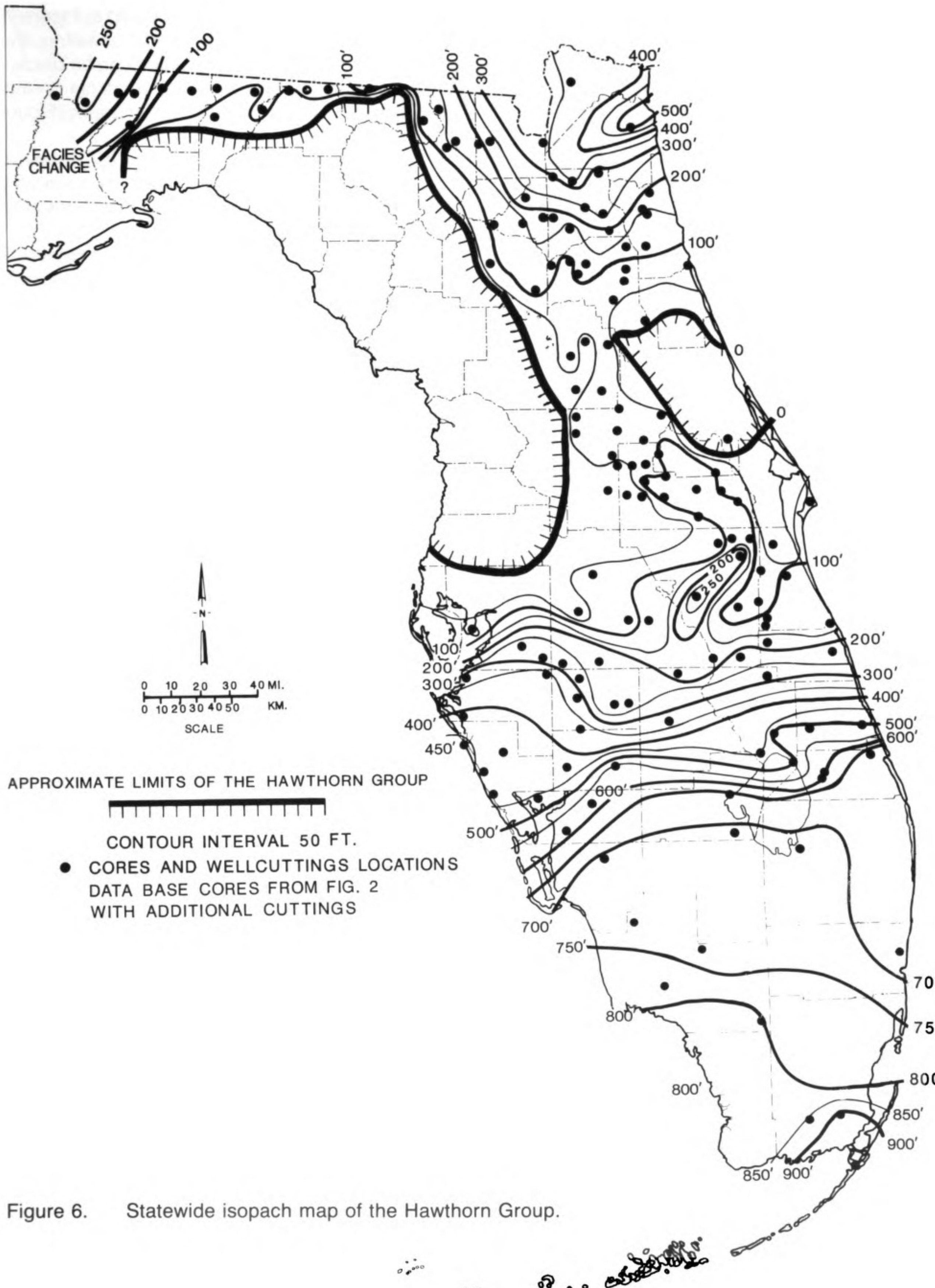


Figure 6. Statewide isopach map of the Hawthorn Group.

The Hawthorn Group in north Florida can be subdivided into four formations as indicated in Figure 7. From oldest to youngest, these are the Penney Farms Formation, the Marks Head Formation, the Coosawhatchie Formation, and the Statenville Formation. The Penney Farms Formation can be divided into two informal members referred to simply as upper and lower members. The Coosawhatchie Formation also has upper and lower informal members and the Charlton Member (Huddlestun, in press) (Figure 7).

The formational breakdown of the Hawthorn Group in north Florida is recognizable in cores. However, due to the highly variable nature of the north Florida Hawthorn sediments, the individual units are very difficult to identify in well cuttings. Therefore it is recommended that when using well cuttings in this area these sediments simply be referred to as Hawthorn Group undifferentiated.

The sediments of the Hawthorn Group are significantly different west of the crest of the Ocala Platform (west of Hamilton County). These units will be discussed separately from those east of the crest in north Florida.

The Hawthorn Group in north Florida shows significant variation when traced into central Florida. In the area between the Sanford High and the Ocala Platform, the Hawthorn is thinned both depositionally and erosionally (Figure 6). Within this zone the upper part of the group changes character, such that it is difficult to correlate with the formations to the north. The basal unit of the group carries through this area, and is apparent in east central Florida where it grades into the lower part of the Arcadia Formation of southern Florida.

Throughout most of the north Florida region the Hawthorn Group unconformably overlies the Upper Eocene Ocala Group (Figure 8). The Crystal River Formation of the Ocala Group underlies the Hawthorn in most of the area where the Ocala Group occurs. However, in areas peripheral to the Sanford High and in portions of the transition zone, the Hawthorn overlies the lower Ocala Group (Williston Formation). The author has not encountered any instances of the Hawthorn overlying the Avon Park Formation when the Ocala Group is absent since the Hawthorn Group is also absent in these cases (Sanford High, for instance). The sediments of the subjacent Ocala Group are typically cream to white, foraminiferal grainstone to wackestone, containing no quartz sand. The limestones are often recrystallized just below the contact with the Hawthorn Group. This contrast of lithologies with the basal Hawthorn Group is generally dramatic, resulting in little confusion in identifying the contact.

The Suwannee Limestone of Oligocene age unconformably underlies the Hawthorn Group on the northeastern-most portion of the Ocala Platform in Hamilton and Columbia Counties. Typically, the Suwannee is a granular, microfossiliferous, cream, white, to very pale orange grainstone to wackestone. It is sometimes recrystallized below the contact with the Hawthorn and rarely may be a dolostone. The lithologic differences between the basal Hawthorn Group sediments and the Suwannee Limestone are quite distinctive; confusion concerning the contact is unlikely.

The St. Marks Formation of Early Miocene age underlies the Hawthorn in an extremely limited area in the western half of Hamilton County. The St. Marks occurs sporadically and generally is less than 30 feet (9 meters) thick (Colton, 1978). Lithologically, the St. Marks is a quartz sandy, silty, sometimes clayey limestone (wackestone to mudstone). Occasionally, it may be dolomitized. The lithology of this unit is similar to the basal Hawthorn sediments except for the lack of phosphate grains in the St. Marks. The St. Marks lithology may occur within the basal Hawthorn carbonates, creating possible confusion concerning the contact. Although the contact is unconformable, it is often not apparent. As a result, the top of the St. Marks is placed below the last occurence of phosphatic sediments. This datum is traceable from western Hamilton County westward into the eastern panhandle in Madison, Jefferson, and Leon Counties.

PENNEY FARMS FORMATION

Definition and Type Locality

The Penney Farms Formation is a new lithostratigraphic name proposed here for the predominantly subsurface basal unit of the Hawthorn Group in north and central Florida. It is named after the town of

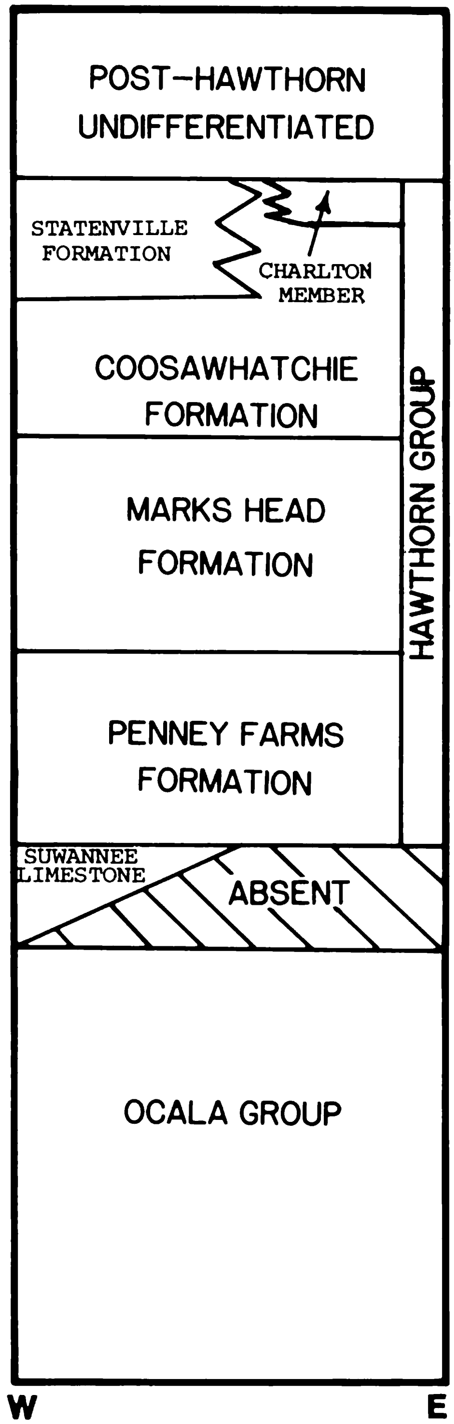


Figure 7. Lithostratigraphic units of the Hawthorn Group in north Florida.

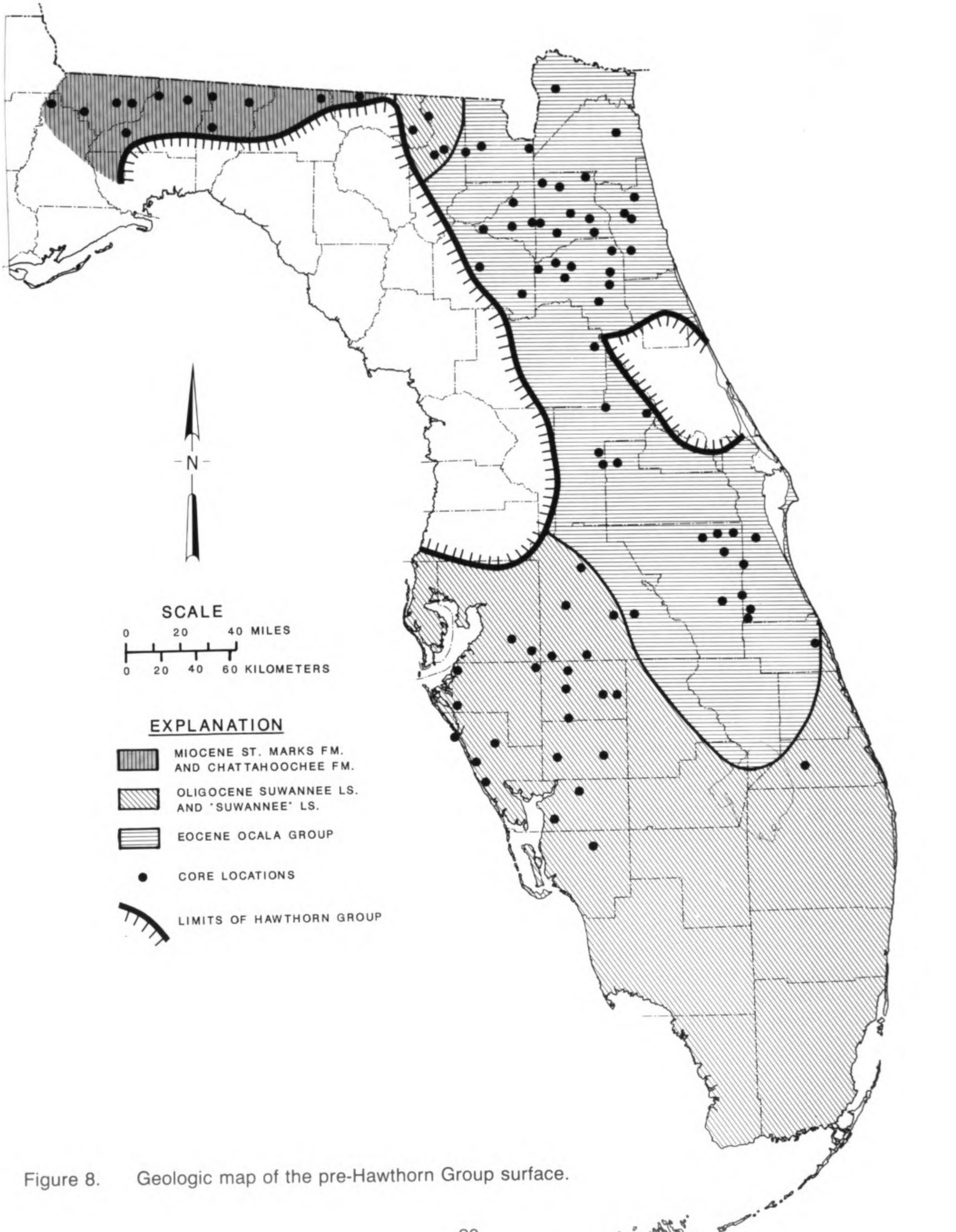


Figure 8. Geologic map of the pre-Hawthorn Group surface.

Penney Farms in central Clay County, Florida. The type core, W-13769 Harris #1, is located near Penney Farms (SW¼, SE¼, Section 7, Township 6S, Range 25E) with a surface elevation of 97 feet (30 meters). The type core was drilled by the Florida Geological Survey in December 1977 and is permanently stored in the Survey's core library. The type Penney Farms Formation occurs between -118 feet MSL (-36 meters) and -205 feet MSL (-63 meters) (Figure 9).

Lithology

The Penney Farms Formation consists of two informal, unnamed members which are distinguished from each other based on the abundance of carbonate beds. Figure 9 graphically shows the variable nature of this formation and its general two member framework. Each member consists of lithologies similar to the other but the proportions of the lithologies are dissimilar. In the lower member, carbonates predominate with sands and clays interbedded in varying proportions. The upper member is a predominantly siliciclastic unit with interbedded carbonate beds. The interbedded sands and clays of the lower member generally increase in abundance upward in the section causing the contact with the upper member to be gradational in nature. The top of the lower member is placed where carbonate beds become dominant over the siliciclastic beds. The North American Code of Stratigraphic Nomenclature (NACSN, 1983) (Article 23) allows for this arbitrary placement of a boundary in a gradational sequence. Occasionally, the siliciclastic beds are abundant enough in the lower member to obscure the contact altogether thus the separation of the informal members within the Penney Farms Formation is not always possible.

The carbonates are variably quartz sandy, phosphatic, clayey dolostones. Sand content is variable to the point that the sediment may become a dolomitic sand. Phosphate grains may be present in amounts greater than 25 percent with an average of approximately 5 to 10 percent. Clay percentages are generally minor (below 5 percent) but often increase in the dolostones of the upper member. The dolostones are medium gray (N5) to pale yellowish brown (10 YR 6/2). They are generally moderately to well indurated and finely to coarsely crystalline in the lower member. The dolostones of the upper member are generally less indurated. Thicker, more massive beds predominate in the lower unit while thinner beds are most common in the upper section. Mollusk molds are common in the dolostones, particularly in the more coarsely crystalline type.

Zones of intraclasts are common in the hard, finer grained dolostones of the lower part of the Penney Farms. The intraclasts are composed of dolomite that is essentially the same as the enclosing matrix. The intraclasts are recognizable due to a rim of phosphate replacement along the edges of the clasts (Figure 10). Edges of the clasts vary from angular to subrounded indicating very little to no transport of the fragments. They also may be bored, indicating at least a semi-lithified state prior to being redeposited.

Limestone, in the basal portion of the Penney Farms Formation, occurs sporadically. When it does occur, it is generally dolomitic, quartz sandy and phosphatic.

The quartz sands are fine to coarse grained, moderately to poorly sorted, variably phosphatic, dolomitic, silty and clayey. The phosphate grain content varies considerably, sometimes to the point of being classified as phosphorite sand (50 percent or greater phosphate grains). In general, however, the phosphate grain content averages between 5 and 10 percent. The sands are typically olive gray (5 Y 3/2) or grayish olive (10 Y 4/2) to medium light gray (N 6). Clay content varies considerably in the sands.

Clay beds in the Penney Farms Formation are typically quartz sandy, phosphatic, silty and dolomitic. The proportions of the accessory minerals vary from nearly zero to more than 50 percent. Nearly pure clay beds are uncommon. Dolomite is very common in the clays, often being the most abundant accessory mineral. Olive gray (5 Y 3/2) and grayish olive green (5 GY 3/2) colors generally predominate, but colors may range into the lighter shades. Smectite typically dominates the clay mineralogy of this unit with palygorskite, illite and sepiolite also present. X-ray analyses by Hettrick and Friddell (1984) indicate that palygorskite may become predominant over smectite in some samples. Reik (1982) indicated that palygorskite dominates in the lower part of the Penney Farms while smectite dominates in the upper por-

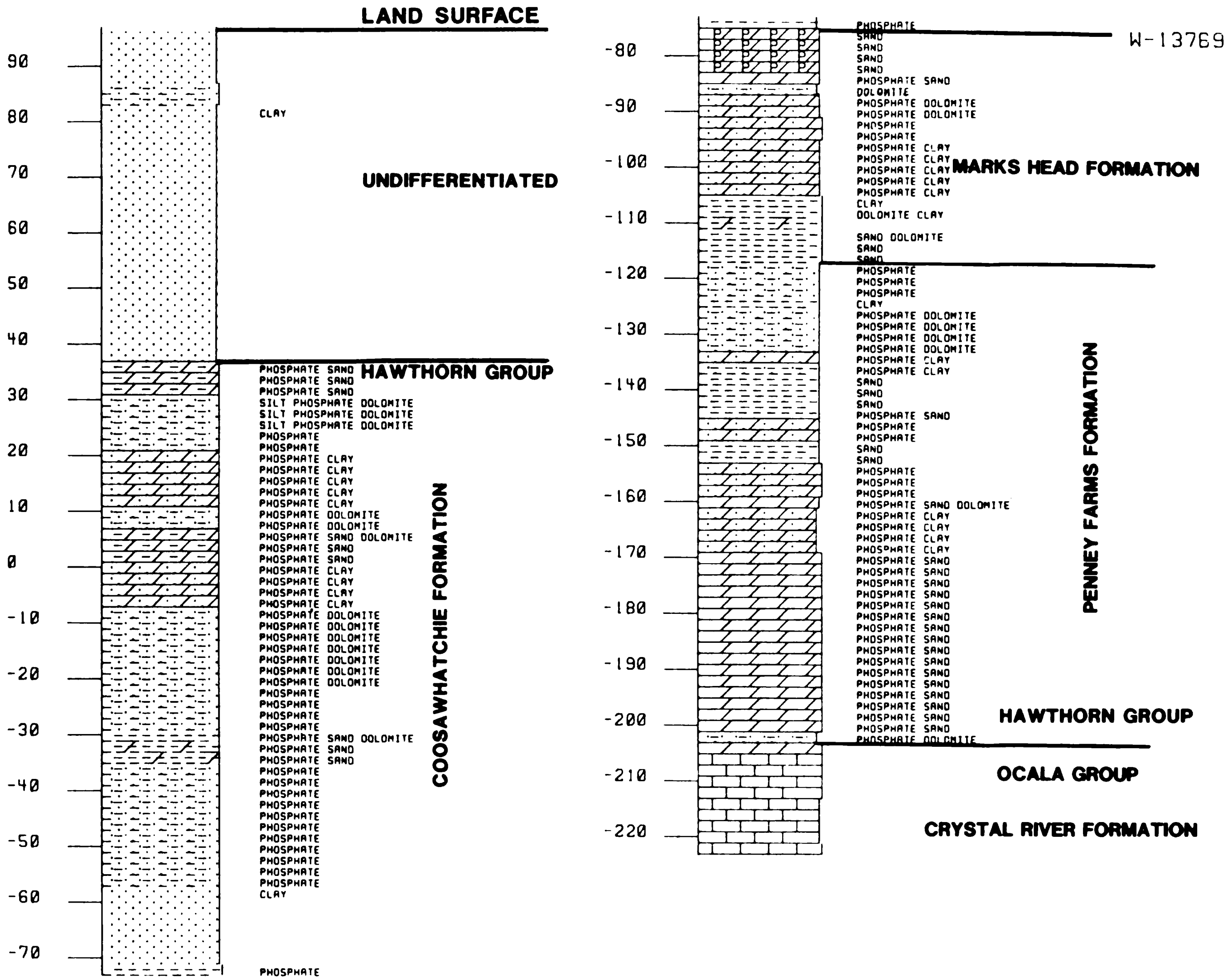


Figure 9. Type section of the Penney Farms Formation, Harris #1, W-13769, Clay County (Lithologic legend Appendix A).

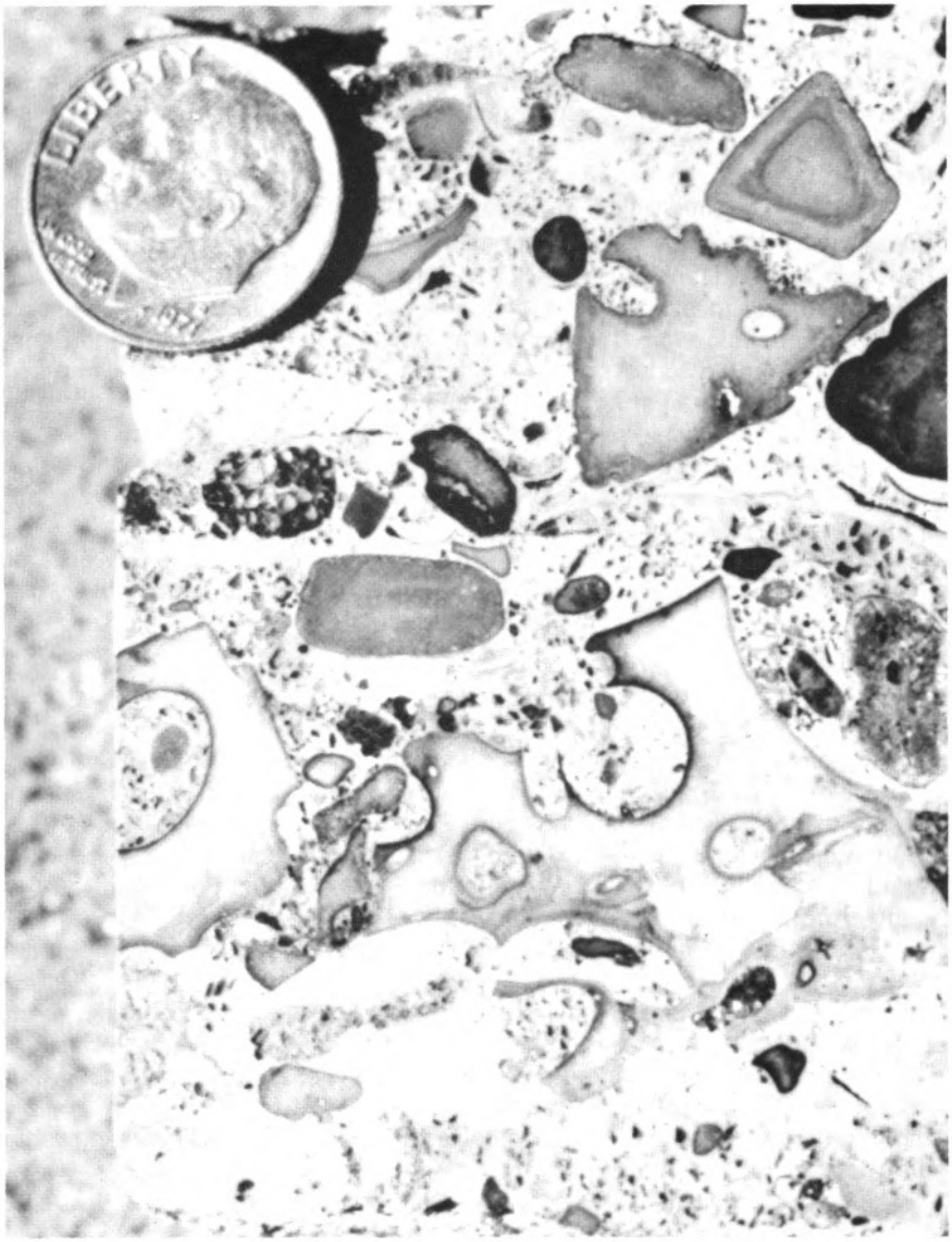


Figure 10. Intraclasts with phosphatic rims from Penney Farms Formation, St. Johns County, W-13844.

tion in Clay County. Other minor mineralogic constituents include mica, K-feldspar and opal ct. Clinoptilolite has been identified in a few samples (Huddlestun, in press).

When abundant silt-sized, unconsolidated dolomite occurs, difficulty arises in determining whether the actual rock type is a very dolomitic clay or a very clayey dolostone. Insoluble residue analysis is the only accurate method of determining the clay and dolostone contents. Rough analysis indicates that, in general, the lighter the color of the sediment, the higher the dolomite content. This method was employed for determining the sediment type in these situations.

The siliciclastic beds of the Penney Farms Formation are lithologically very similar to those in the Parachucla Formation in southeastern Georgia (Huddlestun, in press). As the Penney Farms Formation begins to lose its carbonate units northward and northwestward into Georgia, the characteristic lithologies are no longer apparent and the formation can no longer be identified as the Penney Farms. These sediments in Georgia are included in the Parachucla Formation (Huddlestun, in press).

Southward into central Florida, the Penney Farms contains more carbonate than in the type area. Between the Sanford High and the Ocala Platform in portions of Lake and western Orange Counties, the percentage of siliciclastic beds decreases to the point that the separation of upper and lower members becomes unfeasible. The carbonates in this area contain coarser sand and a noticeably coarser phosphate grain fraction.

Further to the east, in Orange County, and southward into eastern Osceola and Brevard Counties, the basal Hawthorn Group consists predominantly of dolostone. This basal unit is tentatively placed in the Arcadia Formation until further investigations can be conducted.

Subjacent and Suprajacent Units

The Penney Farms Formation unconformably overlies limestones of the Eocene Ocala Group or the Oligocene Suwannee Limestone. Figure 8 indicates the areas in which each occurs. The unconformity is very apparent due to the drastically different lithologies. Previous discussion of the base of the Hawthorn Group in north Florida descibes the lithologic differences in greater detail.

The Marks Head Formation unconformably overlies the Penney Farms Formation throughout north Florida except in those areas where it has been removed by erosion. In areas where the Marks Head has been eroded, the Penney Farms is overlain by sands and clays classified as undifferentiated post-Hawthorn deposits.

The top of the Penney Farms is placed at the break between the lighter colored sediments of the Marks Head and the darker colored sands and clays of the upper part of the Penney Farms. Occasionally, a rubble zone marks the break between the Marks Head and the Penney Farms Formations. When it occurs, the rubble consists of clasts of phosphatized carbonate.

The relationship of the Penney Farms Formation and to the underlying and overlying sediments is illustrated in Figures 11 through 16.

Thickness and Areal Extent

The Penney Farms Formation of the Hawthorn Group occurs primarily as a subsurface unit. The top of the Penney Farms Formation ranges in cores from -333 feet MSL (-101 meters) in Carter #1, W-14619, Duval County to +80 feet MSL (24.3 meters) in Devils Millhopper #1, W-14641, Alachua County (Figure 17). Limited data from one outcrop in Marion County (Martin-Anthony roadcut, NE¼, NE¼, NE¼, Sec. 12, Township 14S, Range 21E) indicates the sediments assigned to the Penney Farms occur at +140 to +150 feet MSL (43 to 46 meters). This is the only recognized occurrence of the basal Hawthorn Group at elevations this high.

The Penney Farms Formation dips in a general northeasterly direction from the flanks of the Ocala Platform toward the Jacksonville Basin with an average dip of 4 feet per mile (0.8 meters per kilometer). The direction of dip of the Penney Farms trends toward the north into the Jacksonville Basin from the St. Johns Platform (Figure 17). Locally, both the direction and angle of dip may vary.

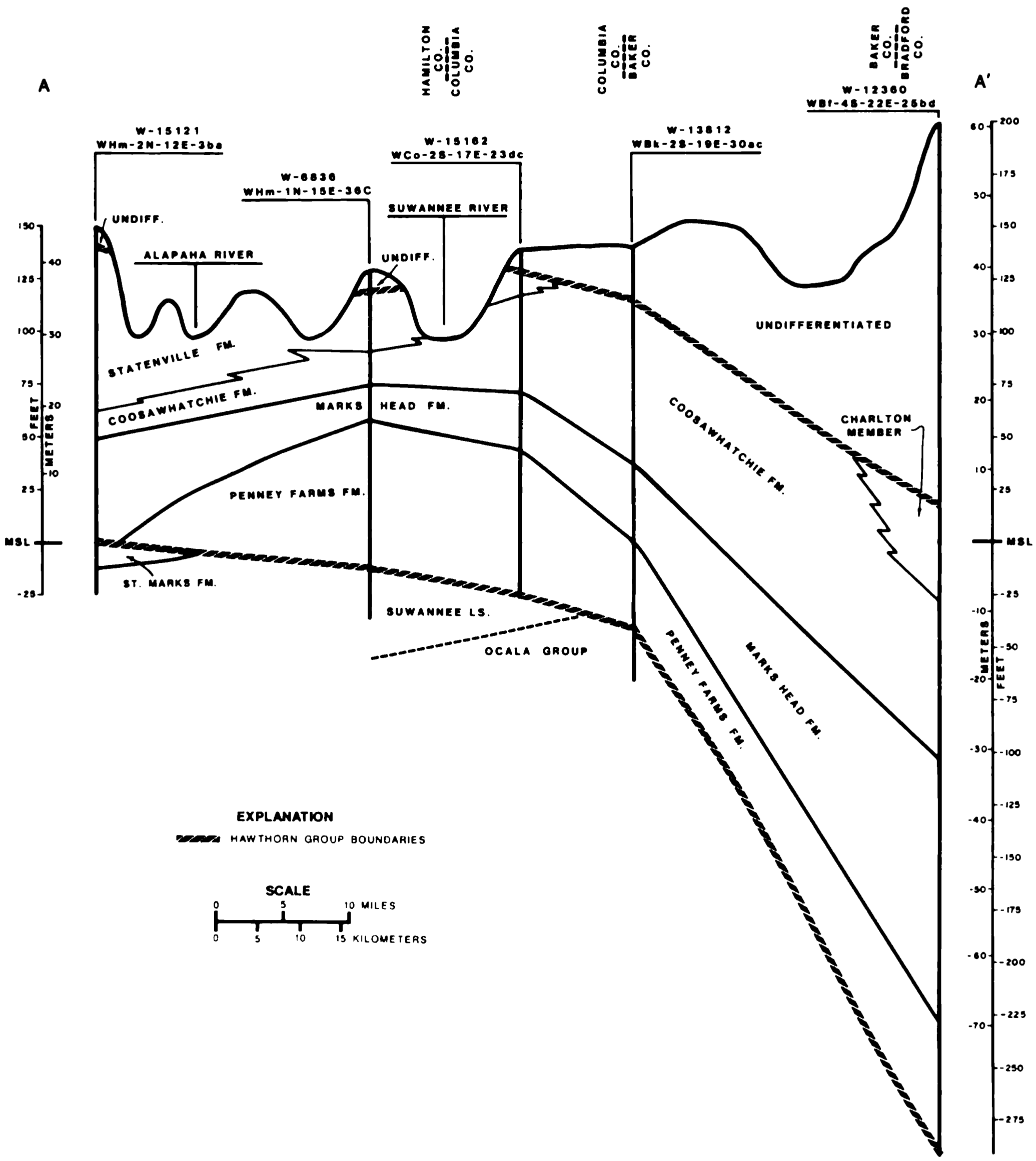


Figure 11. Cross section A-A' (see figure 3 for location) (See Scott (1983) for discussion of faults).

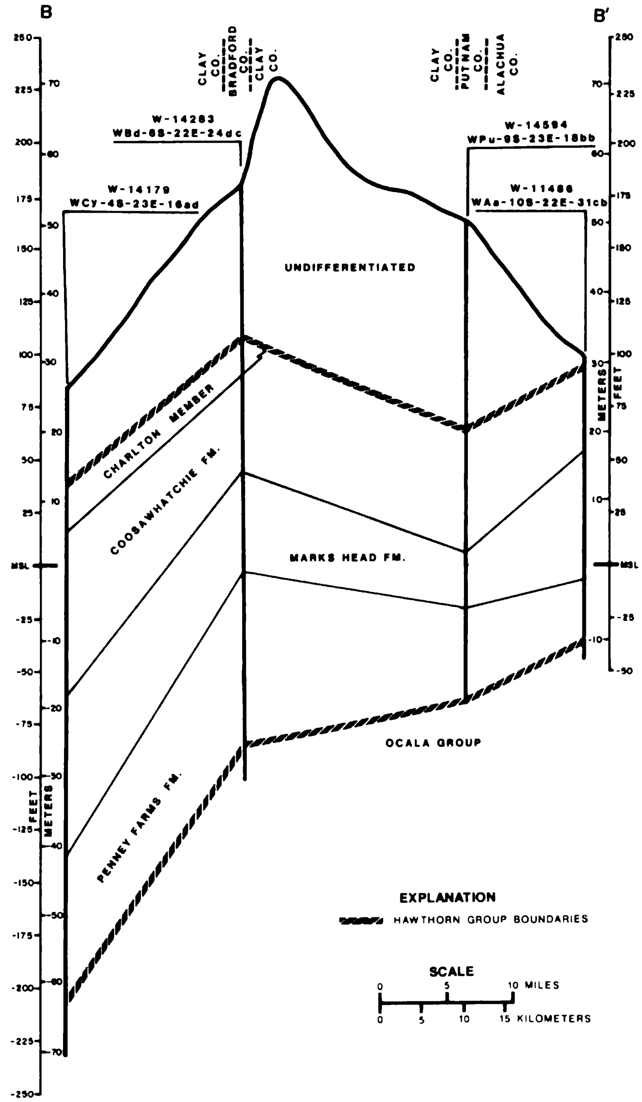


Figure 12. Cross section B-B' (see figure 3 for location) (See Scott (1983) for discussion of faults).

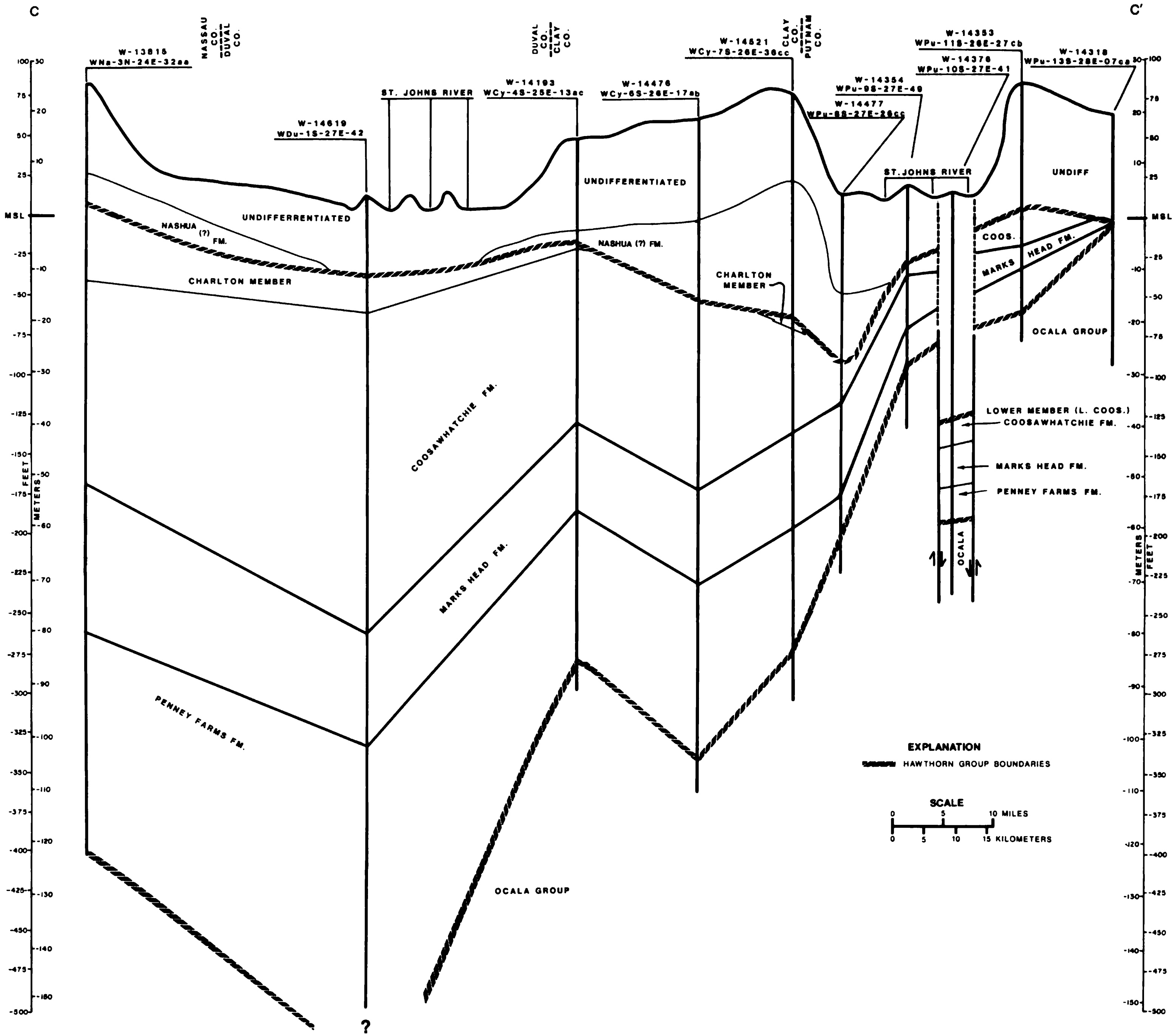


Figure 13. Cross section C-C' (see figure 3 for location) (See Scott (1983) for discussion of faults).

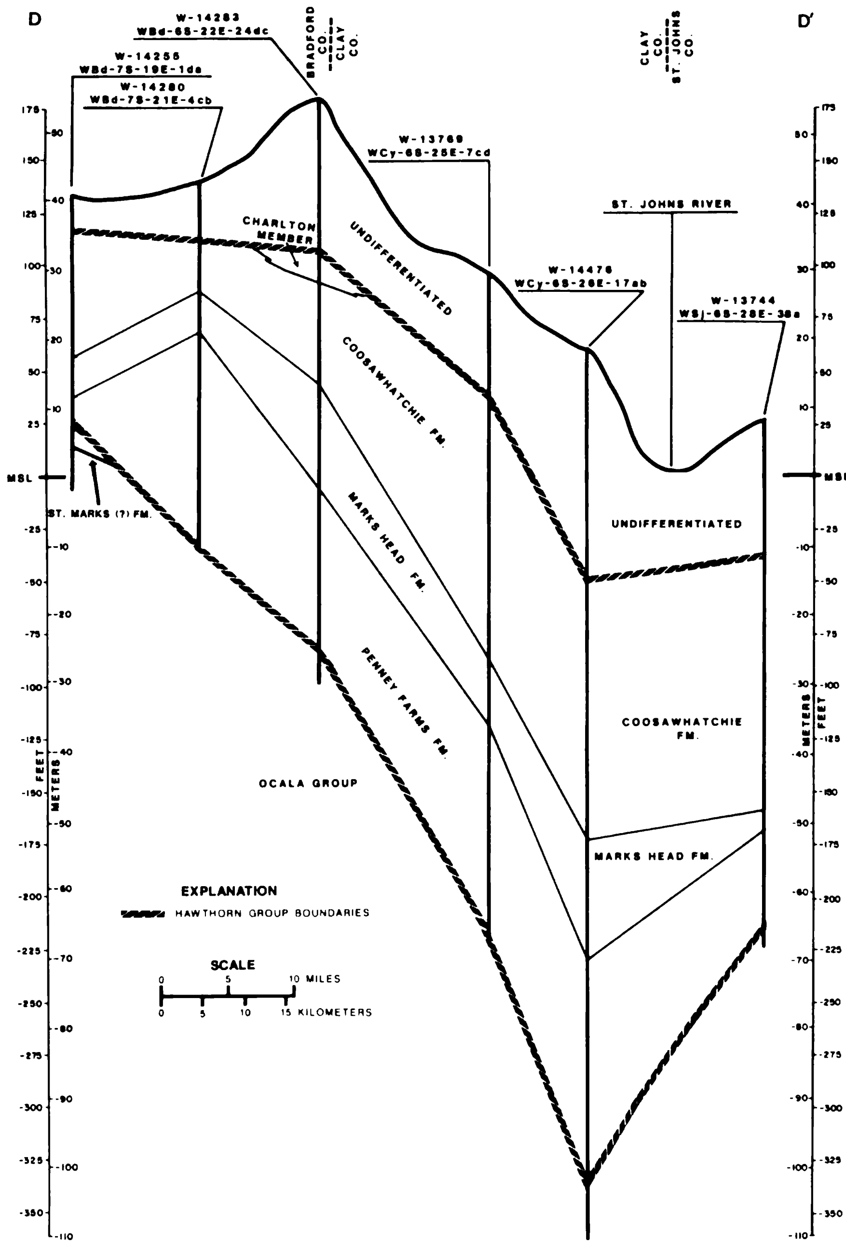


Figure 14. Cross section D-D' (see figure 3 for location) (See Scott (1983) for discussion of faults).

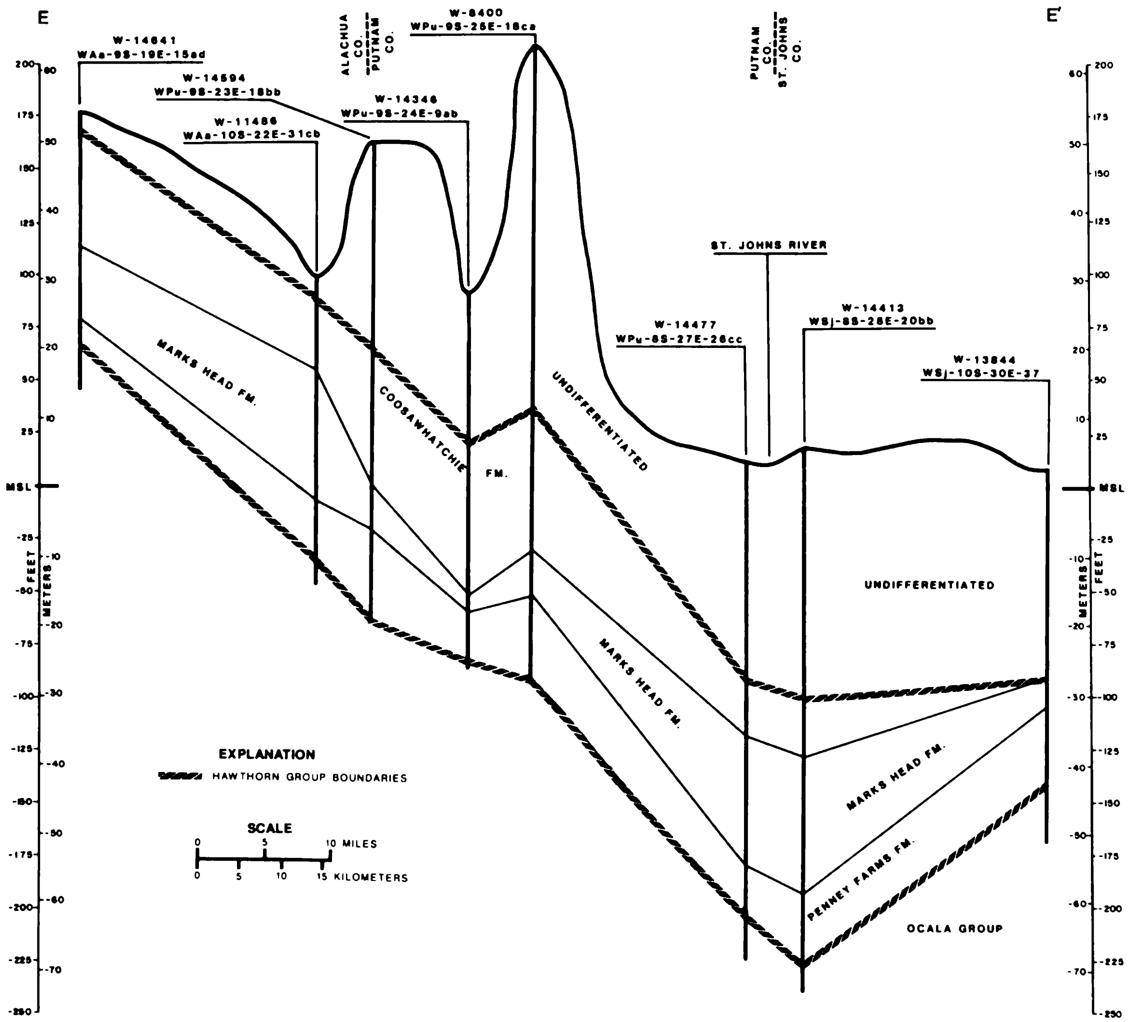


Figure 15. Cross section E-E' (see figure 3 for location) (See Scott (1983) for discussion of faults).

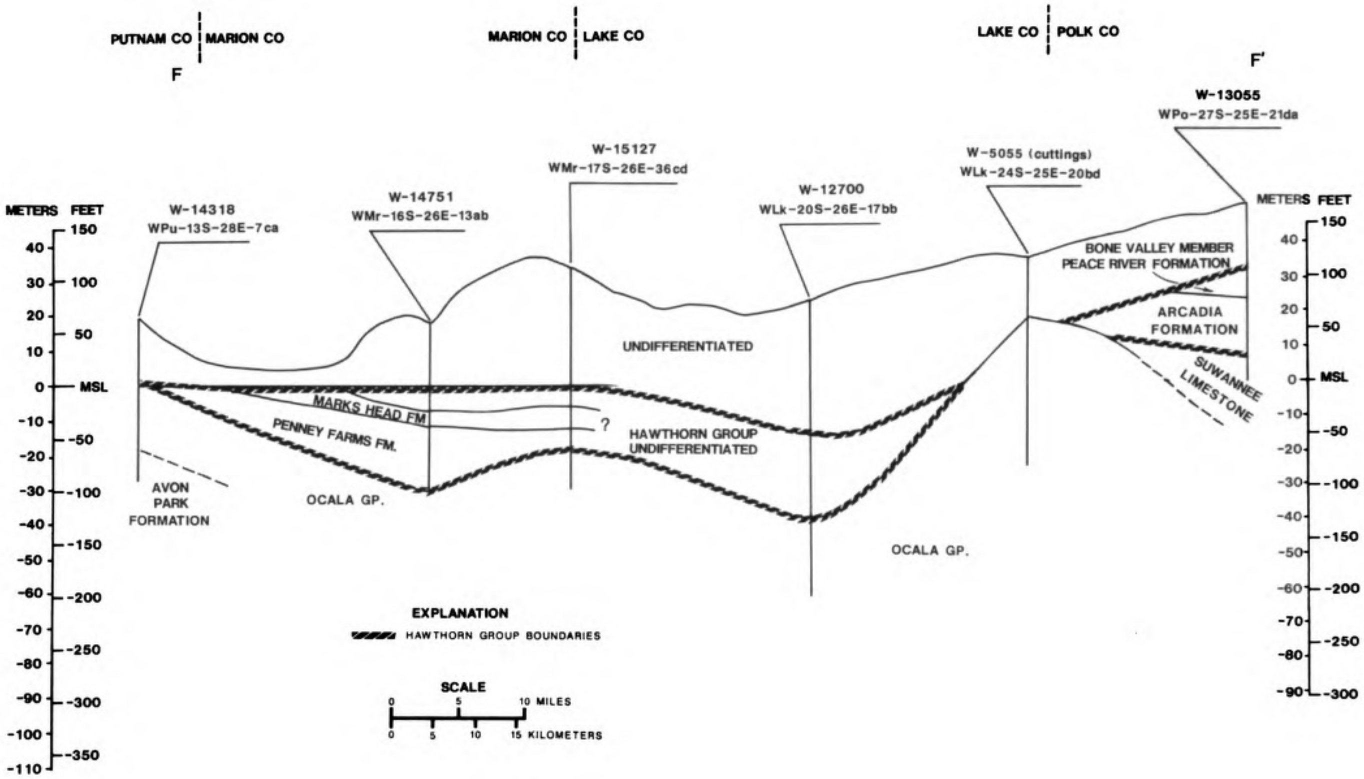


Figure 16. Cross section F-F' (see figure 3 for location) (See Scott (1983) for discussion of faults).

The Penney Farms Formation varies in thickness from being absent on the crests of the Ocala Platform and Sanford High to more than 155 feet (47 meters) in Carter #1, W-14619, Duval County in the Jacksonville Basin (Figure 18). The total thickness of this unit was not determined in this core as the core terminated in the Penney Farms Formation after penetrating 155 feet (47 meters). This author estimates that the base of the Penney Farms should occur near -575 feet (-175 meters) MSL based on nearby water wells. This suggests that approximately 230 feet (70 meters) of the unit should be present in the deepest portion of the Jacksonville Basin. The informal upper member attains its maximum observed thickness of 88 feet (27 meters) in Cassidy #1, W-13815, Nassau County. Seventy-five feet (23 meters) of the lower informal member were penetrated in W-14619. This author estimates that approximately 150 feet (46 meters) of this member should be present based on previously discussed criteria.

The Penney Farms Formation of the Hawthorn Group occurs throughout much of north and central Florida. It is absent from the crest of the Ocala Platform and the Sanford High due to erosion and nondeposition. The Penney Farms Formation thins on the St. Johns Platform and is absent from the highest part of the structure, the area where the Sanford High and the St. Johns Platform merge (Figure 4).

Age and Correlation

The Hawthorn Group sediments of northern Florida have yielded very few dateable fossils or fossil assemblages. Diagenetic overprinting on the sediments has obliterated the vast majority of fossils leaving mainly molds and casts. Diatom and mollusk molds are the most frequently encountered fossil remains.

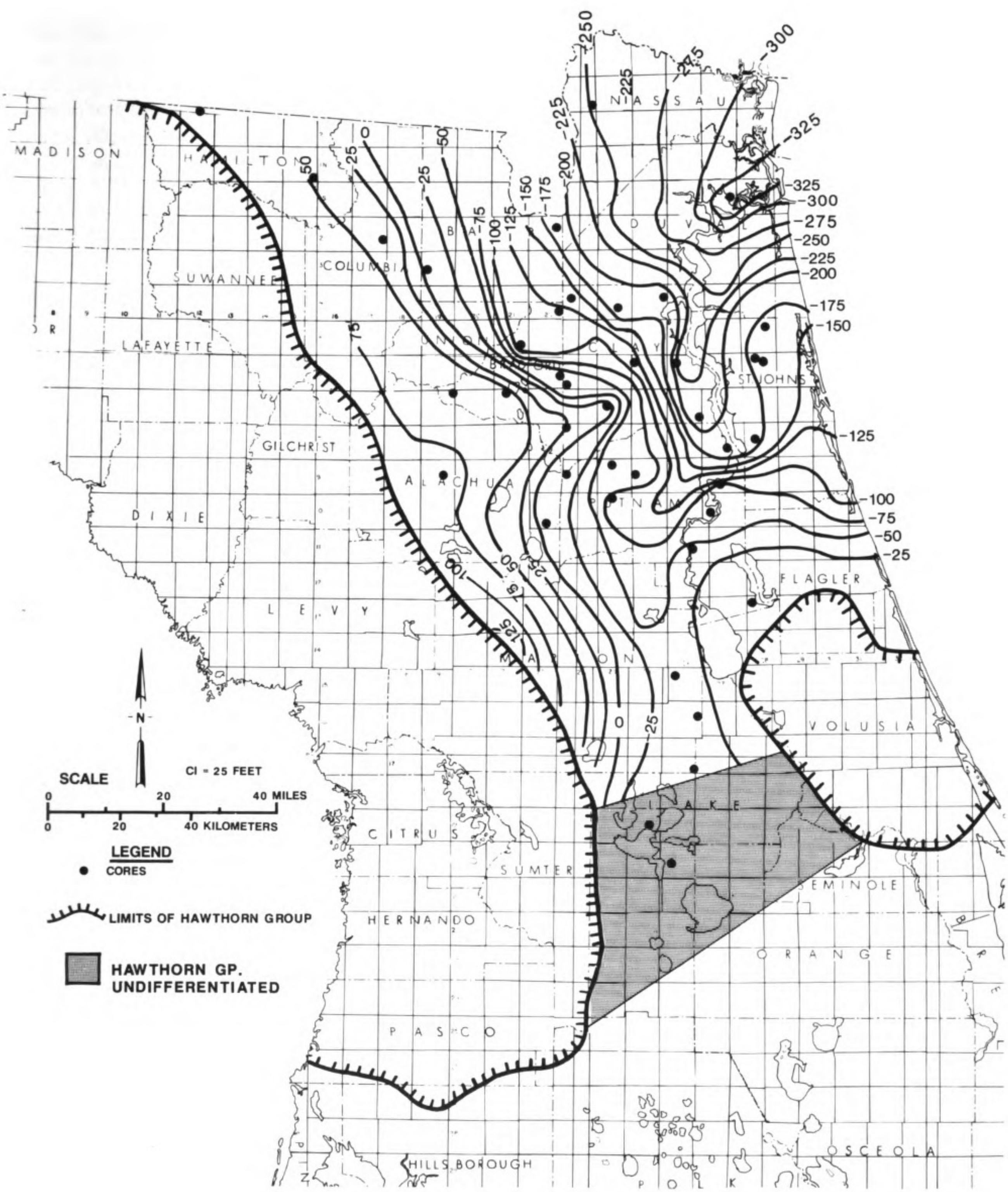


Figure 17. Top of Penney Farms Formation. Shaded area indicates undifferentiated Hawthorn Group.

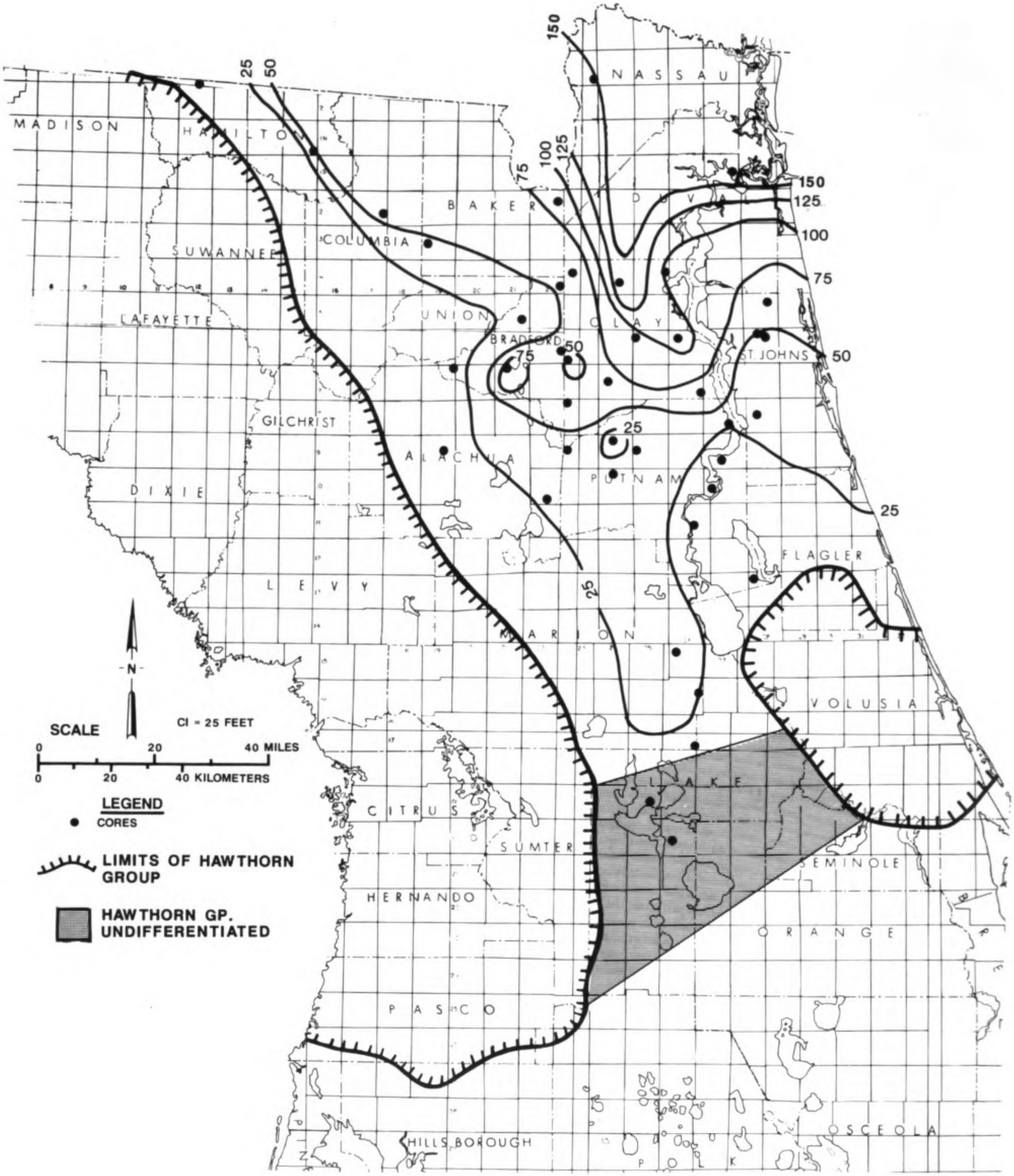


Figure 18. Isopach of Penney Farms Formation. Shaded area indicates undifferentiated Hawthorn Group.

At the present time, dateable fossils from the Penney Farms Formation have been obtained from only two sites. The first is from the Cassidy #1 core, W-13815, Nassau County in the interval from -450 to -455 feet LSD (-137 to -138.7 meters LSD). The sediment, a calcareous, quartz sandy clay, contained benthic and planktonic foraminifera, ostracods, spicules (sponge?), echinoid fragments and bryozoans. The planktonic foraminifera indicate an Aquitanian age upper Zone N.4 or lower N.5 of Blow (1969) for this interval (Huddlestun, personal communications, 1983).

The second site encompasses the Martin-Anthony roadcut in north central Marion County (NE¼, NE¼, NE¼, of Section 12, Township 14S, Range 21E). An oreodont jaw collected from the hard carbonates exposed in the roadcut was dated as Late Arikareen (equates to Early to Middle Aquitanian) (MacFadden, 1982).

The few ages obtained in north Florida correlate well with dates obtained by Huddlestun (personal communication, 1983) in the Hawthorn Group of Georgia. The age suggested for the Penney Farms Formation correlates with the age of the upper part of the Parachucla Formation in Georgia (Figure 19). Lithologically, the Penney Farms Formation grades laterally into the Parachucla Formation through a transition zone north of the Jacksonville Basin. These ages indicate that the basal portion of the Penney Farms Formation is slightly older (1-2 million years) than the base of the Pungo River Formation in the Miocene of North Carolina as indicated by Gibson (1982) and Riggs (1984).

The type Penney Farms appears to be equivalent to at least part of the Tampa Member of the Arcadia Formation (as described in this report). Based on Huddlestun's (in press) suggestion that the Parachucla Formation correlates with the Chattahoochee Formation of western Florida and southwest Georgia, the Penney Farms Formation is also equivalent to part of the Chattahoochee Formation (Figure 19). The Penney Farms appears to equate with Miller's (1978) unit E from the Osceola National Forest.

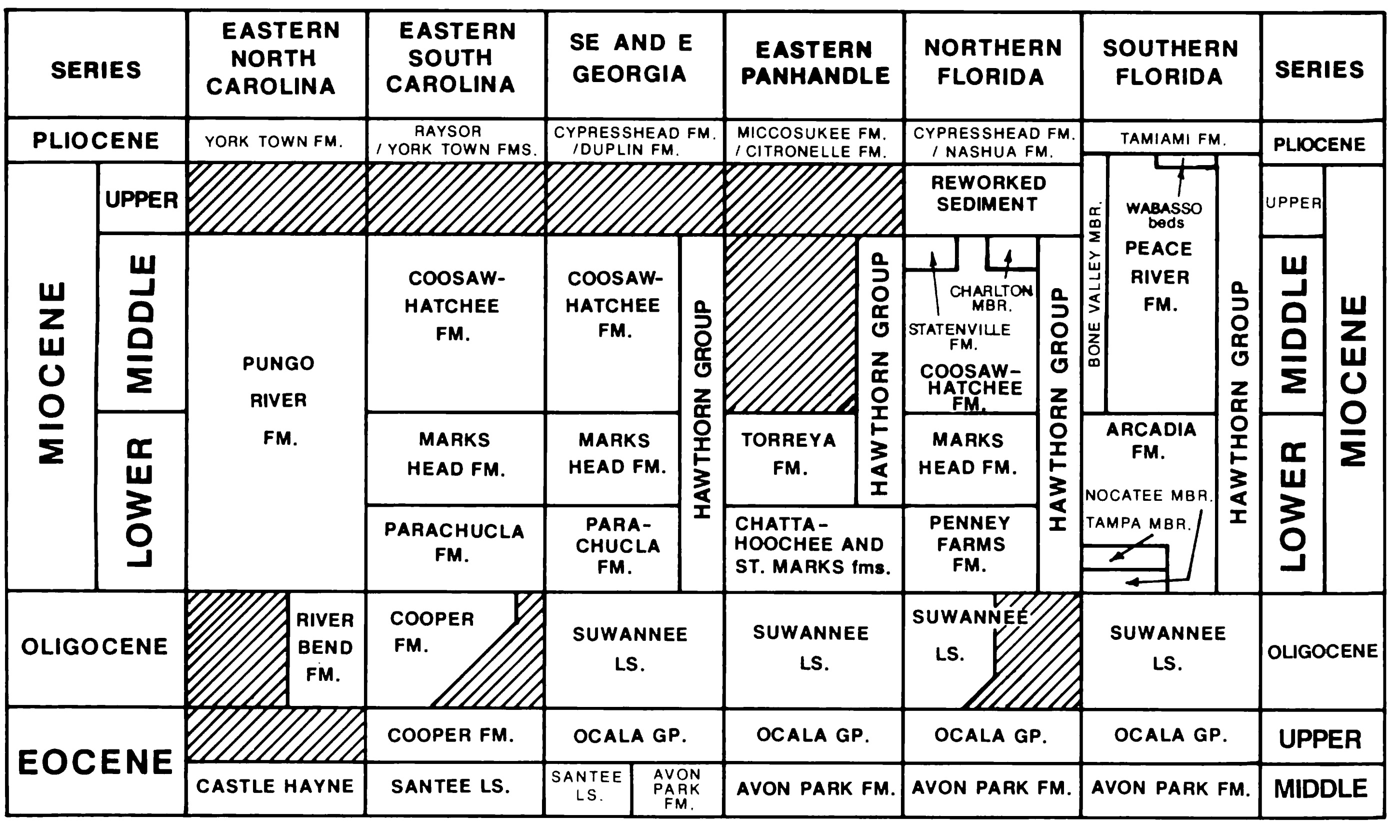


Figure 19. Formational correlations (modified from unpublished C.O.S.U.N.A. Chart, 1985).

The Penney Farms Formation of the Hawthorn Group is older than the commonly accepted age for the Hawthorn Formation as described by Puri and Vernon (1964). This age, Middle Miocene, was accepted for the Hawthorn Formation by the Florida Geologic Survey for sometime. The data presented here indicate this should be revised (see Figure 19). Armstrong et al. (1985) have even suggested a latest Oligocene age for the base of the Hawthorn in southeastern Florida.

Discussion

As stated previously, the Penney Farms Formation in northern Florida is equivalent to the Parachucla Formation in southeastern Georgia. The Penney Farms represents a southern extension of the Parachucla siliciclastics, but contains a significant amount of dolostone which is not present in the Parachucla. The two units are laterally gradational with each other. Within the gradational sequence the lateral boundary between the units is arbitrarily placed where carbonate becomes an important lithologic factor. This boundary usually occurs just north of the state line in Georgia; however, the Parachucla occurs in northernmost Nassau County, Florida. The Penney Farms Formation also grades laterally, to the south, into undifferentiated Hawthorn Group.

The carbonate section of the Penney Farms Formation has often been referred to as the basal Hawthorn dolostone in northern Florida. It is lithologically distinctive enough to be recognizable in well cuttings, even in relatively poor quality cuttings. The gamma-ray signature also is quite distinctive, consisting of a number of very high counts per second (cps) peaks (see section on gamma-ray logs).

The full areal extent of the Penney Farms deposition on the Ocala Platform is not presently known. The occurrence of sediments assigned to this unit at the Martin-Anthony road cut in Marion County (elevation 140 to 150 feet [43-46 meters] above MSL) suggest deposition on a significant portion of the platform.

MARKS HEAD FORMATION

Definition and Reference Section

Huddlestun (in press) reintroduced the Marks Head Formation as part of the Hawthorn Group in Georgia. The Marks Head Formation is extended here to encompass the middle unit of the Hawthorn Group in north Florida. The lithologic similarities between the Marks Head Formation in southeast Georgia and in north Florida warrants the use of the same nomenclature.

Huddlestun (in press) describes the type locality of the Marks Head Formation in Georgia from outcrops at and near Porters Landing in northern Effingham County, Georgia. The reader is referred to Huddlestun (in press) for descriptions of these localities and for a historical summary of the Marks Head Formation in Georgia.

The proposed reference section for the Marks Head Formation in Florida lies between -89 feet (-29 meters) MSL and -190 feet (-58 meters) MSL in the Jennings #1 core, W-14219, Clay County, Florida (SE¼, SE¼, Section 27, Township 4S, Range 24E) (Figure 20). The land surface elevation is 90 feet (27 meters) MSL.

Lithology

The Marks Head Formation in Florida consists of interbedded sands, clays and dolostones throughout its extent. Carbonate beds are more common in the Marks Head Formation in Florida than in Georgia; the proportion of carbonate, both as a rock type and an accessory (matrix) mineral, gradually increases into Florida. This unit is the most lithologically variable formation of the Hawthorn Group in north Florida. Miller (1978) defined his Unit D (equivalent to the Marks Head Formation) as being "complexly interbedded shell limestone, clay, clayey sand and fine grained sandstone." The variable nature of the Marks

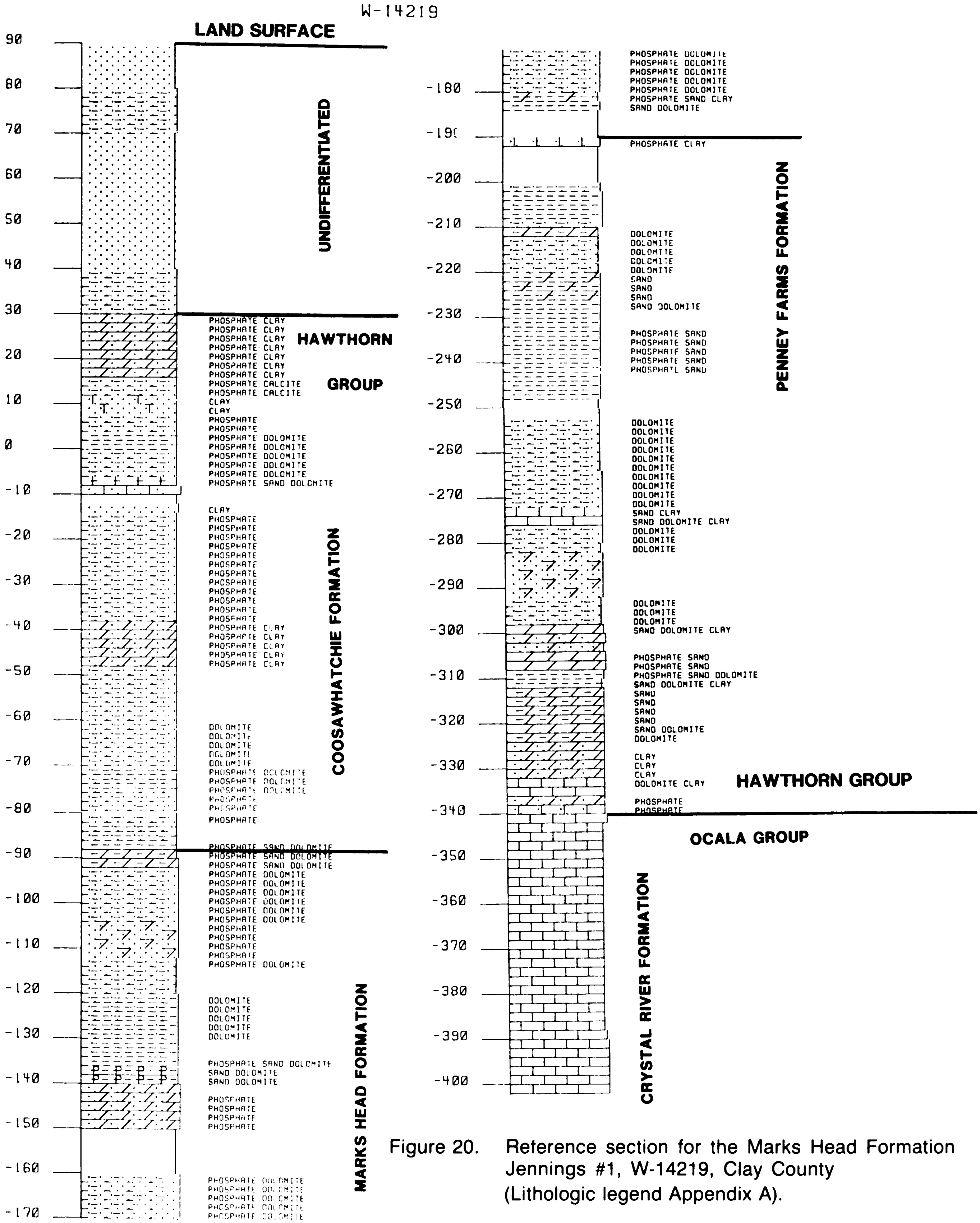


Figure 20. Reference section for the Marks Head Formation Jennings #1, W-14219, Clay County (Lithologic legend Appendix A).

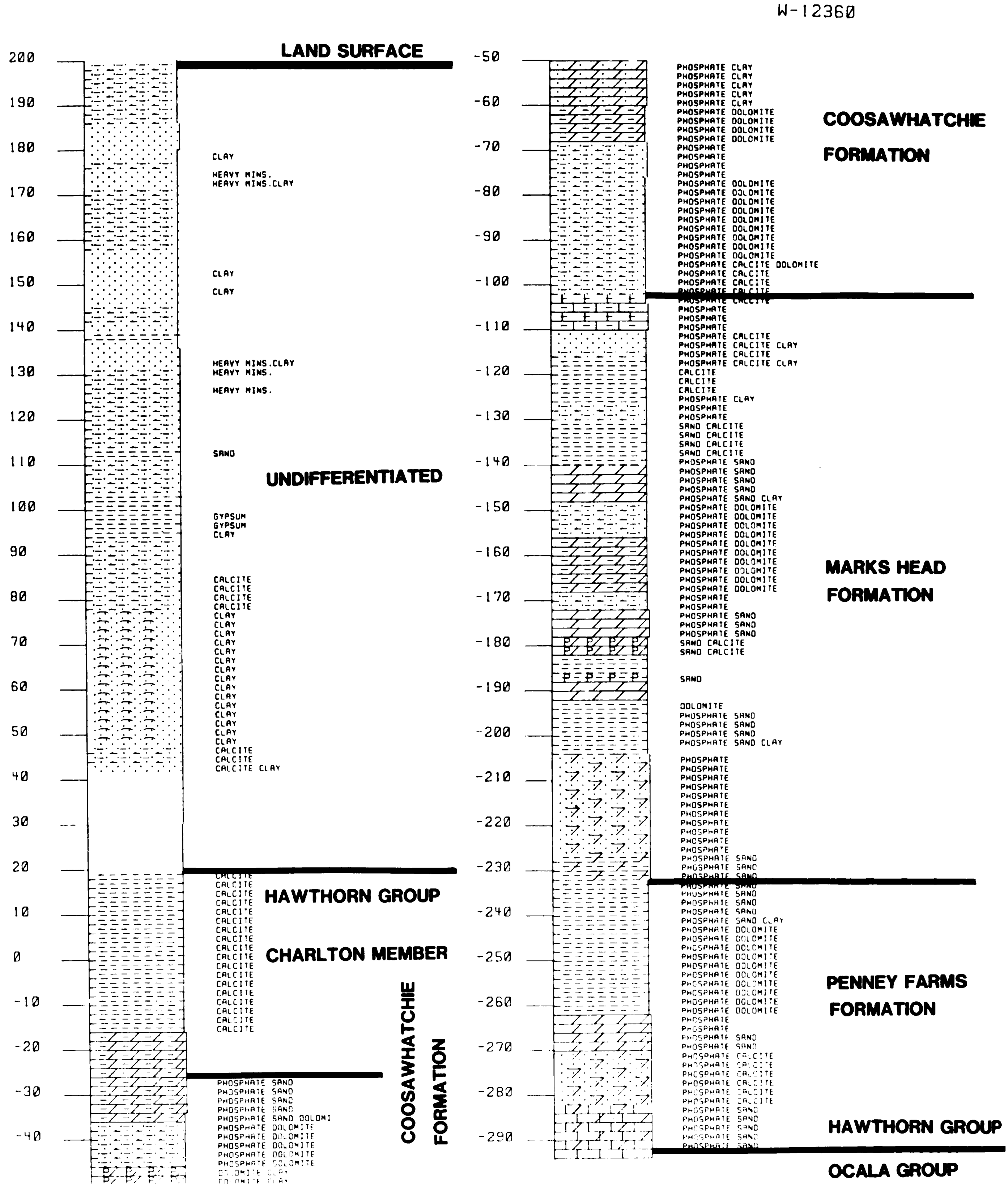


Figure 21. Reference section for the Marks Head Formation, N.L. #1, W-12360, Bradford County (Lithologic legend Appendix A).

Head is readily apparent when comparing the lithologic columns of W-14219 (Figure 20) and W-12360 (Figure 21).

The carbonate portion of the Marks Head Formation is typically dolostone; limestone is uncommon but does occur sporadically as is the case throughout the Hawthorn Group. The Marks Head dolostones are generally quartz sandy, phosphatic and clayey. The dolostones vary in induration from poorly consolidated to well indurated. The induration varies in inverse relationship to the amount of clay present within the sediment. Phosphate grains normally comprise up to 5 percent; however occasional beds may contain significantly higher percentages. Quartz sand content varies from less than 5 percent to greater than 50 percent where it grades into a dolomite cemented quartz sand. The dolostones range from yellowish gray (5 Y 7/2) to olive gray (5 Y 4/1) in color. Crystallinity varies from micro- to very finely crystalline with occasional more coarsely crystalline zones. Molds of mollusk shells are often present.

The occurrence of limestone within the Marks Head Formation in Florida is quite rare. The majority of the "limestone" reported from this part of the section by other workers is actually dolostone. The limestone that does occur is characteristically dolomitic, quartz sandy, phosphatic, clayey, and fine grained.

The quartz sands from the Marks Head Formation are generally fine to medium grained (occasionally coarse grained), dolomitic, silty, clayey and phosphatic. The dolomite, silt and clay contents are highly variable and the quartz sands are gradational with the other lithologies. Phosphate sand is usually present in amounts ranging from 1 to 5 percent; however, phosphate grain percentages may range considerably higher in thin and localized beds. The quartz sands are typically light gray (N 7) to olive gray (5 Y 4/1) in color. Induration varies from poor to moderate.

Clay beds are quite common in the Marks Head Formation, occasionally comprising a large portion of the section. The clays are quartz sandy, silty, dolomitic and phosphatic. As is the case in the Penney Farms Formation, the Marks Head clays contain highly variable percentages of accessory minerals; relatively pure clays do occur but are not common. The clays range from greenish gray (5 GY 6/1) to olive gray (5 Y 4/1) in color and are typically lighter colored than the clays of the underlying unit.

Phosphate grains are present virtually throughout the Marks Head Formation. They characteristically occur as brown to black, sand-sized grains scattered throughout the sediments. The phosphate grains are rounded and often in the same size range as the associated quartz sands. Phosphate pebbles occur rarely.

Mineralogically, the Marks Head Formation clays contain palygorskite, sepiolite, smectite and illite; kaolinite is present only in the weathered section (Hettrick and Friddell, 1984). Hettrick and Friddell (1984) indicated that palygorskite is often the dominant clay mineral in this unit; smectite is the second most abundant clay mineral. Smectite becomes the most abundant clay mineral when palygorskite content decreases. Other minor mineralogic constituents include mica, opal-ct, and feldspar. Huddlestun (in press) reports the occurrence of zeolite in the Marks Head Formation in Georgia.

The Marks Head Formation becomes difficult to identify in the southern portion of the area between the Sanford High and the Ocala Platform (Figure 22). Within this transition zone the Marks Head loses most of the dolostone beds. The distinction between this unit and the overlying Coosawhatchie Formation becomes problematic. As a result, the Hawthorn Group in this area is referred to as undifferentiated. Additional coring in the transition zone may delineate the facies changes through this zone and more accurately determine the correlation of this unit into central and south Florida.

Subjacent and Suprajacent Units

The Marks Head Formation is underlain disconformably throughout most of its extent by the Penney Farms Formation. The upper member of the Penney Farms Formation consists predominantly of darker, olive gray (5 Y 3/2) colored sands and clays with occasional dolostone beds. The base of the Marks Head Formation is placed at the contact between the darker colored sands and clays of the upper Penney Farms and the generally lighter colored, more complexly interbedded sands, clays and dolostone of the Marks Head. Occasionally, the contact is marked by a rubble zone containing phosphatized carbonate

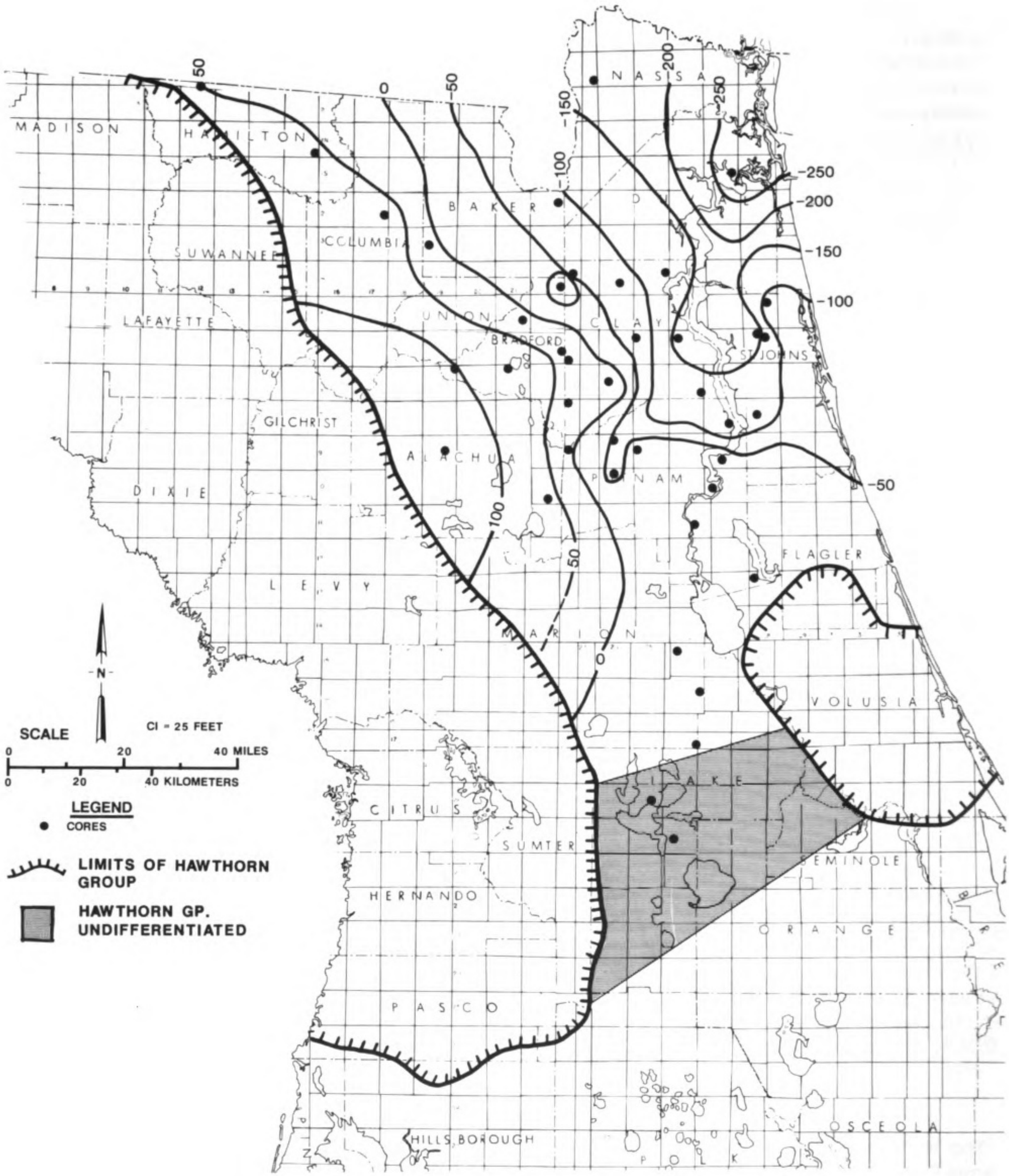


Figure 22. Top of the Marks Head Formation. Shaded area indicates undifferentiated Hawthorn Group.

clasts but the unconformity is often difficult to recognize in cores. In the western-most portion of Hamilton County, the Marks Head is underlain by the sandy carbonates of the Penney Farms Formation.

The Coosawhatchie Formation disconformably overlies the Marks Head Formation throughout north Florida except where it has been removed by erosion. In these areas the Marks Head is overlain by sediments referred to as undifferentiated, post-Hawthorn deposits.

The Coosawhatchie-Marks Head contact is generally placed at the top of the first hard carbonate bed or light colored clay unit below the darker colored clayey, dolomitic, quartz sands and dolostones of the basal Coosawhatchie Formation. Occasionally, the contact appears gradational in a sequence of dolostones and interbedded sands. In this case the top of the upper-most dolostone bed is regarded as the boundary. Occasionally a rubble bed marks the unconformity.

The relationship of the Marks Head Formation to the underlying and overlying units is graphically illustrated in Figures 11 through 16.

Thickness and Areal Extent

The Marks Head Formation of the Hawthorn Group in Florida occurs primarily as a subsurface unit. The top of the Marks Head Formation in the subsurface varies from -260 feet MSL (-79 meters) in Carter #1, W-14619, Duval County to +114 feet MSL (+35 meters) in Devil's Millhopper #1, W-14641, in Alachua County (Figure 22).

The Marks Head Formation dips to the northeast from the flanks of the Ocala Platform toward the Jacksonville Basin with an average dip of 4 feet per mile (0.8 meters per kilometer) (Figure 22). The direction of dip of the Marks Head Formation trends towards the north from the St. Johns Platform into the Jacksonville Basin (Figure 4). The direction and angle of dip may vary locally.

The thickness of the Marks Head Formation varies from being absent on the crest of the Ocala and Sanford Highs to 130 feet (40 meters) in N.L. #1, W-12360, Bradford County (Figure 23). It is interesting to note that this well is not in the Jacksonville Basin but to the southeast of it.

The Marks Head Formation is present throughout much of north Florida. It apparently has been removed by erosion from the Sanford High (Figures 4 and 23) and has not been identified on the Ocala Platform possibly being absent as a result of erosion or non-deposition. In the area between the Ocala and Sanford Highs, the Marks Head is very thin and becomes difficult to recognize, merging southward into the undifferentiated Hawthorn Group.

Age and Correlation

Dateable fossil assemblages within the Marks Head Formation have not been found in north Florida. The only fossils noted were scattered molds of mollusk shells and occasional diatom molds. Lithologic correlation between these sediments and those in Georgia, where fossiliferous sediments are found, indicates that the Marks Head Formation is late Early Miocene (Burdigalian) age (Huddlestun, personal communication, 1983). Planktonic foraminifera in Georgia indicate Zone N.6 or early N.7 of Blow (1969).

Huddlestun (in press) suggests that the Marks Head Formation in Georgia is correlative with the Torreya Formation (Banks and Hunter, 1973) in the eastern panhandle of Florida (Figure 19). Huddlestun (in press) considers both formations to be slightly older than the Chipola Formation in the Florida panhandle which has been correlated with the upper part of planktonic zone N.7 of Blow (1969). It is suggested here that the Marks Head Formation of north Florida is correlated with at least the upper part of the Arcadia Formation and is younger than the Arcadia's Tampa Member in southwest Florida. The Marks Head Formation is thought to be a time equivalent of the lower part of the downdip Bruce Creek Limestone in the southern part of the Apalachicola Embayment. It appears that the Marks Head Formation may be correlative with the lower Pungo River Formation in North Carolina, based on ages suggested for the Pungo River by Gibson (1982).

As is the case for the Penney Farms Formation, the Marks Head Formation is older (see Figure 19) than the previously accepted age for the "Hawthorn Formation" in Florida as interpreted by Cooke

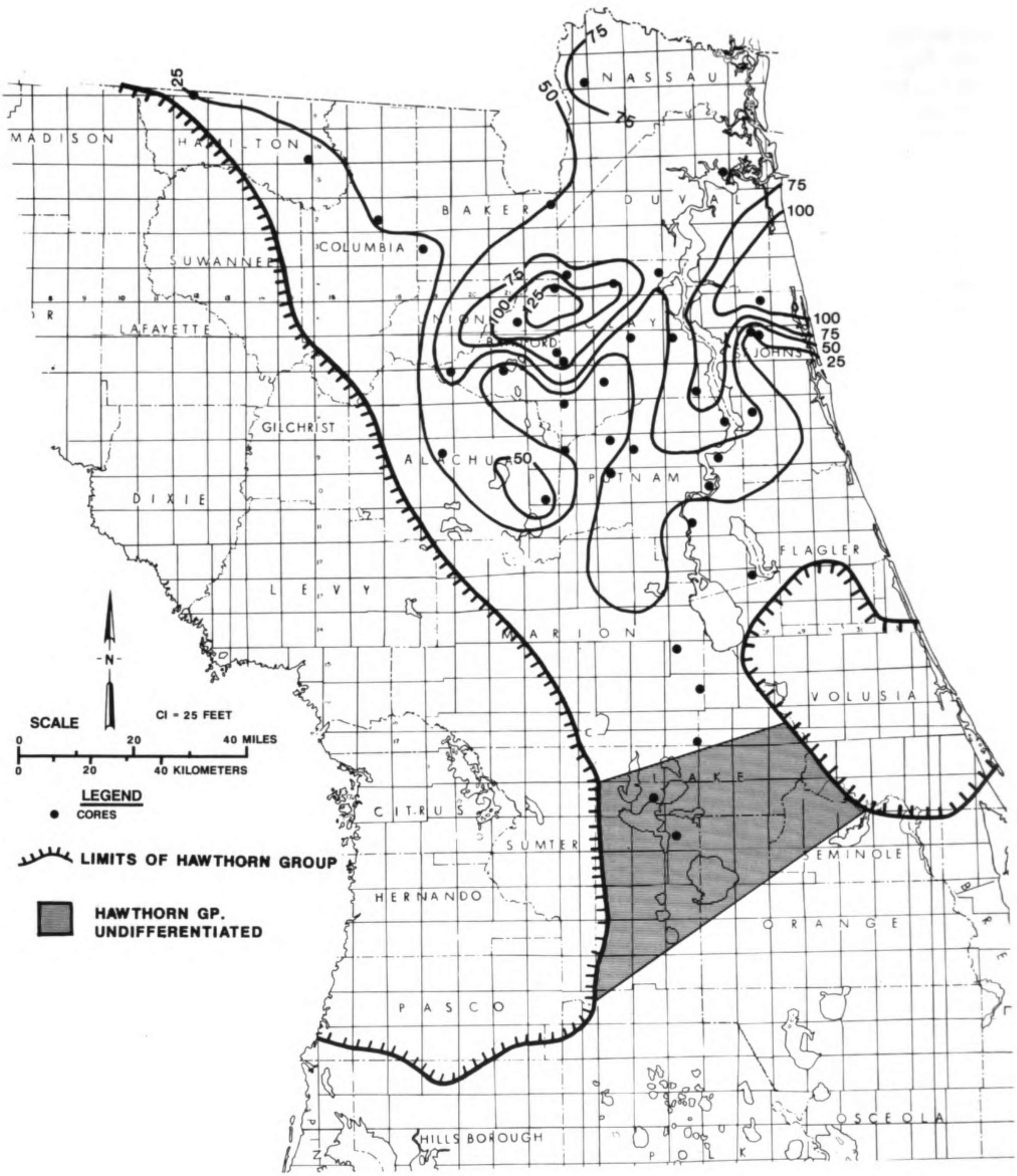


Figure 23. Isopach of Marks Head Formation. Shaded area indicates undifferentiated Hawthorn Group.

(1945) and Puri and Vernon (1964). Puri and Vernon suggested a strictly Middle Miocene age for their "Hawthorn."

Discussion

The extension of the name Marks Head Formation into Florida was based on the general lithologic similarities between the sediments in Georgia and those in Florida. Despite an increased carbonate content in the Florida section, the units are quite similar and the Georgia lithostratigraphic nomenclature is used to avoid stratigraphic confusion.

The Marks Head Formation, like the time-equivalent unit in the panhandle, the Torreya Formation, contains significant amounts of clay. As reported by Hetrick and Friddell (1984), palygorskite is generally the dominant clay mineral with subordinate amounts of smectite. The occurrence of large amounts of palygorskite is suggestive of an unusual set of environmental circumstances which prevailed over large areas of the southeastern coastal plain. The exact conditions are not well understood. However, whether palygorskite is a product of brackish water lagoons (Weaver and Beck, 1977) or ephemeral (alkaline) lakes (Upchurch, et al., 1982), the fluctuating sea levels in late Early Miocene could have reworked these deposits, incorporating vast amounts of palygorskite into the Marks Head sediments. Future detailed clay mineralogy investigations may facilitate a better understanding of the genesis of the clays and of the depositional environments of the Marks Head Formation.

COOSAWHATCHIE FORMATION

Definition and Reference Section

The Coosawhatchie Formation of the Hawthorn Group is used in this paper for the upper unit of the group in much of north Florida. Huddlestun (in press) proposed the Coosawhatchie as a formal lihtostratigraphic unit in Georgia. It extends into north Florida with only minor lithologic changes.

The Coosawhatchie Formation in Florida consists of three members: informal lower and upper members and the Charlton Member, as defined by Huddlestun (in press). The Charlton Member will be discussed separately. A basal clay bed occurs in a few cores in St. Johns County and may equate with the Berryville Clay (Huddlestun, in press).

The type locality for the Coosawhatchie Formation is at Dawsons Landing on the Coosawhatchie River in Jasper County, South Carolina, as described by Heron and Johnson (1966). Huddlestun (in press) suggests a reference locality in Georgia along the Savannah River in Effingham County.

The reference section for north Florida is in the Harris #1 core, W-13769, Clay County (SW¼, SE¼, Sec. 7, T6S, R25E) (Figure 24). The surface elevation of the core is 97 feet (30 meters) MSL. The top of the Coosawhatchie Formation in Harris #1 is at +37 feet (+11 meters) MSL (Figure 24), the base is at -74 feet (-23 meters) MSL.

Lithology

The Coosawhatchie Formation in Florida consists of quartz sands, dolostones and clays. Characteristically, sandy to very sandy dolostone is the most common lithology in the upper informal member, where it is interbedded with quartz sands and clays. In the lower informal member, the quartz sands and clays predominate with interbedded dolostones.

The quartz sands are dolomitic, clayey and phosphatic. The sand grains are fine to medium grained, poorly to moderately sorted, and subangular to subrounded. The proportions of accessory materials vary greatly. The sands grade into the dolostones and clays in many instances. The phosphate grain content is quite variable ranging from a trace to more than 20 percent. Clay content varies from less than 5 per-

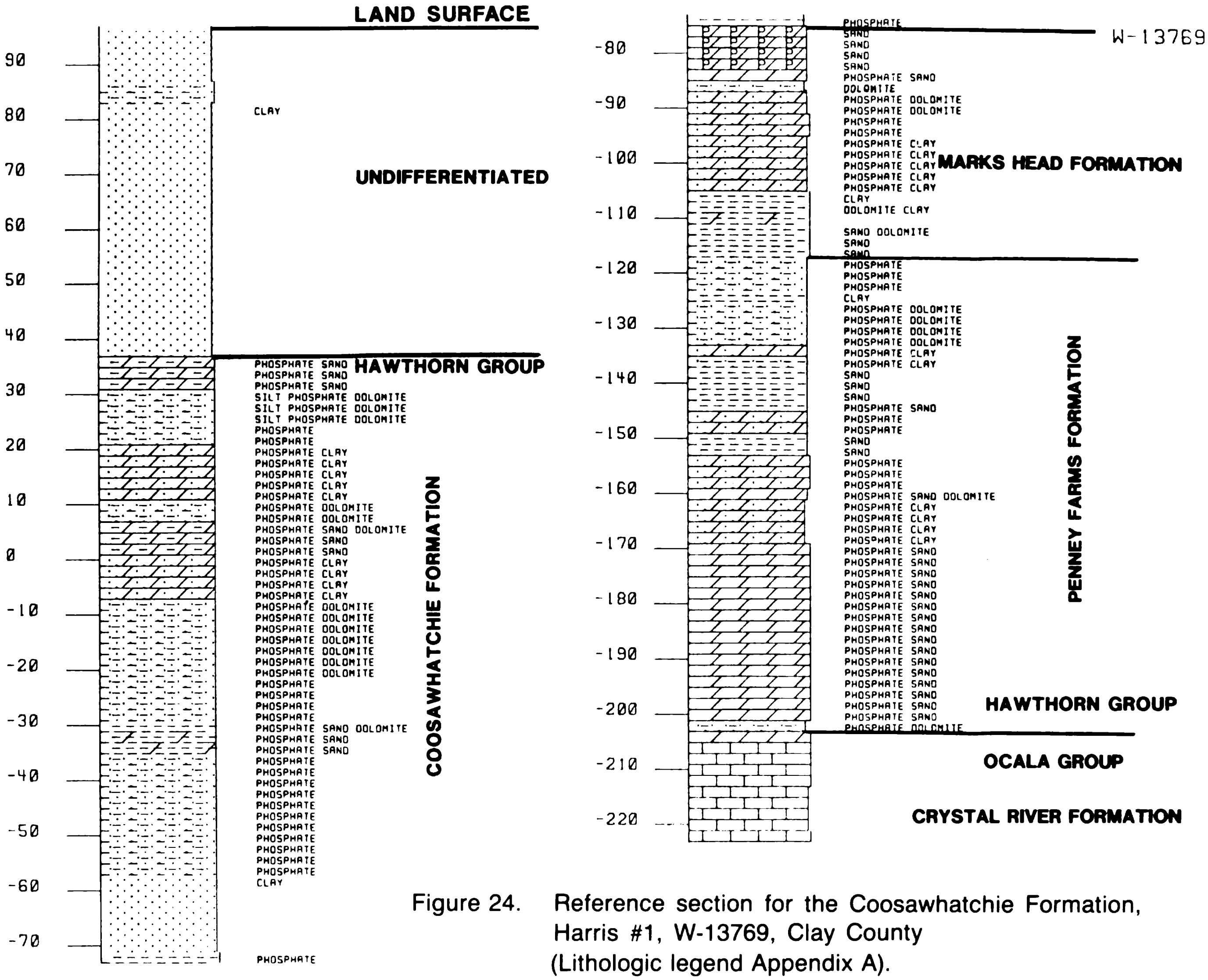


Figure 24. Reference section for the Coosawhatchie Formation, Harris #1, W-13769, Clay County (Lithologic legend Appendix A).

cent to greater than 30 percent. The sands are often lighter colored in the upper member where there is more carbonate in the matrix and darker in the lower member. Colors range from greenish gray (5 GY 6/1) and light gray (N 7) to olive gray (5 Y 4/1). Induration is generally poor.

The dolostones of the Coosawhatchie Formation are quartz sandy, clayey and phosphatic. The percentages of quartz sand and clay vary widely and may be as much as 50 percent in transitional zones. Phosphate grain content is quite variable also, but is generally less than 10 percent. The dolostones are micro- to fine crystalline, poorly to moderately indurated and occasionally contain molds of fossils. They range in color from light gray (N 7) and greenish gray (5 GY 6/1) to olive gray (5 Y 6/1). The dolostones of the upper member appear to become more calcareous in the Jacksonville Basin.

The clays in the Coosawhatchie Formation are typically quartz sandy, silty, dolomitic and phosphatic. The clays are light olive gray (5 Y 6/1) to olive gray (5 Y 4/1). Clay beds are most common in the lower member (Scott, 1983). The clay mineralogy is dominated by smectite (Hetrick and Friddell, 1984). The clay beds often contain diatoms (Hoenstine, 1984).

The phosphate grains present in the Coosawhatchie Formation are normally amber colored to brown or black; lighter colors occur near the land surface. The phosphate grains are usually well rounded and in the same size range as the associated quartz sands. Coarser phosphate sands and phosphate pebbles or rubble are not common but are present.

Subjacent and Suprajacent Formations

The Coosawhatchie Formation disconformably overlies the Marks Head Formation but the disconformity is often not readily apparent. It is, however, recognized biostratigraphically in Georgia (Huddlestun, personal communication, 1983). The contact often occurs in a thin gradational sequence of interbedded sands and dolostones. Occasionally, the contact is marked by a rubble bed.

The Statenville Formation of the Hawthorn Group overlies and interfingers with the Coosawhatchie in Hamilton and Columbia Counties and possibly a small portion of Baker County. The contact is conformable and is recognized by the occurrence of more phosphate grains and less carbonate in the Statenville and the thin bedded nature of the Statenville.

With the exception of the area described above, the Coosawhatchie in Florida is overlain unconformably by undifferentiated post-Hawthorn deposits. These include sands, clays, shell beds and occasional limestones. The relationship of the Coosawhatchie to the underlying and overlying units is indicated in Figures 11 through 16.

Thickness and Areal Extent

The Coosawhatchie Formation occurs throughout much of north Florida. The top of the Coosawhatchie ranges from -93 feet MSL (-28 meters) in Bostwick #1, W-14477, Putnam County to +168 feet MSL (51 meters) in Devils Millhopper #1, W-14641, Alachua County (Figure 25). It attains a maximum thickness in Florida (including the Charlton Member) of 222 feet (68 meters) in Carter #1, W-14619, Duval County (Figure 26). The Charlton Member in this core is 23 feet (7 meters) thick. Huddlestun (in press) indicates that the Coosawhatchie attains a maximum thickness of 284 feet (87 meters) in the southeast Georgia Embayment.

The Coosawhatchie Formation dips in a northeasterly direction from the flanks of the Ocala Platform toward the Jacksonville Basin (Figures 4 and 26). From the St. Johns Platform it dips to the west off the structure and to the north into the Jacksonville Basin (Figures 4 and 26). The average dip is approximately 4 feet per mile (0.8 meters per kilometer). Variations in the angle and direction of dip are evident from Figures 11 through 16.

The Coosawhatchie Formation is not known to occur over the Ocala and Sanford Highs or in the immediately surrounding areas. This is thought to be due primarily to erosion; nondeposition may also have played a role. The Coosawhatchie extends from Georgia southward into central Flordia. In central Florida (between the Ocala and Sanford Highs) it becomes difficult to distinguish and is included in the undifferentiated Hawthorn Group.

Age and Correlation

Huddlestun (in press) suggests a Middle Miocene (Early Serravallian) age for the Coosawhatchie Formation based on planktonic foraminifera. Huddlestun placed it in Zone N.11 of Blow (1969).

Hoenstine (1984) studied diatoms from a few selected cores through the Hawthorn. He recognized a Middle Miocene assemblage in Florida sediments assigned in this paper to the Coosawhatchie Formation.

The Coosawhatchie Formation is thought to be correlative with the lower portion of the Intracoastal Limestone in the Apalachicola Embayment (Schmidt, 1984) and the lower Shoal River Formation in the Florida panhandle (Huddlestun, pers. comm., 1983). In the peninsular area of Florida, it appears to correlate with the lower part of the Peace River Formation of this paper. The Coosawhatchie was correlated with much of the Pungo River Formation in North Carolina by Gibson (1982) and Riggs (1984) (Figure 19).

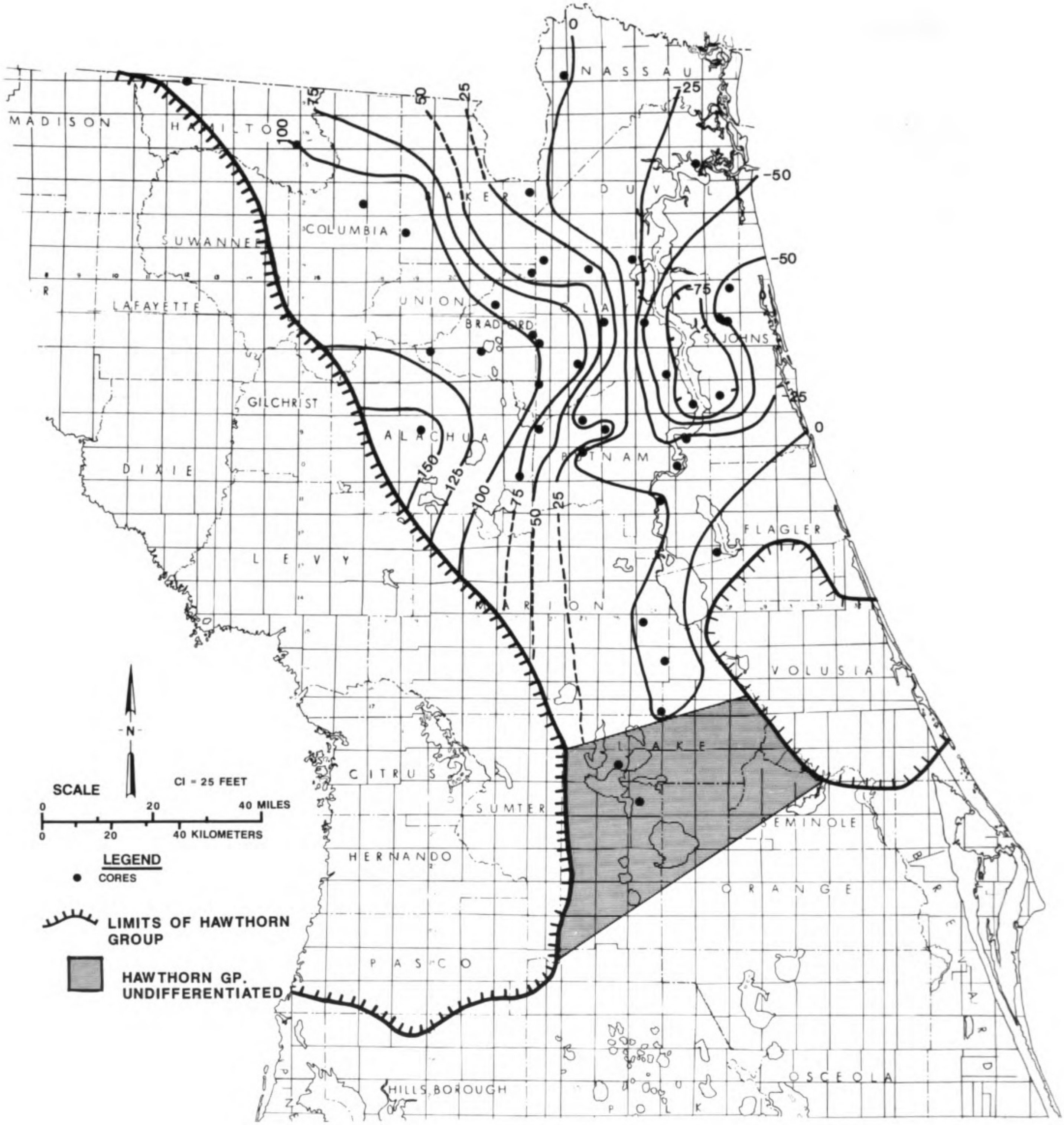


Figure 25. Top of Coosawhatchie Formation. Shaded area indicates undifferentiated Hawthorn Group.

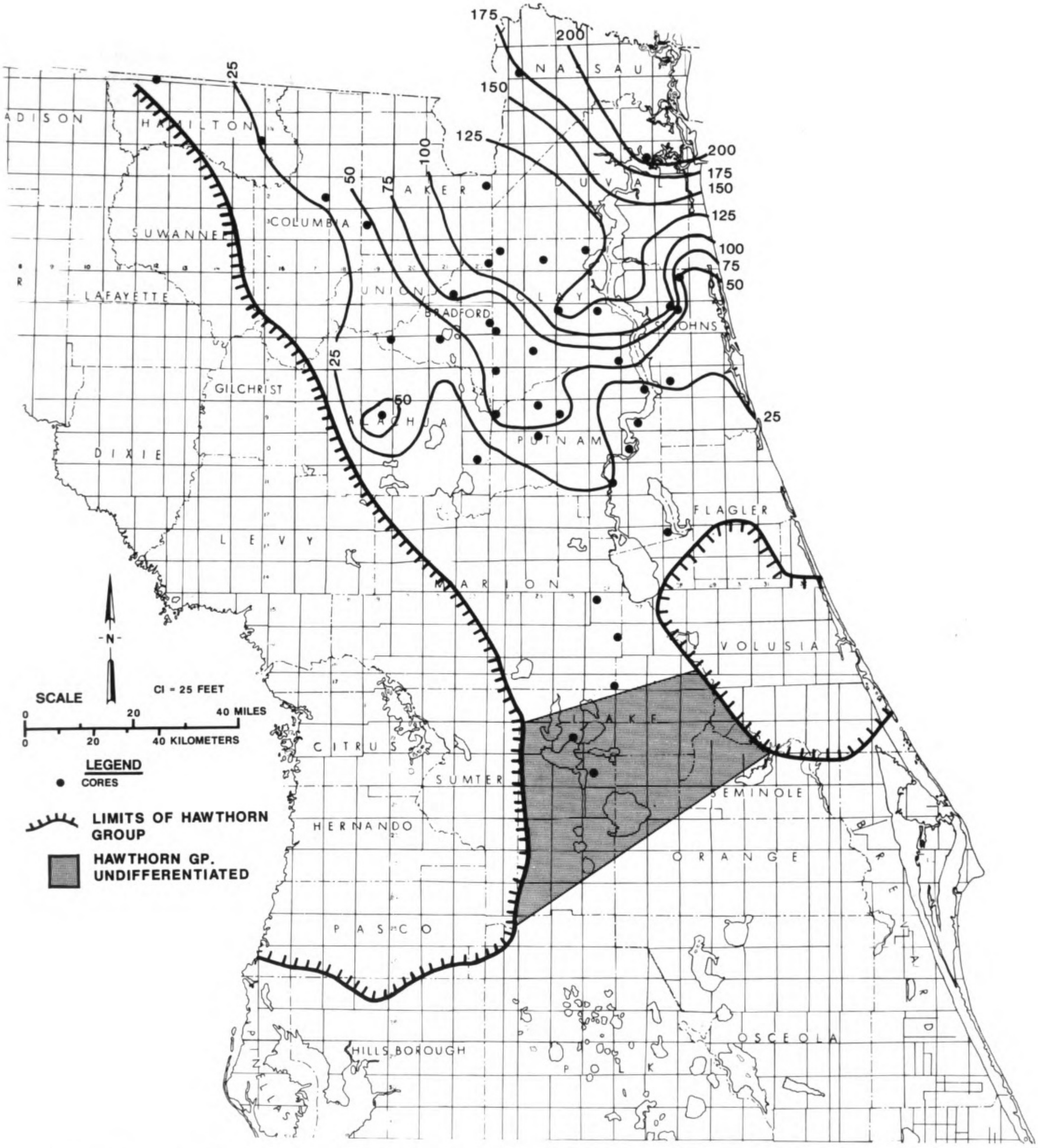


Figure 26. Isopach of Coosawhatchie Formation. Shaded area indicates undifferentiated Hawthorn Group.

Discussion

The Coosawhatchie Formation is widespread in northern Florida and throughout most of this area it is the uppermost Hawthorn sediment encountered in the subsurface. In limited areas it is shallow enough to be exposed in some foundation excavations. The Coosawhatchie Formation in the Jacksonville Basin contains a lower clay bed of variable thickness. This clay bed correlates with the Berryville Clay Member of the Coosawhatchie Formation in southeastern Georgia.

The Coosawhatchie Formation is quite similar to the Peace River Formation of southern Florida in that both are predominantly siliciclastic units. However, the Coosawhatchie contains significantly more carbonate in the matrix than the Peace River. The formations are gradational with each other through the zone of undifferentiated Hawthorn Group sediments in central Florida.

CHARLTON MEMBER OF THE COOSAWHATCHIE FORMATION

Definition and Reference Section

Huddlestun (in press) redefined the "Charlton formation" of Veatch and Stephenson (1911) as a formal member of the Coosawhatchie Formation in Georgia. He found that the Charlton Member is a lithofacies of the upper part of the Coosawhatchie (Huddlestun's Ebenezer Member) in south Georgia and north Florida. Huddlestun (in press) discussed the reference localities in some detail. A reference section for the Charlton Member of the Coosawhatchie Formation in Florida is the Cassidy #1 core, W-13815, Nassau County (NW¼, NW¼, Sec. 32, T3N, R24E). The surface elevation is 80 feet (24 meters) MSL. The Charlton Member occurs from +3 feet (+1 meter) MSL to -43 feet (-13 meters) MSL (Figure 27).

Lithology

The Charlton Member characteristically consists of interbedded carbonates and clays. It is less sandy than the upper member of the Coosawhatchie, into which it grades laterally and vertically and typically contains less sand and phosphate grains. It contains a clay component that is often very conspicuous in the cores (Huddlestun, in press). This has been found to be true in Florida also.

The carbonate beds of the Charlton Member are often dolostones but range into limestone. They are slightly sandy, slightly phosphatic to non-phosphatic and clayey. They often contain abundant molds of fossil mollusks. The dolostones are finely crystalline, light olive gray (5 Y 6/1) and poorly to moderately indurated. The limestones are characteristically very fine grained, slightly sandy, clayey, poorly to moderately indurated, and yellowish gray (5 Y 8/1).

The clays are dolomitic to calcareous, with poor to moderate induration, silty, and light gray (N 7) to greenish gray (5 GY 6/1). The clay minerals present include smectite, palygorskite, illite and kaolinite (Hetrick and Friddell, 1984).

Subjacent and Suprajacent Units

The Charlton Member both overlies and interfingers laterally with the upper informal member of the Coosawhatchie Formation. The Charlton is simply a distinctive facies of the upper informal member. The Charlton is disconformably overlain by the sediments discussed as overlying the Coosawhatchie Formation.

Thickness and Areal Extent

Sediments assigned to the Charlton occur at Brooks Sink (SW¼, SW¼, Sec. 12, T7S, R20E, Bradford

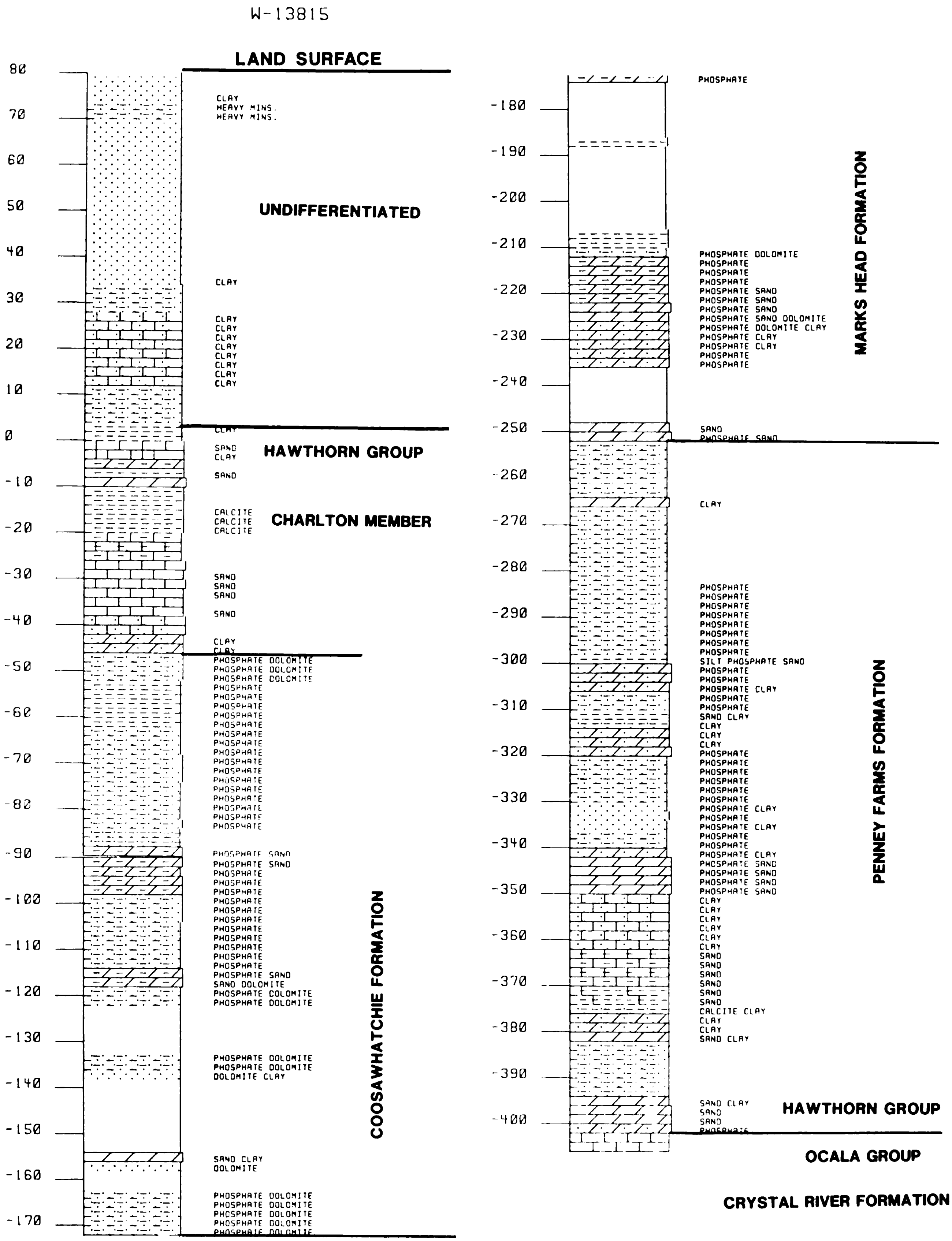


Figure 27. Reference core for the Charlton Member of the Coosawhatchie Formation, Cassidy #1, Nassau County (Lithologic legend Appendix A).

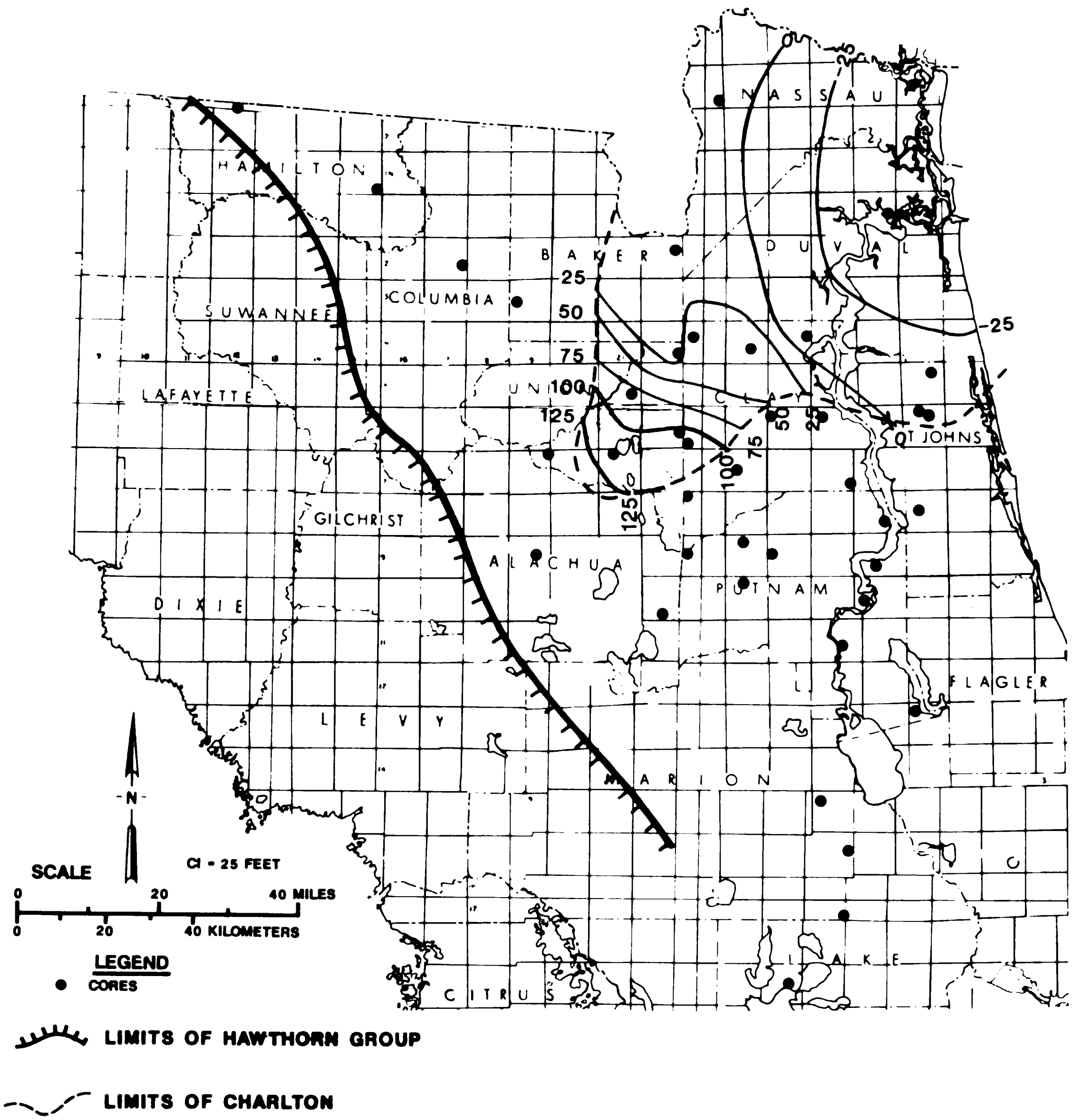


Figure 28. Top of the Charlton Member (dashed line indicates extent of Charlton).

County) at an elevation of + 145 feet (44 meters) MSL (Figure 28). The highest elevation for the top of the Charlton in a core was in Wainwright #1, W-14283, Bradford County where it occurred at + 109 feet (+ 33 meters) MSL. The deepest that the top of the Charlton Member was found is in Carter #1, W-14619, Duval County, where it is -38 feet MSL (-12 meters).

The Charlton Member of the Coosawhatchie Formation reaches its maximum recognized thickness in Florida in Cassidy #1, W-13815, Nassau County, where it is 40 feet (13 meters) thick (Figure 29). It is very spotty in its occurrence, as is evident from the cross-sections (Figures 11 through 16).

Age and Correlation

The Charlton Member, as originally defined by Veatch and Stephenson (1911), was considered Pliocene. Huddlestun (in press) postulates that, based on his observations of the molluskan fauna and

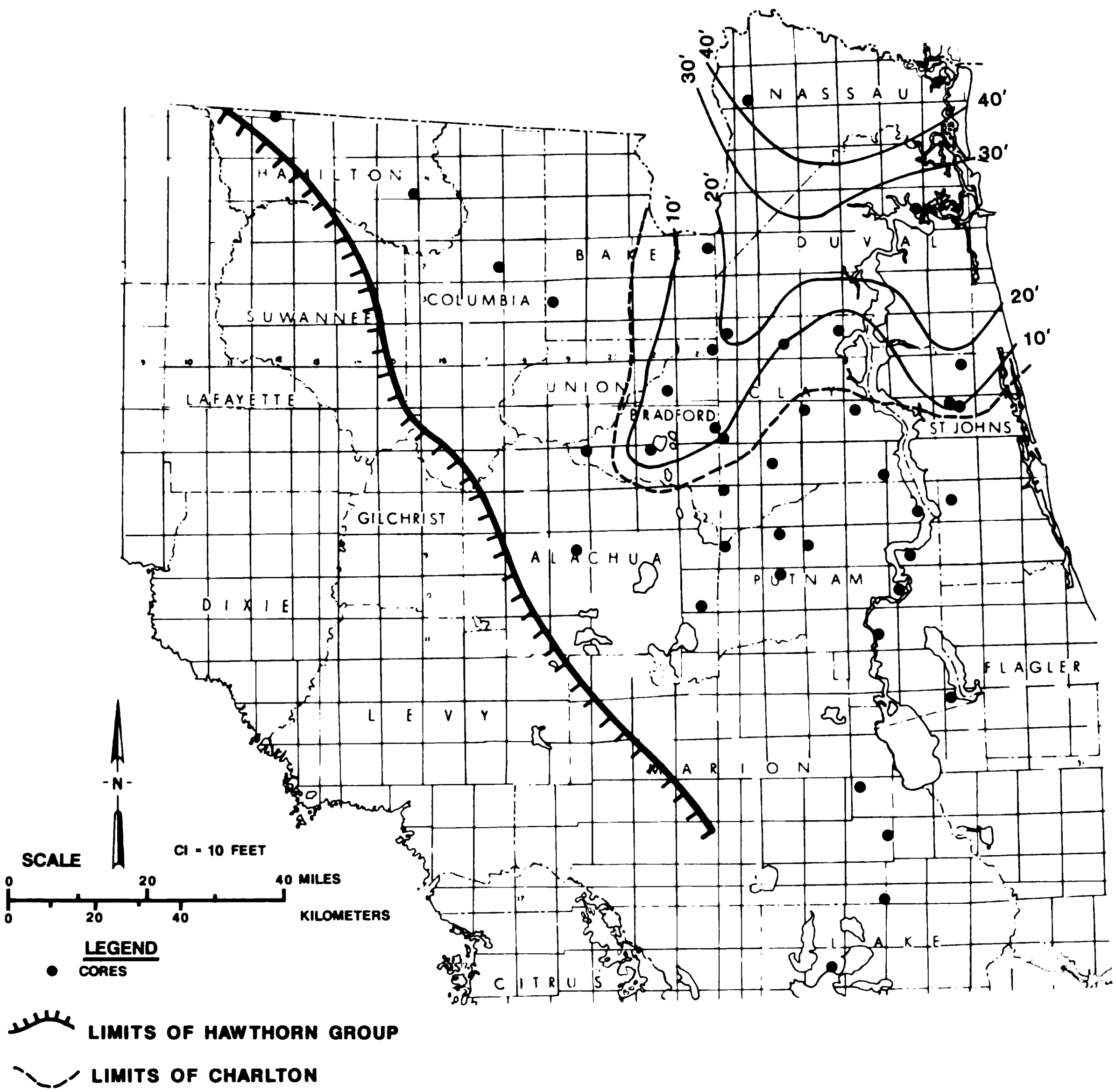


Figure 29. Isopach of the Charlton Member (dashed line indicates extent of Charlton).

the lithostratigraphy of the unit, it is Middle Miocene (Seravallian) in age (Figure 19).

The Charlton Member correlates with at least part of the informal upper member of the Coosawhatchie Formation. Correlations for the Coosawhatchie Formation are discussed in the previous section.

Discussion

The sediments assigned to the Charlton Member of the Coosawhatchie Formation were referred to as the "Jacksonville limestone" by Dall and Harris (1892). Dall and Harris suggested that the "Jacksonville limestone" was Pliocene in age. Matson (1915) changed the Jacksonville Limestone to the "Jacksonville formation." Cooke (1945) suggested placing the "Jacksonville formation" in the Duplin Marl. No type section was ever formally designated for the Jacksonville formation.

The lithologic relationship of these sediments to the rest of the Coosawhatchie Formation as recognized in this study supports the work of Huddlestun (in press). The use of the Charlton Member rather than reintroducing the "Jacksonville limestone (or formation)" is suggested here to aid in nomenclatural consistency between the Georgia coastal plain and peninsular Florida. The reduction in status of the Charlton is necessary due to its limited extent.

STATENVILLE FORMATION

Definition and Type Location

The Statenville Formation is a new lithostratigraphic name proposed by Huddlestun (in press) for interbedded phosphatic sands, dolostones and clays at the top of the Hawthorn Group in the type section along the Alapaha River near Statenville, Georgia, north of Georgia Highway 94. The Statenville Formation extends southward into Hamilton and Columbia Counties area of Florida.

Reference localities listed by Huddlestun (in press) include exposures along the Alapahoochee Creek between the Georgia Highway 135 bridge in southwest Echols County and at the bridge over the river 1.25 miles (2 km) northeast of Jennings in Hamilton County, Florida; and exposures along the Suwannee River approximately one mile (1.6 km) above and below the site of the former Cones Bridge (now a boat landing) in Sec. 36, T1N, R16E in Hamilton and Columbia Counties, Florida. None of these outcrop sections expose the entire unit. The best section available is present in the designated reference core Betty #1, W-15121, Hamilton County (NE¼, NW¼, Sec. 3, T2N, R12E), Florida. This core provides the only complete section available. The Statenville Formation extends from the surface to 87 feet (26 meters) MSL. Surface elevation is 150 feet (46 meters) MSL (Figure 30).

Lithology

The Statenville Formation of the Hawthorn Group consists of interbedded sands, clays and dolostones with common to abundant phosphate grains. The diagnostic feature of the Statenville Formation is its thin bedded, often crossbedded, nature that is exhibited in outcrop (Figure 31). Outcrops generally consist of thin beds of dolostone and clay alternating with thin beds of sand.

Quartz sands predominate in much of the unit. The sands are fine to coarse grained (with occasional quartz gravel present), clayey to dolomitic, poorly indurated, poorly to moderately sorted, and subangular to angular. Colors range from very light gray (N 8) to light olive gray (5 Y 6/1). The sands are quite phosphatic with thin zones grading into phosphorite sands. The average phosphate grain percentage is approximately 10 percent.

The dolostones, which occur commonly as thin beds within the Statenville, are sandy, clayey, phosphatic and poorly to well indurated. The dolostones are typically yellowish gray (5 Y 8/1) to very light orange (10 YR 8/2). The percentages of sand, phosphate, and clay in the dolomites vary widely. Sediments in the Betty #1 core indicate that dolostone is most common in the lower portion of the unit.

Clay beds are not readily apparent in the outcrop sections. However, in the Betty #1 core they are quite common and are more abundant in the upper portion of the Statenville (Figure 30). The clay beds are characteristically sandy, dolomitic, phosphatic, light olive gray (5 Y 6/1) to yellowish gray (5 Y 8/1) and poorly indurated. The clay minerals present are characteristically smectite, palygorskite and illite.

Phosphate grains are abundant in the Statenville Formation. The phosphate grains are tan, amber, and brown to black, rounded, and generally are in a similar size range as the associated quartz sands. Huddlestun (in press) discusses phosphate pebbles and clasts (conglomerate) as being present in dolomite beds along the Suwannee River and also along the Alapaha River. Phosphorite from the Statenville Formation is presently being mined by Occidental Chemical Company in Hamilton County, Florida. These phosphorite sands occur in the upper, less dolomitic portion of the unit.

The thin bedded nature of the Statenville sediments is quite distinctive in outcrop. Huddlestun (in press) reports that the bedding ranges from horizontal to undulatory to variously cross bedded, with

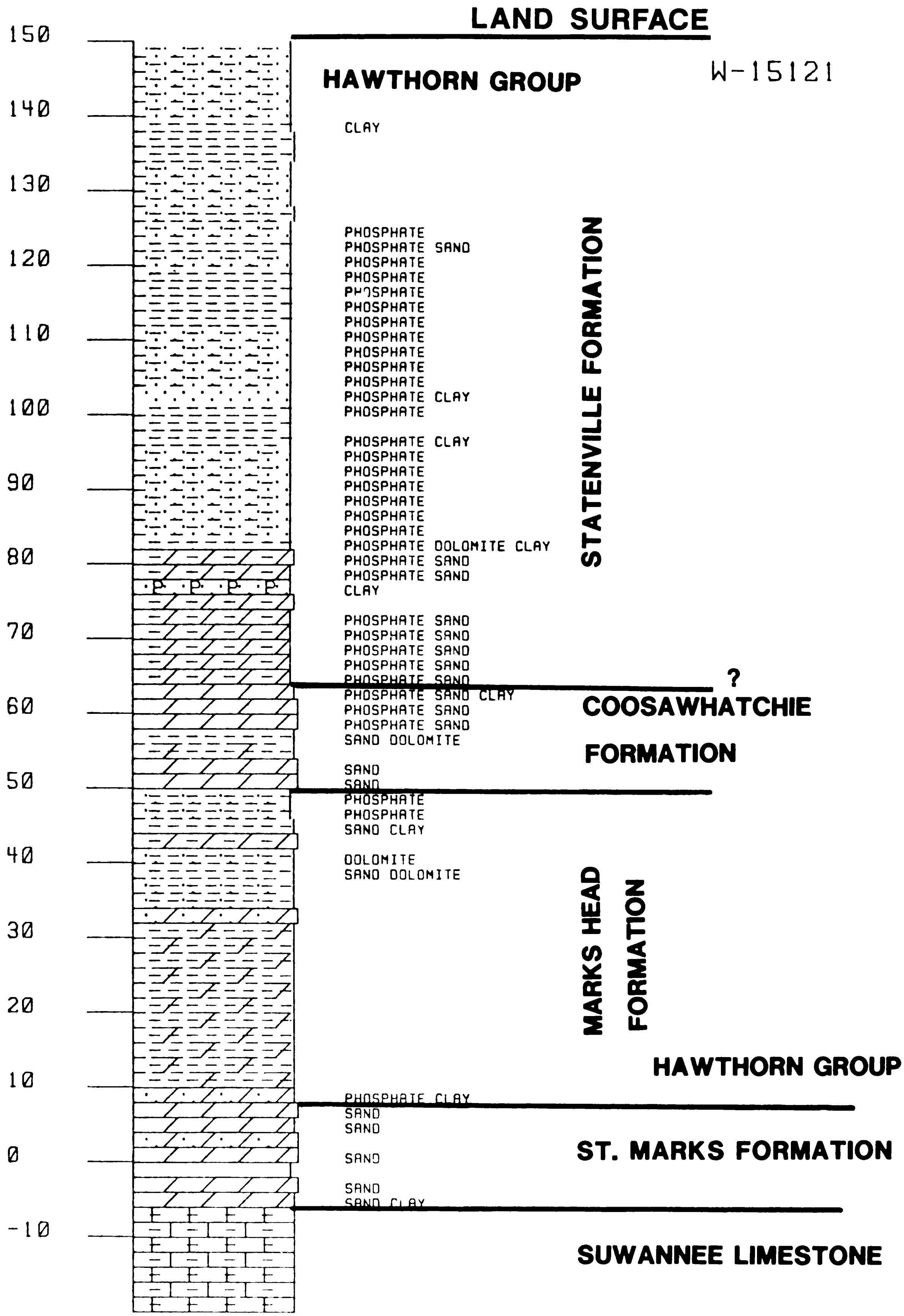


Figure 30. Reference core for the Statenville Formation, W-15121, Betty #1, Hamilton County (Lithologic legend Appendix A).

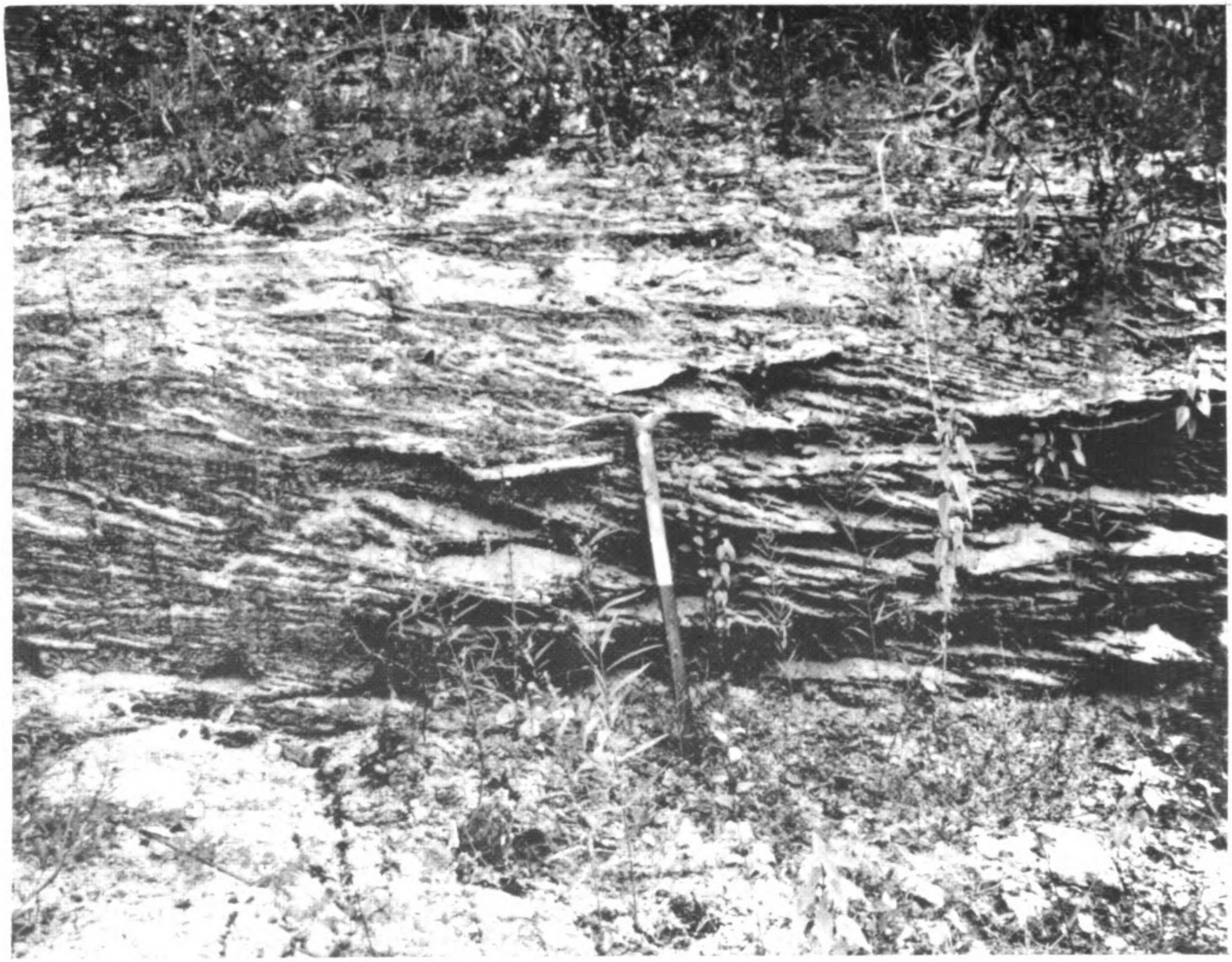


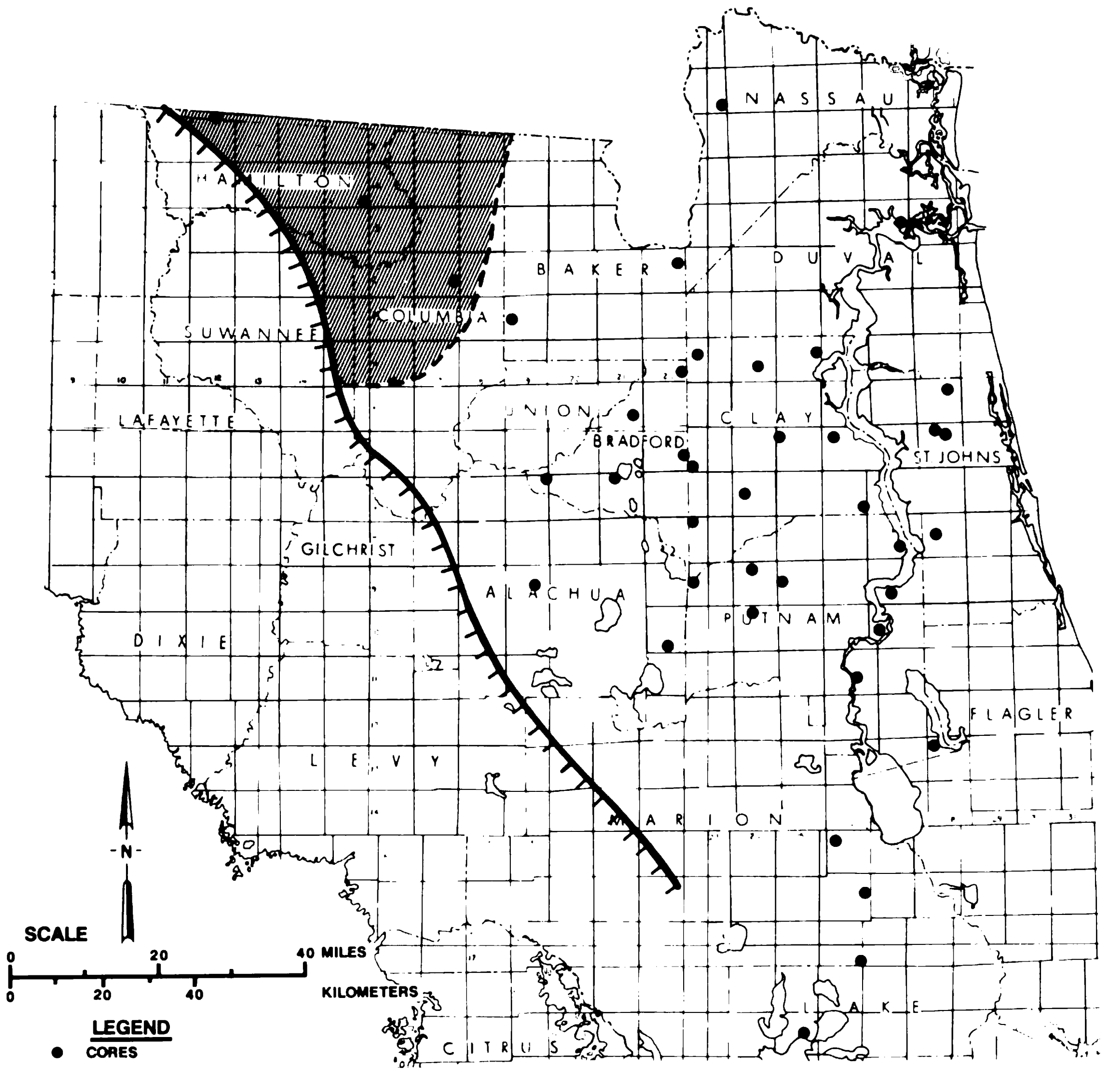
Figure 31. Photograph of Statenville Formation outcrop showing distinct cross bedding.

locally common cut and fill structures. The thin dolostone and clay beds remain as small ledges while the sands erode deeper into the outcrop (Figure 31). This distinctive bedding is also exposed in the phosphate pits in Hamilton County. A reworked zone with more parallel bedding is present above the crossbedded and thinbedded section.

Subjacent and Suprajacent Units

The Statenville Formation is underlain throughout its extent in north Florida by the Coosawhatchie Formation with which it also interfingers. The contact between the formations is conformable. The contact is placed at the base of the section of thinbedded, significantly (>15 percent) phosphatic sands, clays and dolostones.

The Statenville Formation occurs from very near the ground surface to the top of the Coosawhatchie Formation throughout most of its occurrence. The uppermost portion of the section is often weathered and has lost its dolomite and phosphate content. Near its eastern limit, it may be overlain by undifferentiated post-Hawthorn deposits (Figures 11 through 16).



LIMITS OF HAWTHORN GROUP

AREA OF STATENVILLE OCCURRENCE

Figure 32. Area of occurrence of the Statenville Formation.

Thickness and Areal Extent

The Statenville Formation is recognized in three cores in north Florida (Figure 32). It also crops out along rivers and streams in the Hamilton and Columbia County area. Figure 32 shows the area where the Statenville is known to be present; lateral limits of the formation are poorly defined at this time.

The thickness of the Statenville Formation ranges up to 87 feet (26.5 meters) as recognized in Betty #1, W-15121, Hamilton County. This represents the greatest known thickness.

Age and Correlation

Brooks (1966) believed that these sediments were Late Miocene in age based on what he referred to as inconclusive paleontologic evidence. Limited collections of terrestrial vertebrate fossils from the Statenville Formation indicate a Middle Miocene age (Huddlestun, in press). Webb (personal communication, 1983 *in* Huddlestun, in press) states that the Statenville mammal fauna is late Barstovian (late Middle Miocene) and is between 14 million and 12 million years old. Huddlestun (in press) believes this unit to be of Serravallian age, possibly in part equivalent to Zone N.11 of Blow (1969). The reworked zone at the top of the Statenville section appears to be Late Miocene based on vertebrate fossils (Cathcart, 1985, personal communication).

The Statenville Formation appears equivalent to the upper part of the Coosawhatchie Formation. Huddlestun's (in press) zonal correlation indicates an equivalence to the upper part of the Pungo River Formation in North Carolina. The Statenville is also correlative with part of the Intracoastal Formation in the Florida panhandle (Schmidt, 1984) and part of the Peace River Formation in southern Florida.

Discussion

The Statenville Formation of northern Florida is recognized primarily in outcrops along the Alapaha and Suwannee Rivers in Hamilton County and northward into Georgia. The Statenville's limited extent in north Florida is at least in part due to a rather limited data base. Additional cores and further research will be necessary to better define the limits and relationships of the Statenville and associated units.

ALACHUA FORMATION

The Alachua Formation, originally called the "Alachua clays" by Dall and Harris (1892), is an often misused and misunderstood unit. The original definition included sands and clays filling in karst depressions or stream channels related to sinkholes.

Sellards (1914) greatly expanded the definition of the Alachua Formation by including the hardrock phosphate-bearing deposits of the "Dunnellon formation" in the Alachua. He felt that the sands of the "Dunnellon" were a facies of the "Alachua clays." Later authors (Cooke and Mossom, 1929; Cooke, 1945) followed the expanded definition of the Alachua.

Vernon (1951) discussed the Alachua as "a mixture of interbedded, irregular deposits of clay, sand and sandy clay of the most diverse characteristics." Puri and Vernon (1964) also used this definition.

Discussions of the origin of the Alachua Formation have yielded a number of theories. Cooke (1945) believed that this unit was a residual, *in situ* accumulation of weathered Hawthorn sediments. Puri and Vernon (1964) felt the Alachua Formation was terrestrial and in part lacustrine and fluviatile. Brooks (1966, *in* Teleki, 1966) suggested that the Alachua was formed by deposition in an estuarine environment and included residual Hawthorn deposits overlain by slumped Pliocene fluvial and sinkhole accumulations. Based on the occurrence of the hard rock phosphates, the paleoextent of the Hawthorn Group sediments (Scott, 1981), field inspection of outcrops and the existing literature, the present author feels that this unit resulted from the weathering and/or reworking of Hawthorn Group sediments. The Alachua Formation at this time is not considered as part of the Hawthorn Group in peninsular Florida.

Suggested ages of the Alachua Formation range from as old as Middle Miocene (Vernon, 1951) to as young as Plio-Pleistocene (Pirkle, 1956b). The range in suggested ages can be attributed to a multiple phase development for this deposit. For example, different generations of karst or different cycles of reworking can incorporate similar lithologic packages with differing vertebrate faunas enclosed. As a result sediments assigned to the Alachua Formation may range in age from the Miocene to the Pleistocene.

It is readily apparent that the Alachua Formation is a complex unit. Further research is necessary to better understand and delineate this complex unit.

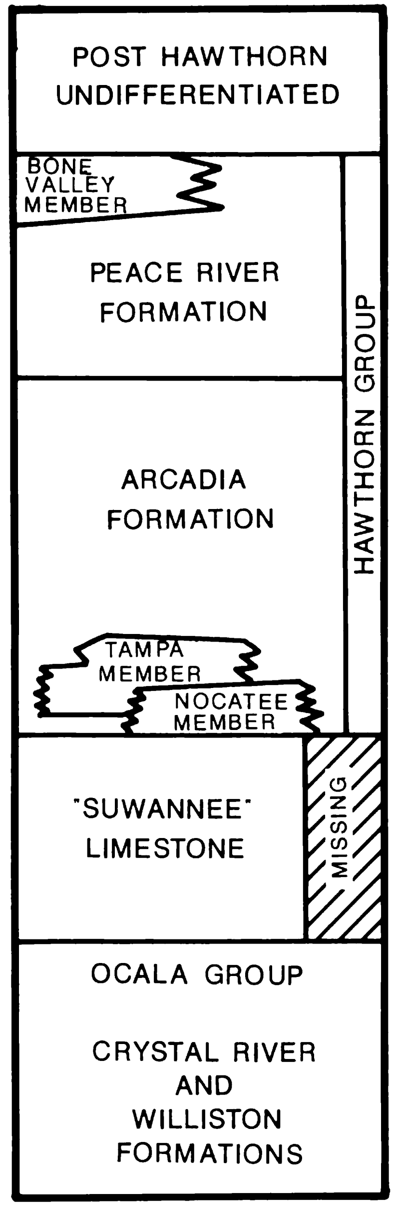


Figure 33. Lithostratigraphic units of the Hawthorn Group in southern Florida.

SOUTH FLORIDA

Although the Hawthorn Group in south Florida consists of the same general sediment types (carbonate, quartz sand, clay and phosphate), the variability and complexity of the section is different from the strata in northern Florida. In the south Florida area (Figure 1), particularly the western half of the area, the Hawthorn Group consists of a lower, predominantly carbonate unit and an upper, predominantly siliciclastic unit. Eastward the section becomes more complex due to a greater percentage of siliciclastic beds present in the lower portion of the Hawthorn Group.

The differences that exist between the northern and southern sections of the Hawthorn Group require separate formational nomenclature. In southern Florida, the Hawthorn Group consists of in ascending order, the Arcadia Formation (new name) with the Tampa and Nocatee (new name) Members and the Peace River Formation (new name) with the Bone Valley Member (Figure 33). The new nomenclature helps alleviate many of the previously existing problems associated with the relationship of the Bone Valley, Tamiami, Hawthorn, and Tampa units in the south Florida region.

ARCADIA FORMATION

Definition and Type Section

The Arcadia Formation is a new formational name proposed here for the lower Hawthorn carbonate section in south Florida. This unit includes sediments formerly assigned to the Tampa Formation or Limestone (King and Wright, 1979) and the "Tampa sand and clay" unit of Wilson (1977).

Dall and Harris (1892) used the term "Arcadia marl" to describe beds along the Peace River. This term was never widely used and did not appear in the literature again except in reference to Dall and Harris. It appears that their use of the "Arcadia marl" described a carbonate bed now belonging in the Peace River Formation of the upper Hawthorn Group. Riggs (1967) used the term "Arcadia formation" for the carbonate beds often exposed at the bottom of the phosphate pits in the Central Florida Phosphate District. Riggs' use of this name was never formalized. The "Lexicon of Geologic Names" (U.S.G.S., 1966) listed the name Arcadia as being used as a member of the Cambrian Trempealeau Formation in Wisconsin and Minnesota, thereby precluding its use elsewhere. Investigations into the current status of this name indicated that the Arcadia member has not been used in some 25 years and does not fit the current Cambrian stratigraphic framework. The Lexicon also indicates Arcadia clays as an Eocene (Claibornian) unit in Louisiana. This name also has been dropped from the stratigraphic nomenclature of Louisiana (Louisiana Geological Survey, 1984, personal communication). Since these former usages of this name are no longer viable, the term can be used for the lower Hawthorn Group sediments in southern Florida in accordance with Article 20 of the North American Code of Stratigraphic Nomenclature (NACSN, 1983).

The Arcadia Formation is named after the town of Arcadia in DeSoto County, Florida. The type section is located in core W-12050, Hogan #1, DeSoto County (SE¼, NW¼, Section 16, Township 38S, Range 26E, surface elevation 62 feet (19 meters)) drilled in 1973 by the Florida Geological Survey. The type Arcadia Formation occurs between -97 feet MSL (-30 meters MSL) to -520 feet MSL (-159 meters) (Figure 34).

Two members can be recognized within the Arcadia Formation in portions of south Florida. These are the Tampa Member and the Nocatee Member (Figure 33). The members are not recognized throughout the entire area. When the Tampa and Nocatee are not recognized, the section is simply referred to as the Arcadia Formation.

Lithology

The Arcadia Formation, with the exception of the Nocatee Member, consists predominantly of limestone and dolostone containing varying amounts of quartz sand, clay and phosphate grains. Thin beds of quartz sand and clay often are present scattered throughout the section. These thin sands and clays are generally very calcareous or dolomitic and phosphatic. Figure 34 graphically illustrates the lithologies of the Arcadia Formation including the Tampa and Nocatee Members. The lithologies of the

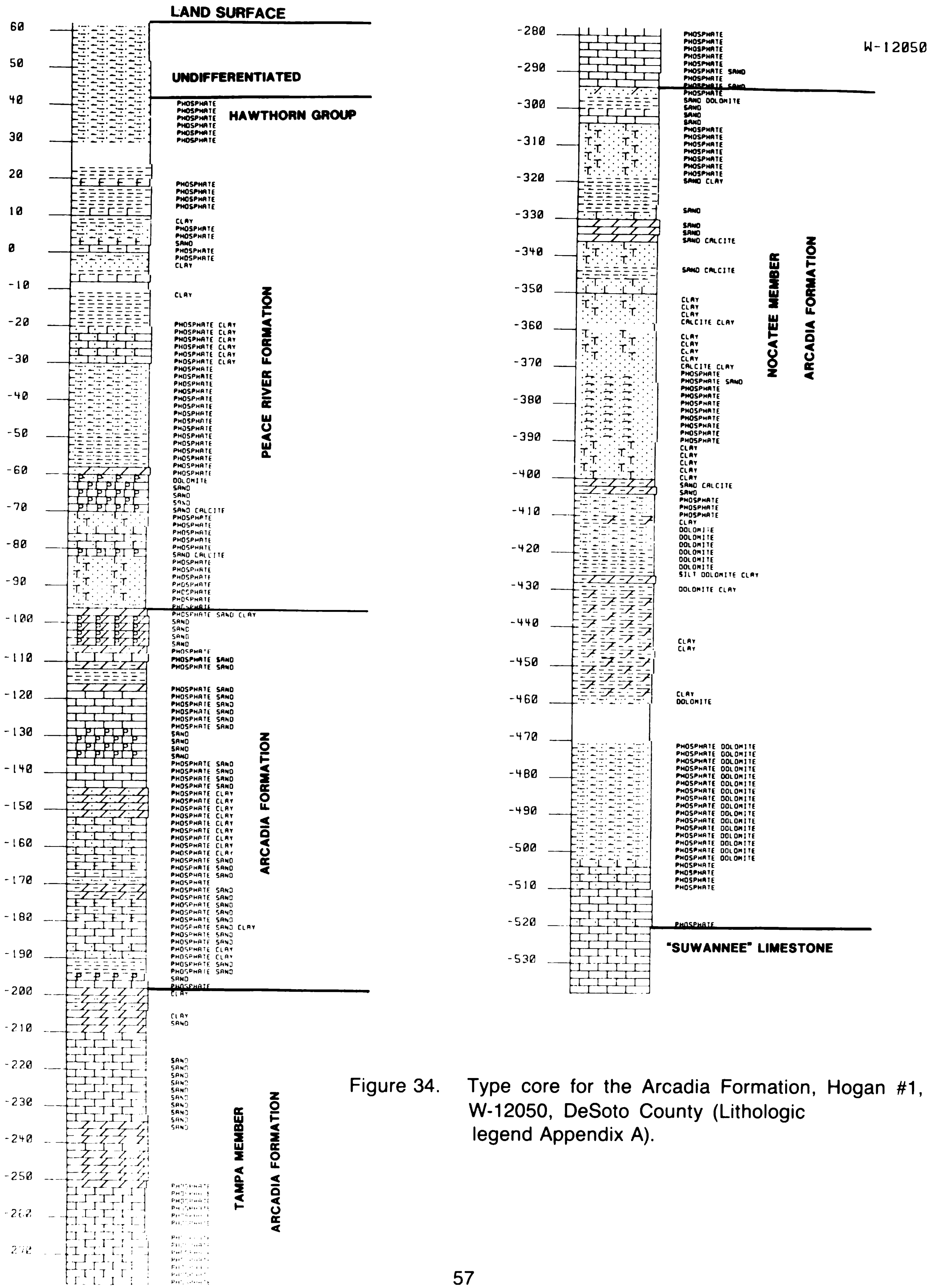


Figure 34. Type core for the Arcadia Formation, Hogan #1, W-12050, DeSoto County (Lithologic legend Appendix A).

Tampa and Nocatee Members will be discussed separately from the undifferentiated Arcadia Formation.

Dolomite is generally the most abundant carbonate component of the Arcadia Formation except in the Tampa Member. Limestone is common and occasionally is the dominant carbonate type. The dolostones are quartz sandy, phosphatic, often slightly clayey to clayey, soft to hard, moderately to highly altered, slightly porous to very porous (moldic porosity) and micro- to fine crystalline. The dolostones range in color from yellowish gray (5 Y 8/1) to light olive gray (5 Y 6/1). The phosphate grain content is highly variable ranging up to 25 percent but is more commonly in the 10 percent range. The limestones of the Arcadia are typically quartz sandy, phosphatic, slightly clayey to clayey, soft to hard, low to highly recrystallized, variably porous and very fine to fine grained. The limestones are typically a wackestone to mudstone with few beds of packstone. They range in color from white (N 9) to yellowish gray (5 Y 8/1). The phosphate grain content is similar to that described for the dolostones. Fossils are generally present only as molds in the carbonate rocks.

Clay beds occur sporadically throughout the Arcadia Formation. They are thin, generally less than 5 feet thick, and of limited areal extent. The clays are quartz sandy, silty, phosphatic, dolomitic and poorly to moderately indurated. Color of the clay ranges from yellowish gray (5 Y 8/1) to light olive gray (5 Y 6/1). Lithoclasts of clay are often found in other lithologies. Smectite, illite, palygorskite, and sepiolite comprise the clay mineral suite (Reynolds, 1962).

Quartz sand beds also occur sporadically and are generally less than 5 feet thick. They are very fine to medium grained (characteristically fine grained), poorly to moderately indurated, clayey, dolomitic and phosphatic. The sands are usually yellowish gray (5 Y 8/1) in color.

Chert is also sporadically presently in the Arcadia Formation in the updip areas (portions of Polk, Hillsborough, Manatee and Hardee Counties). In many instances the chert appears to be silicified clays and dolosilts.

Subjacent and Suprajacent Units

The Arcadia Formation overlies either the Ocala Group or the "Suwannee" Limestone in the south Florida region (Figure 8). The contact between the basal Arcadia and the Ocala Group is an easily recognized unconformity. In the north central and northeastern portions of southern Florida, where the Hawthorn Group overlies the Ocala Group (Figures 8 and 41), the Arcadia is characteristically a gray, hard, quartz sandy, phosphatic dolostone with a few siliciclastic interbeds. This is in contrast to the Ocala Group, which is a cream to white, fossiliferous, soft to hard limestone (packstone to wackestone).

Throughout most of south Florida, the Hawthorn Group overlies limestones most often referred to as the "Suwannee" Limestone (Figure 33). In much of this area the contact is recognizably unconformable. The contrast between the sandy, phosphatic, fine-grained to finely crystalline carbonates of the Arcadia and the coarser grained nonphosphatic, non-quartz-sandy limestones of the "Suwannee" Limestone allow the contact to be easily placed. However, in the downdip areas (e.g., Lee and Charlotte Counties and further south) the contact becomes more obscure. In this area the contact is placed at the base of the last occurrence of a sandy, variably phosphatic carbonate.

The limestones underlying the Arcadia are referred to as "Suwannee" limestone due to the uncertainty of the formational assignment. These sediments have characteristically been called "Suwannee" by previous workers despite the fact that they have never been accurately correlated with the typical Suwannee Limestone in northern Florida. Hunter (personal communication, 1984) believes that these carbonates are not Suwannee or the equivalent but are an unnamed limestone of Chickasawhayan Age (Late Oligocene).

Unconformably overlying the Arcadia Formation is the Peace River Formation (Figure 33). The Peace River Formation is predominantly a siliciclastic unit with varying amounts of carbonate beds. The percentage of carbonate beds is higher near the base of the Peace River, resulting in a transitional or gradational contact with the Arcadia. In some areas the contact is often marked by a phosphatic rubble zone and/or a phosphatized dolostone hardground. In the more gradational sequence the contact is placed where the carbonate beds become significantly more abundant than the siliciclastic beds.

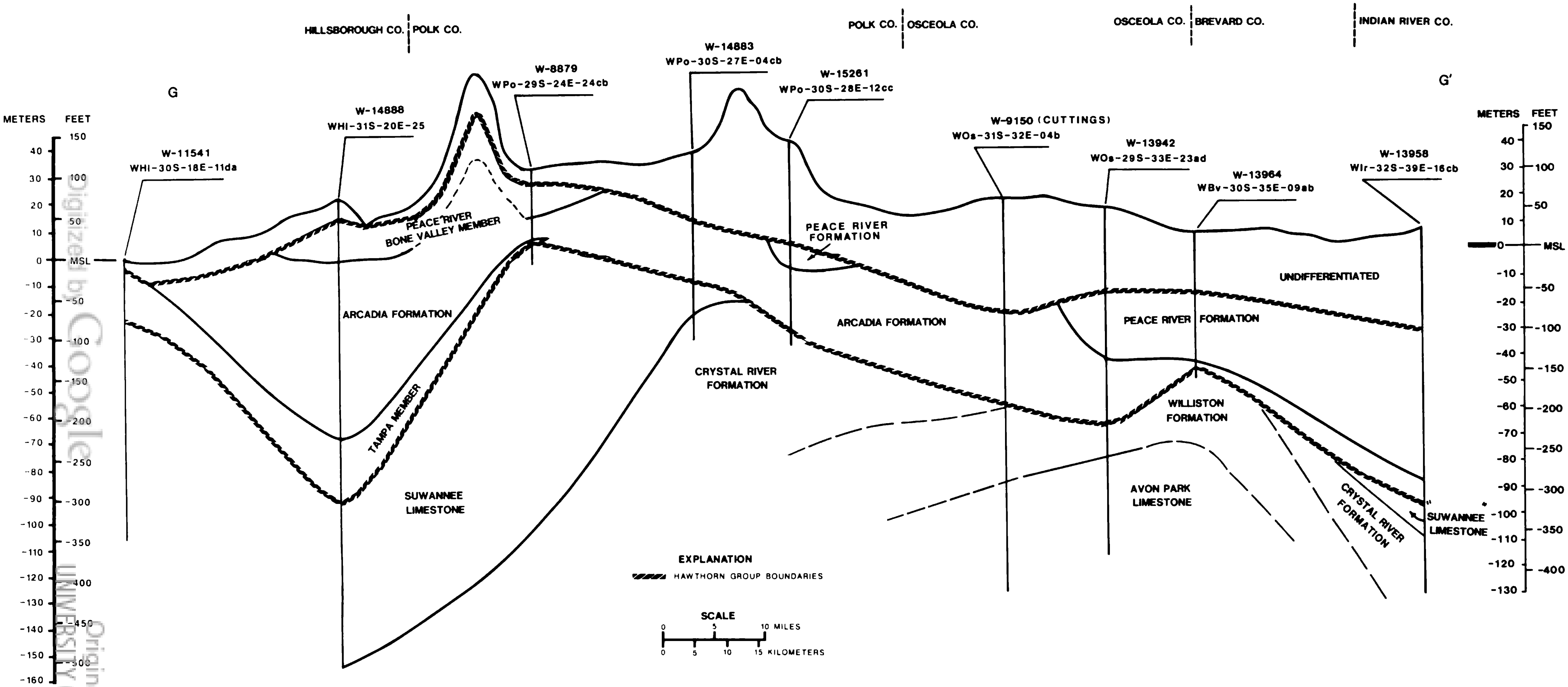


Figure 35. Cross section G-G' (see figure 3 for location).

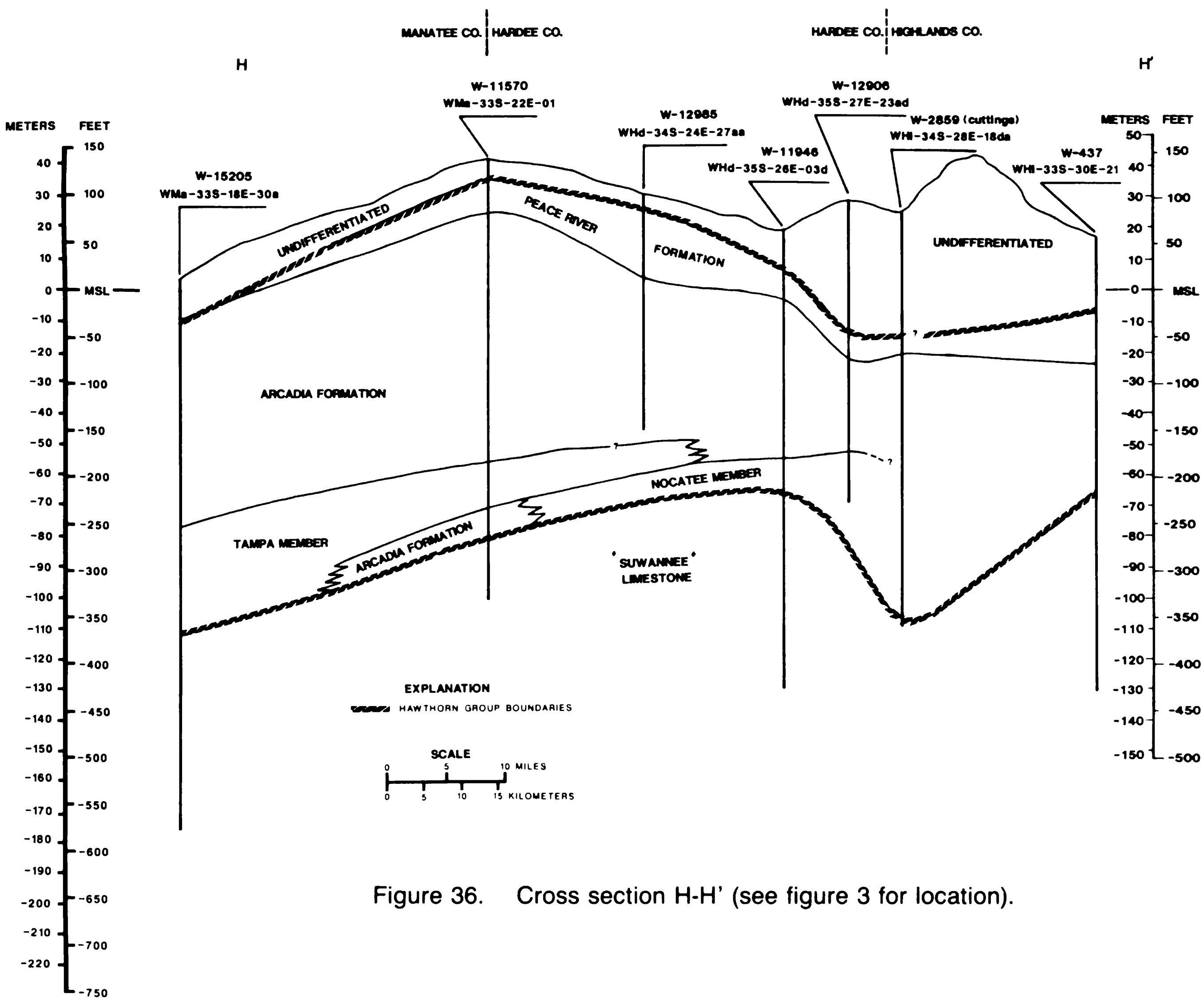


Figure 36. Cross section H-H' (see figure 3 for location).

The relationship of the subjacent and suprajacent units to the Arcadia Formation can be seen in the cross sections shown in Figures 35 through 40.

Thickness and Areal Extent

The Arcadia Formation occurs primarily as a subsurface unit throughout its extent. The top of the Arcadia Formation in cores ranges from -440 feet MSL (134 meters) in W-15493 Monroe County to greater than +100 feet MSL (30 meters) in several cores in Polk County (Figure 41). Data obtained from well cuttings in areas lacking core data indicated that the top of the Arcadia may be greater than -750 feet MSL (229 meters) in Palm Beach and Martin Counties (Figure 41).

The Arcadia Formation appears to be absent from the southern nose of the Ocala Platform, the Sanford High and part of the Brevard Platform (Figures 41 and 42). It increases in thickness away from these features, reaching a maximum of 593 feet (181 meters) in a core in Charlotte County (Southeast Florida Water Management District R.O.M.P. 3-3) and more than 650 feet (198 meters) in a well in southern Dade

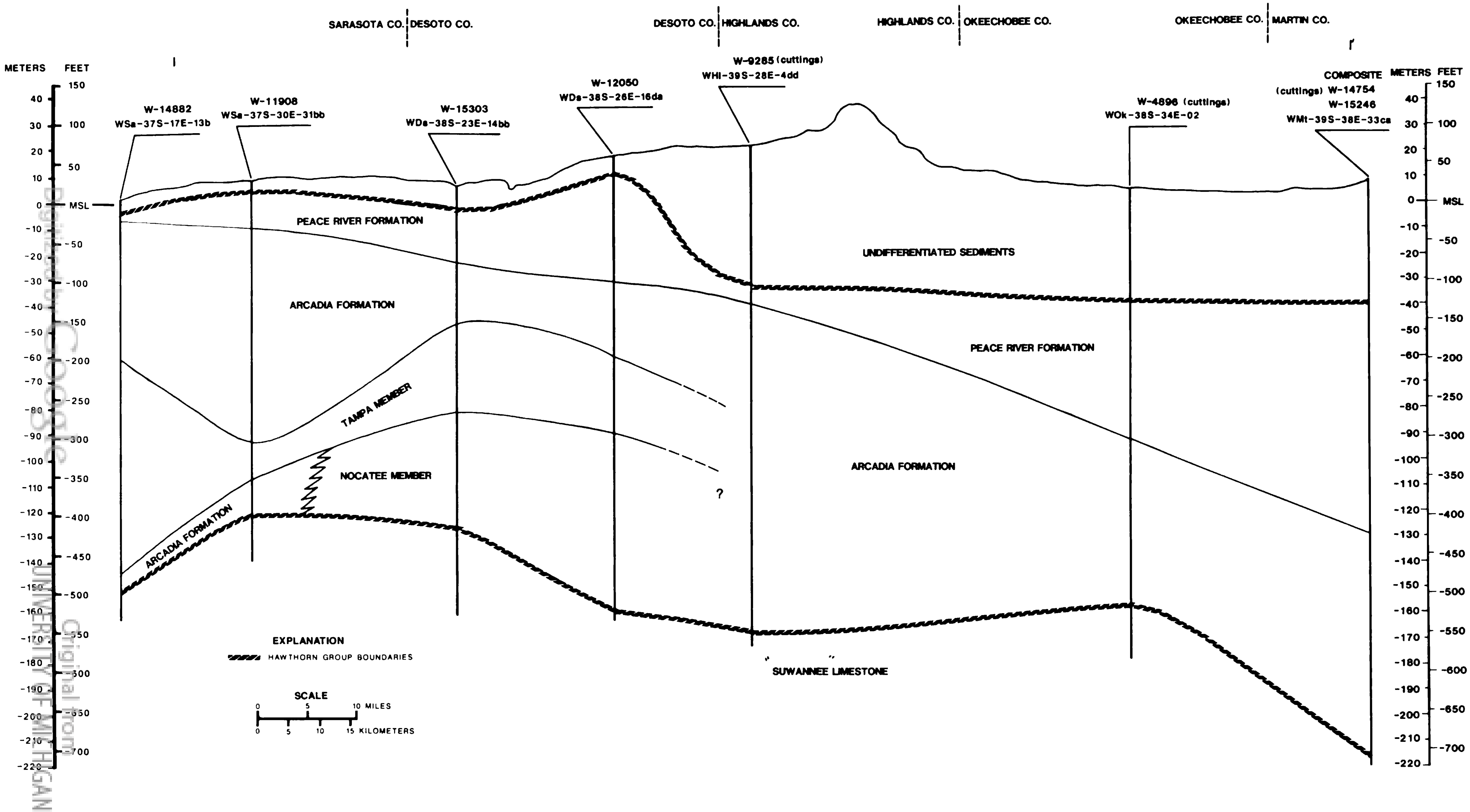


Figure 37. Cross section I-I' (see figure 3 for location).

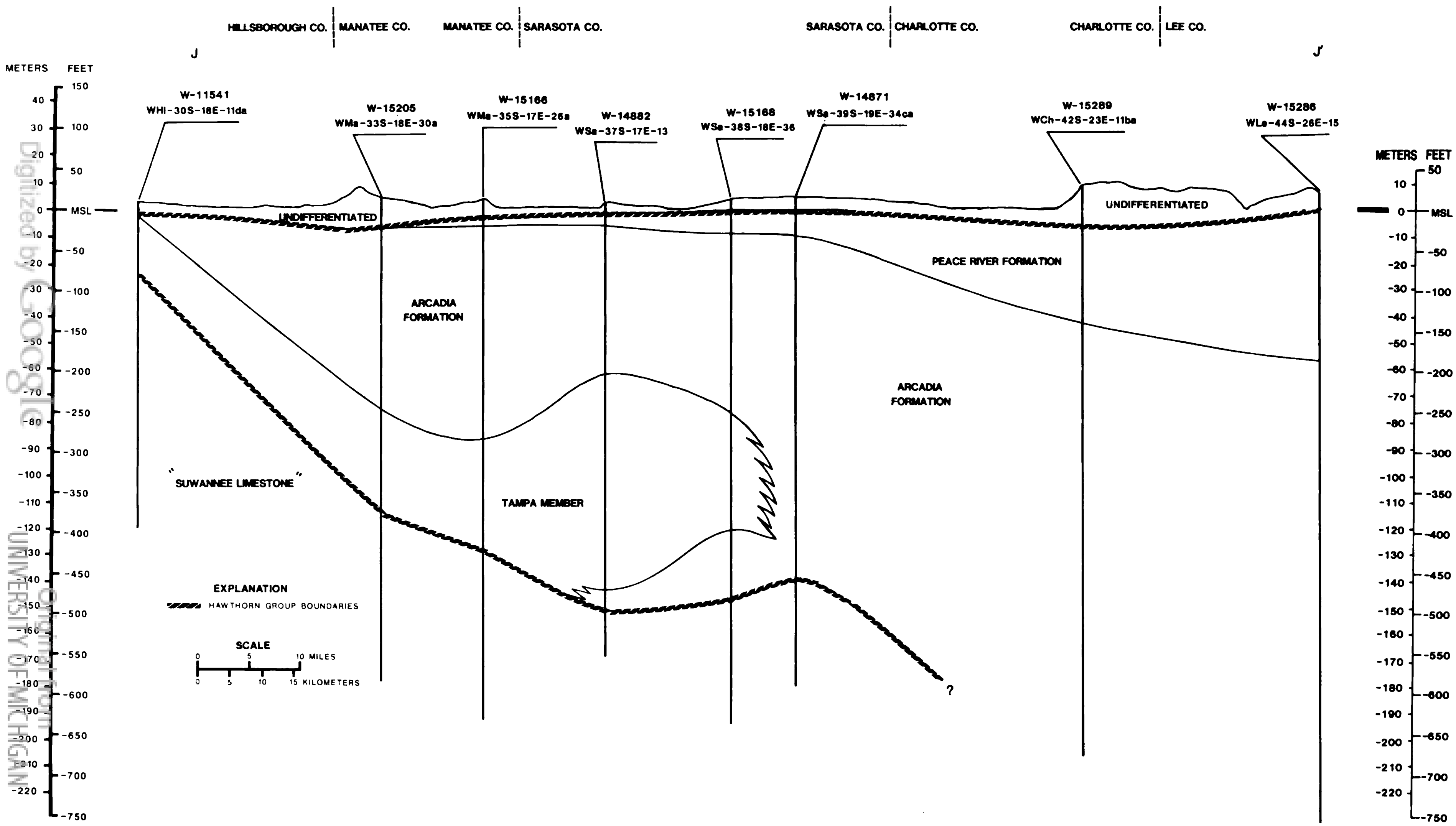


Figure 38. Cross section J-J' (see figure 3 for location).

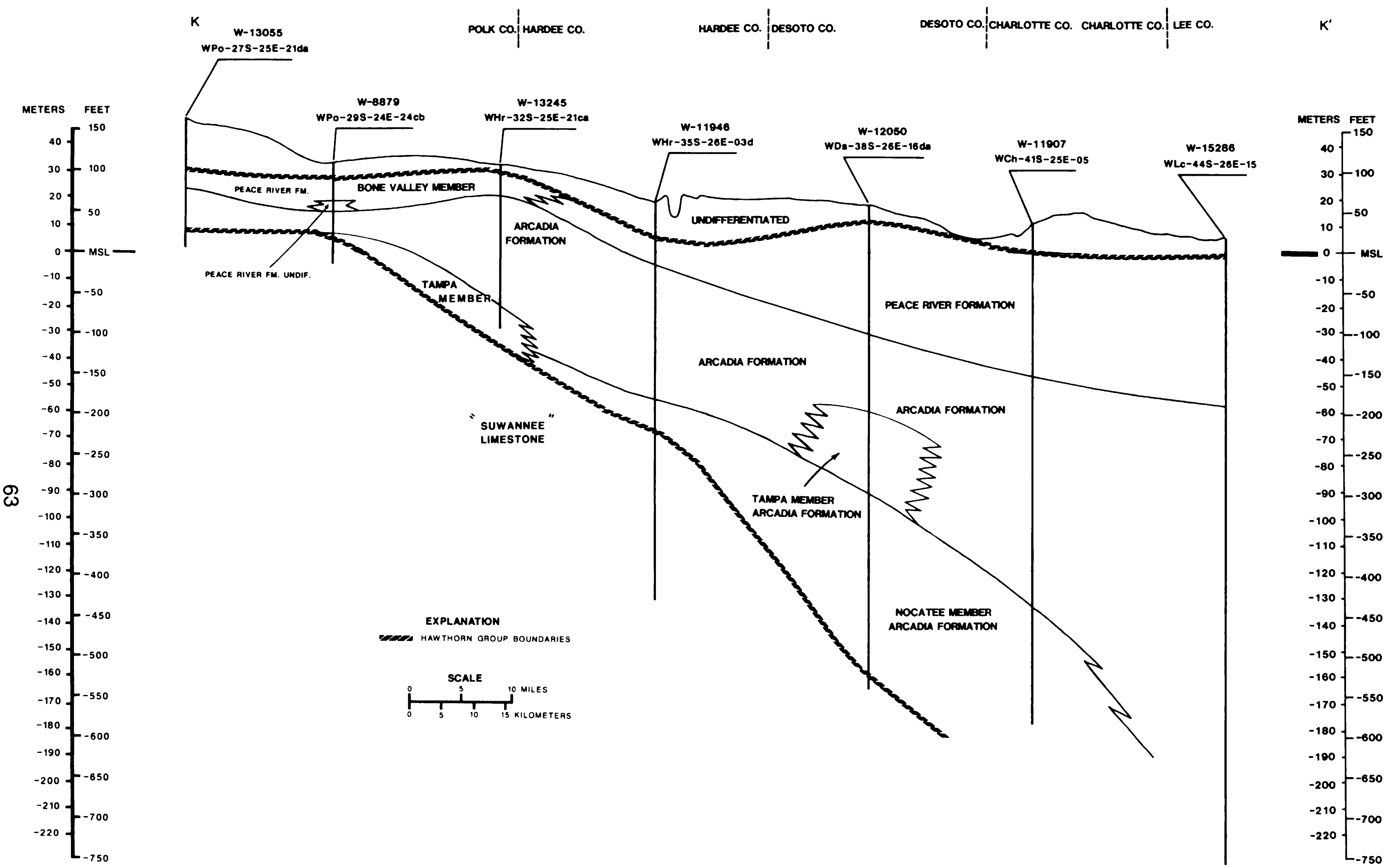


Figure 39. Cross section K-K' (see figure 3 for location).

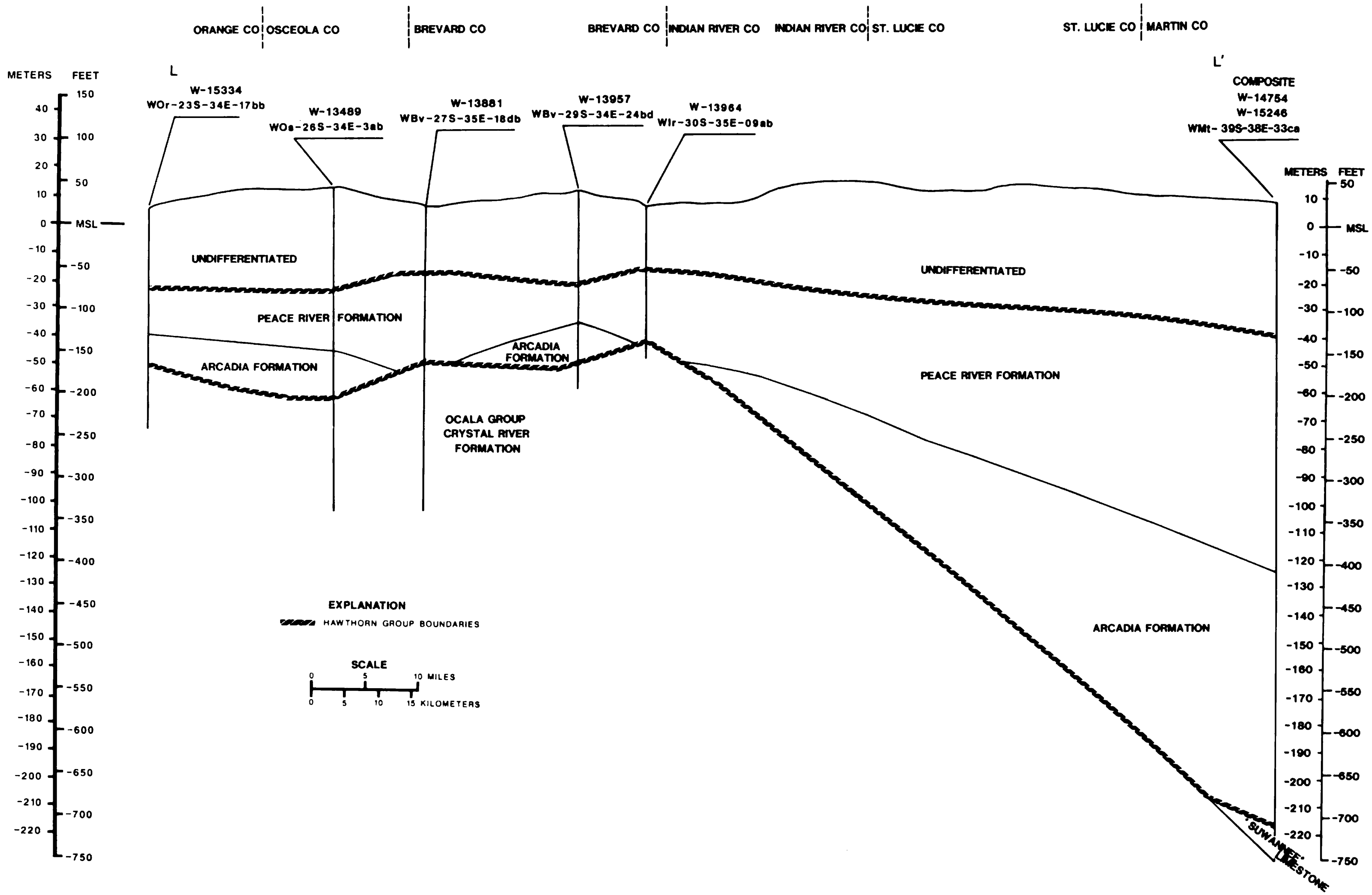


Figure 40. Cross section L-L' (see figure 3 for location).

County (Figure 42).

The dip of the Arcadia Formation exhibits some variability in the northern portion of the south Florida area (Figure 41). This is primarily due to the occurrence of the Ocala Platform, Osceola Low, Sanford High and the Brevard Platform (Figure 4). In general, however, the dip is to the southeast at approximately 5 feet per mile (0.9 meters per kilometer).

The basal unit of the Hawthorn Group is present throughout the south Florida area. It is apparently absent from the southern flanks of the Ocala Platform and the Sanford High and from part of the Brevard Platform. This is at least partially due to erosion prior to Peace River deposition. The Arcadia Formation is not identifiable in the area between the Ocala Platform and the Sanford High. A carbonate unit is present in this area, but it has characteristics attributable to both the Arcadia and Penney Farms Formations. Until further research can be conducted, the Hawthorn Group remains undifferentiated in this area.

In the southern portion of south Florida, the Arcadia contains an increasing percentage of very moldic (mollusk shell molds) limestones and the entire carbonate section becomes less phosphatic to the south.

The Arcadia Formation was tentatively identified in the Port Bougainville core, W-15493, Monroe County (upper Keys). The transition from the typical Arcadia in southwest Florida to that in the upper Keys is difficult to ascertain due to the nearly complete lack of core data and paucity of well cuttings in the area. Further research, when the data become available, will be necessary to clarify these questions.

Age and Correlation

The sediments of the Arcadia Formation have yielded few dateable fossil assemblages. Diagenesis of the original carbonate sediments has destroyed most fossil material leaving only casts and molds. From mollusk samples collected by Hunter (personal communication, 1984) in portions of southwest Florida, the upper part of the Arcadia correlates with part of the Marks Head Formation of north Florida and Georgia and the Torreya Formation of the Florida panhandle. This suggests that the upper Arcadia is no younger than mid-Burdigalian (late Eary Miocene) (Figure 19). The lower Arcadia seems to be equivalent to the Penney Farms Formation and part of the Parachucla Formation Georgia (Figure 19) (Huddlestun, personal communications, 1983; Hunter, personal communication, 1984). The base of the Arcadia may be as old as early to middle Aquitanian (early Early Miocene) (Figure 19).

Discussion

The Arcadia Formation as described in this report is important from both a hydrologic and economic viewpoint. Hydrologically, it incorporates several aquifers and confining units identified within the Hawthorn Group. Economically, the carbonates of the Arcadia form the base of the mineable phosphorite throughout much of the Central Florida Phosphate District. The Arcadia Formation as used here provide a coherent picture of the early part of the Miocene in southern Florida.

TAMPA MEMBER OF THE ARCADIA FORMATION

Definition and Type Section

The Tampa Member of the Arcadia Formation represents a lithostratigraphic change in status from formation to member. The Tampa has long been a problematic unit due to facies changes and apparent gradational contacts with overlying and underlying units. The change from formation to member is necessary due to the limited areal extent of the Tampa and its lithologic similarities and relationships with the remainder of the Arcadia Formation of the Hawthorn Group. The Tampa Member is predominantly a subsurface unit throughout its extent cropping out only in the Tampa area.

King (1979) and King and Wright (1979) thoroughly discussed the Tampa Member (their Tampa Formation) and its type locality. They designated Ballast Point core W-11541, Hillsborough County as the prin-

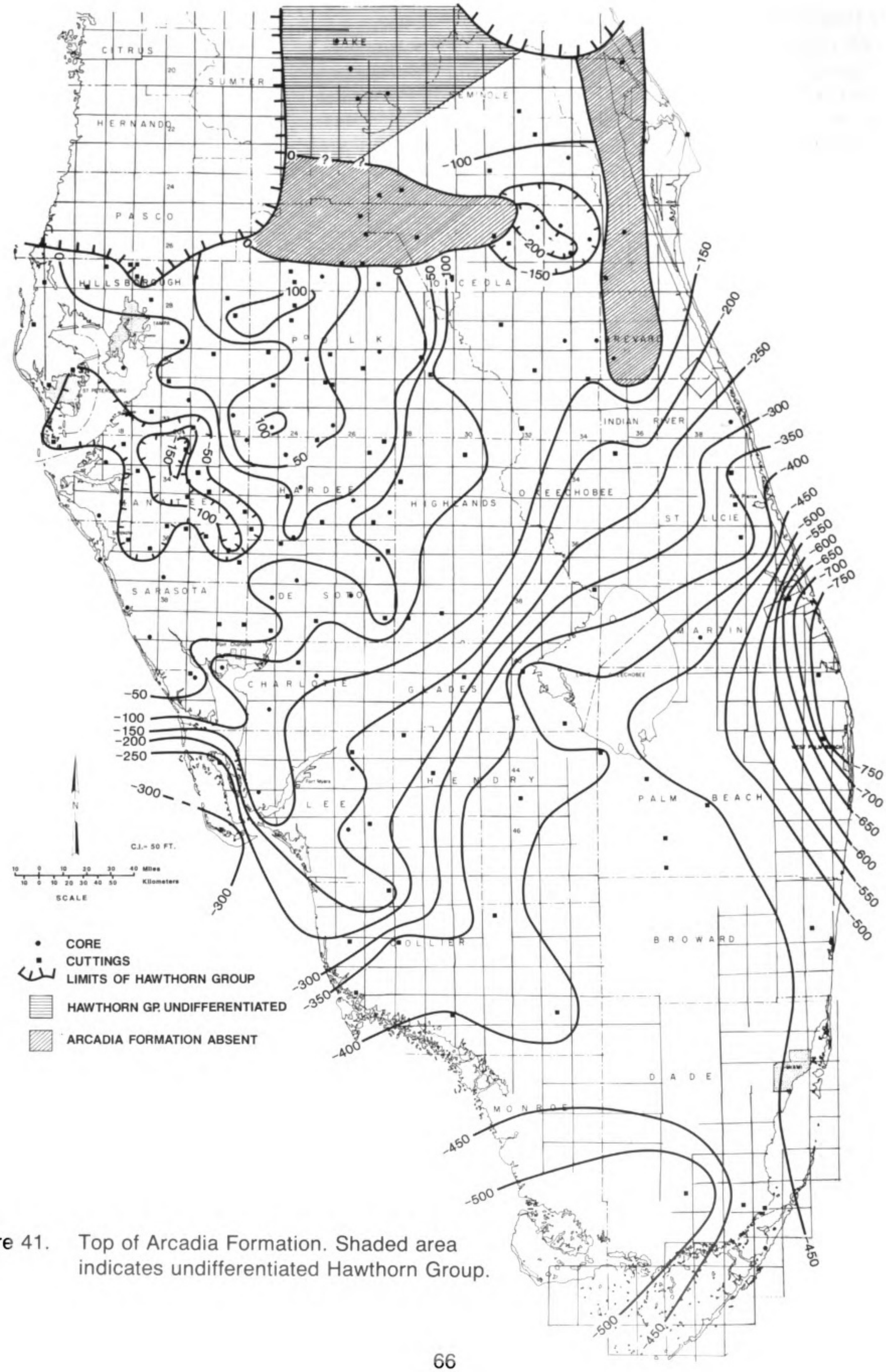


Figure 41. Top of Arcadia Formation. Shaded area indicates undifferentiated Hawthorn Group.

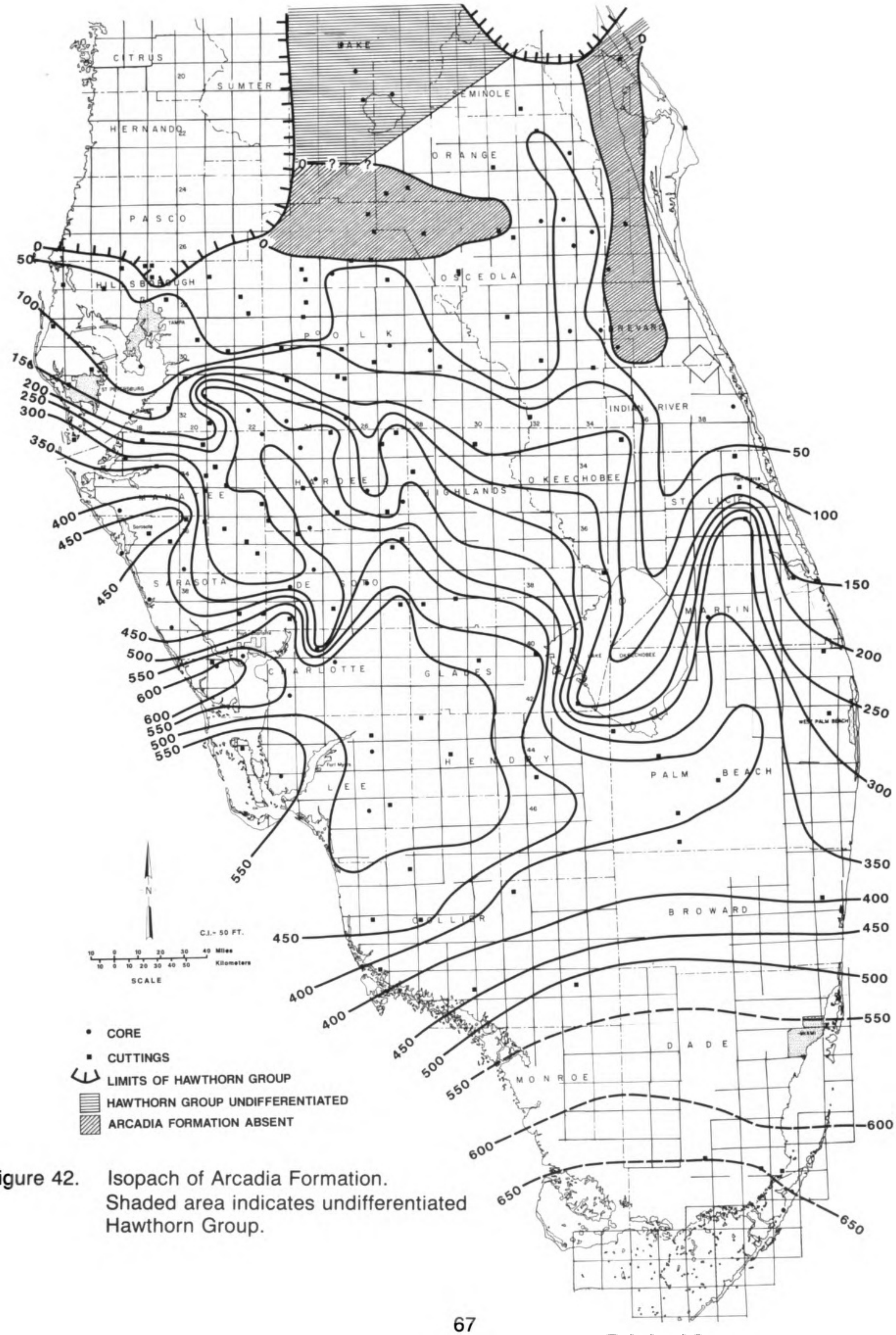


Figure 42. Isopach of Arcadia Formation. Shaded area indicates undifferentiated Hawthorn Group.

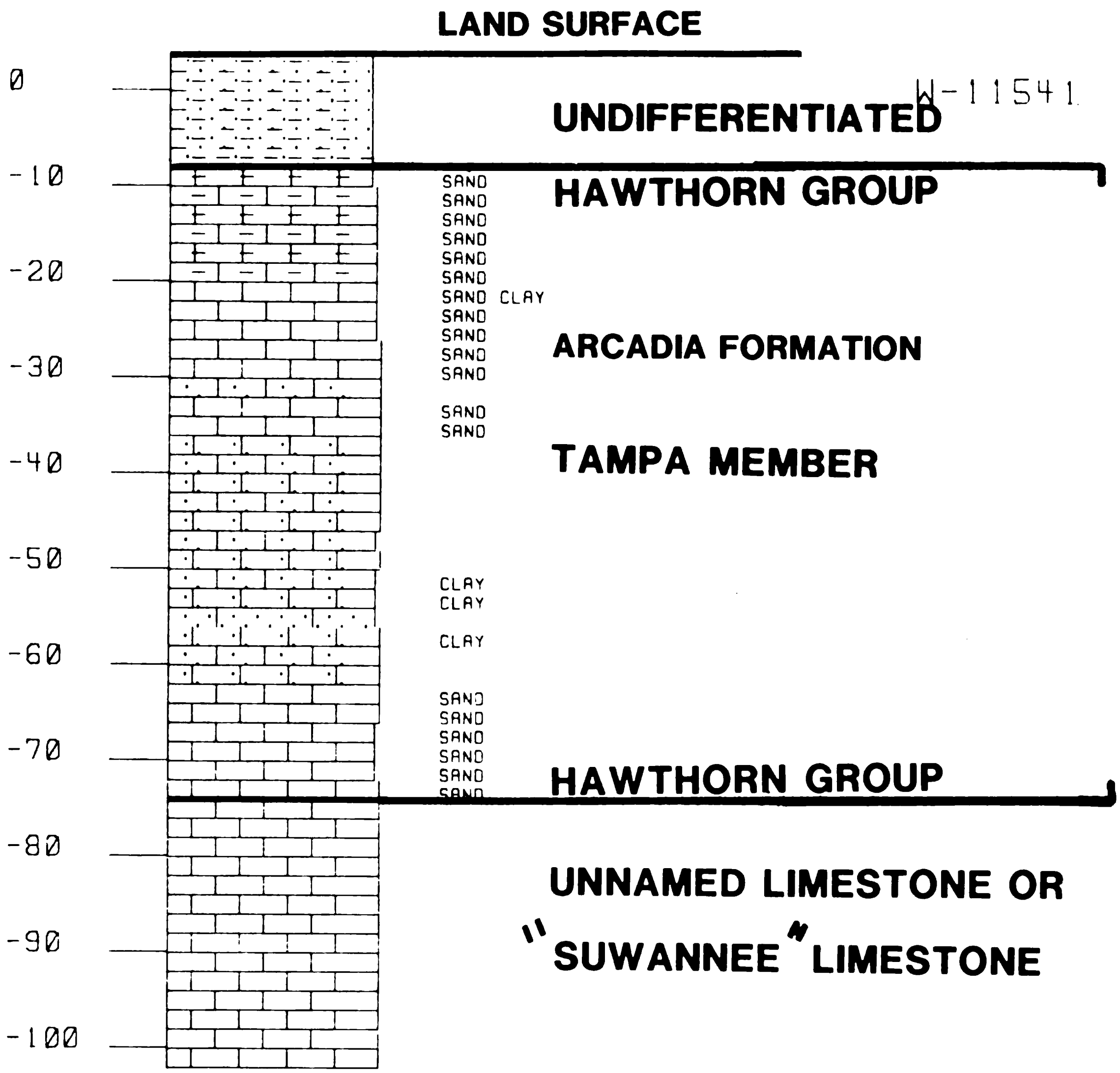


Figure 43. Reference core for the Tampa Member of the Arcadia Formation, Ballast Point #1, W-11541, Hillsborough County (Lithologic legend Appendix A).

cipal reference core (SE¼, NW¼, of Section 11, Township 30S, Range 18E). The Tampa Member occurs from -9 feet (-2.7 meters) MSL to -74 feet (-22.5 meters) MSL in this core (Figure 43). They also referred to two other cores (Duette #1, W-11570, Manatee County and Brandon #1, W-11531, Hillsborough County) as reference cores. This author also recognizes core W-15166 (Bradenton R.O.M.P. TR 7-1, W¼ of Section 26, Township 35S, Range 17E, Manatee County) as an excellent reference section for the Tampa Member. W-15166 contains the Tampa Member from -285 feet (-87 meters) MSL to -423 feet (-129 meters) MSL (Figure 44).

The classical type area of the Tampa Member lies around Tampa Bay at Ballast Point and Six Mile Creek (Dall and Harris, 1892). Unfortunately the type exposures do not completely or accurately represent the Tampa as it occurs in the subsurface. As a result the Tampa Member discussed in this paper as a formal member of the Arcadia Formation of the Hawthorn Group is described from the previously mentioned reference cores.

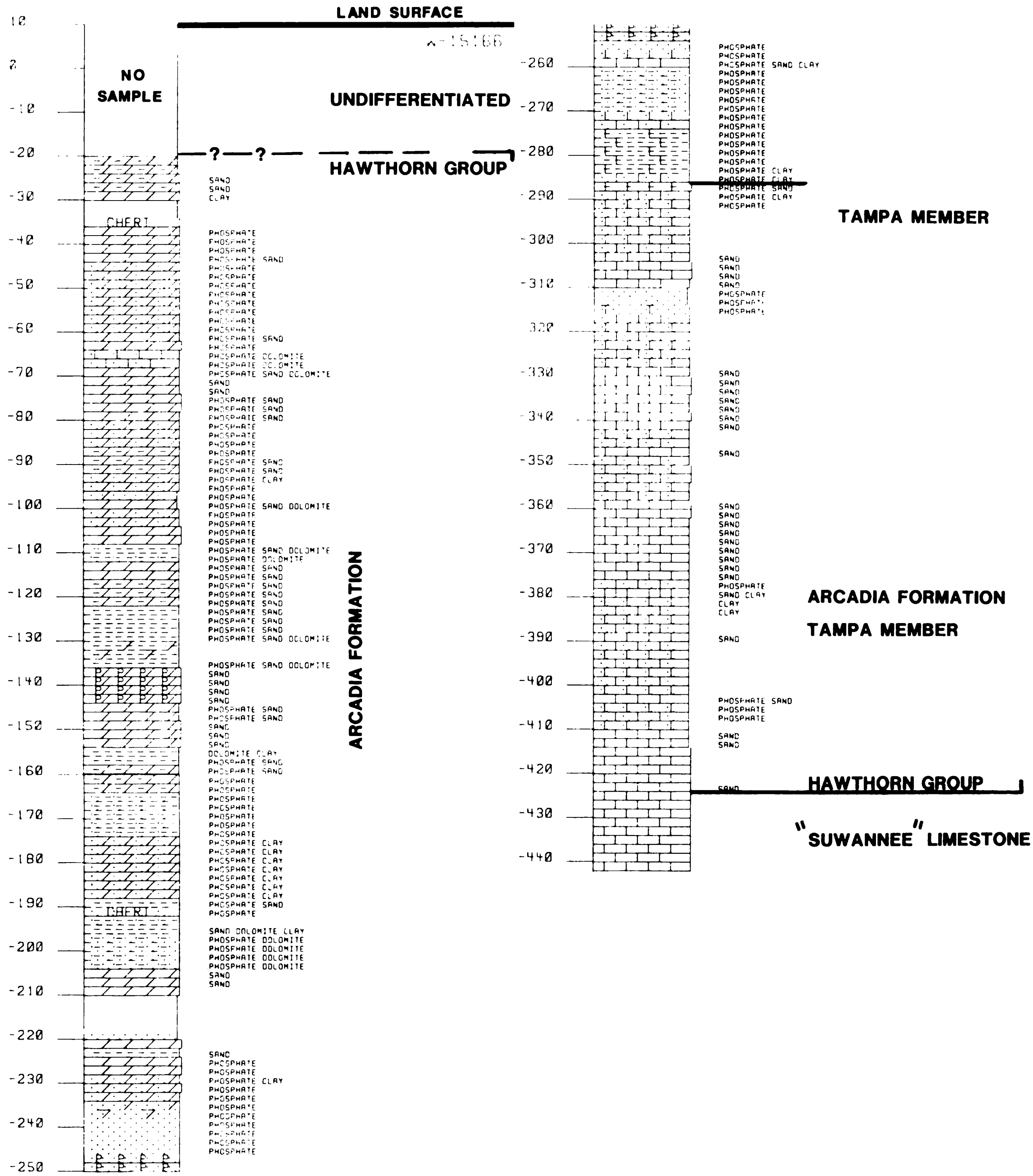


Figure 44. Reference core for the Tampa Member of the Arcadia Formation, R.O.M.P. 7-1, W-15166, Manatee County (Lithologic legend Appendix A).

Lithology

The Tampa Member consists predominantly of limestone with subordinate dolostone, sands, and clays. The lithology of the Tampa is very similiar to the limestone portion of the Arcadia Formation with the exception of its phosphate content which is almost always noticeably less than in the Arcadia. Phosphate grains generally are present in the Tampa in amounts less than 3 percent although beds containing greater percentages do occur, particularly near the facies change limits of the member.

Lithologically, the limestones are variably quartz sandy and clayey with minor to no phosphate. Fossil molds are often present and include mollusks, foraminifera and algae. Colors range from white (N 9) to yellowish gray (5 Y 8/1). The limestones range from mudstones to packstones but are most often wackestones. The dolostones are variably quartz sandy and clayey with minor to no phosphate. They are typically microcrystalline to very fine grained and range in color from pinkish gray (5 YR 8/1) to light olive gray (5 Y 6/1). The dolostones often contain fossil molds similar to those in the limestones.

Sand and clay beds occur sporadically within the Tampa Member. Lithologically, they are identical to those described for the Arcadia Formation except for the phosphate content which is significantly lower in the Tampa Member.

Siliceous beds are often present in the more updip portions of the Tampa. In the type area near Tampa Bay the unit is well known for silicified corals, siliceous pseudomorphs of many different fossils and chert boulders.

Subjacent and Suprajacent Units

The Tampa Member overlies the "Suwannee" Limestone in areas where the Nocatee Member is not present and the Tampa Member forms the base of the Arcadia. The boundary often appears gradational as discussed by King (1979) and King and Wright (1979). Figure 19 indicates an unconformable time relationship with the "Suwannee" Limestone which often is not apparent lithologically. This indicates a probable reworking of underlying materials into the Tampa Member obscuring the unconformity.

The Tampa Member overlies the Nocatee Member in the area where both are present (Figure 33). The contact appears conformable and is easily recognized. In a few areas where the Nocatee is absent, the Tampa may overlie undifferentiated Arcadia Formation sediments. The Tampa Member may be both overlain and underlain by undifferentiated Arcadia.

The Tampa Member is overlain throughout most of its extent by carbonates of the undifferentiated Arcadia Formation. The contact often appears gradational over one or two feet. An increase in phosphate grain content is the dominant factor in defining the lithologic break. In updip areas the Tampa may be overlain by siliciclastic sediments of the Peace River Formation. Further updip it may be exposed at the surface or covered by a thin veneer of unconsolidated sands and clays which may represent residuum of the Hawthorn sediments. Figure 35 through 39 show the relationship of the Tampa Member to the overlying and underlying units.

Thickness and Areal Extent

The Tampa Member is quite variable in thickness throughout its extent. It thins updip to its northern limit where it is absent due to erosion and possibly nondeposition. The thickest section of Tampa encountered is in W-14882 in Sarasota County where 270 feet (82 meters) of section are assigned to this member (Figure 45). More typically an average thickness is approximately 100 feet (30.5 meters).

The top of the Tampa Member (Figure 46) ranges in elevation from as high as +75 feet (23 meters) MSL in northeastern Hillsborough County to -323 feet (-98.5 meters) MSL in northern Sarasota County. The lowest elevation for the top of the unit occurs in a rather large depression that encompasses part of northern Sarasota County and southern Manatee County.

The Tampa dips towards the south in the northern half of the area of occurrence (Figure 46). Dip direction in the southern half is more to the southwest and west. Dip angle varies from place to place but the

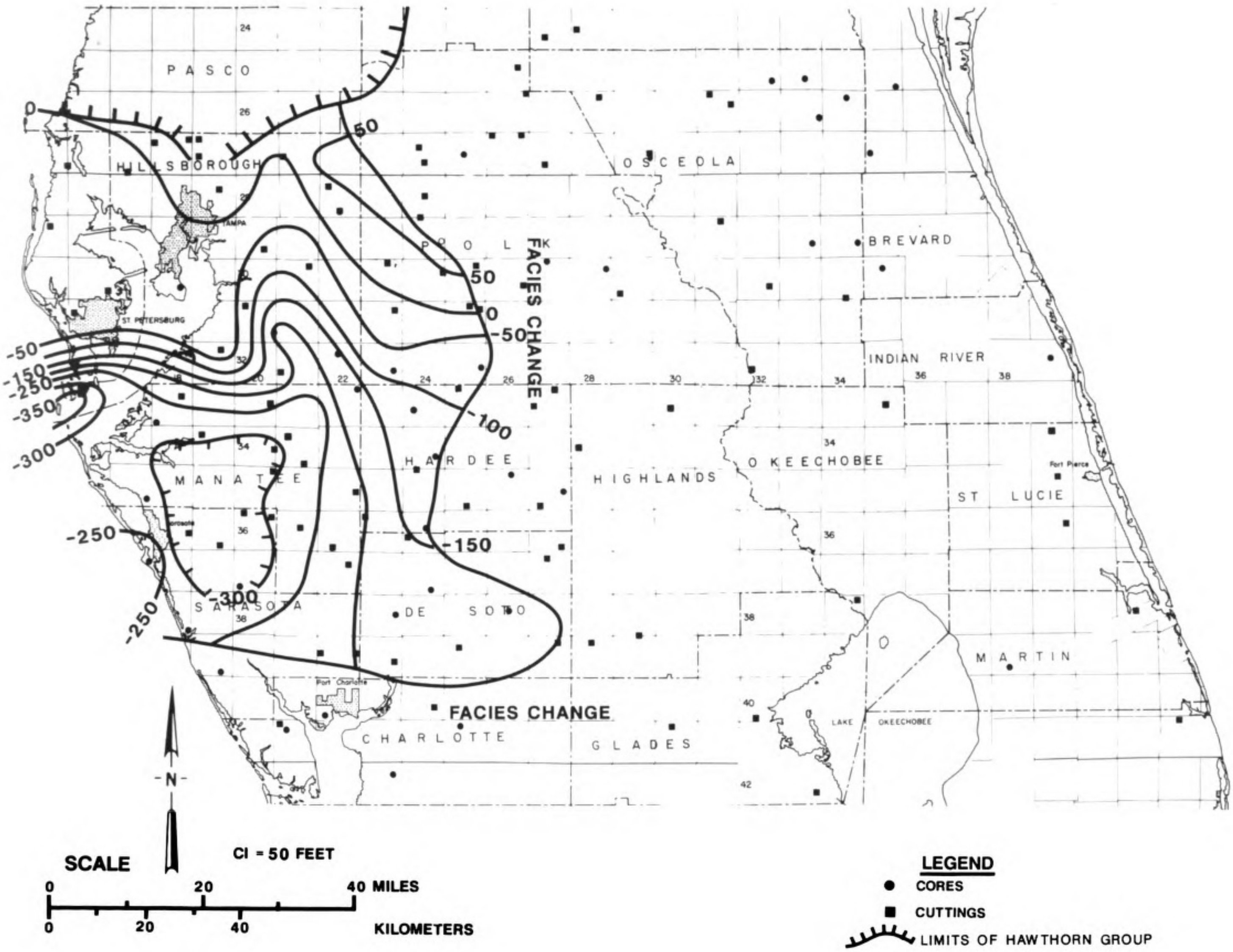


Figure 45. Top of Tampa Member.

average from highest to lowest point is approximately 8 feet per mile (1.5 meters per kilometer). The dip appears steeper in the northern and central area (Figure 46).

Figures 45 and 46 show the area of occurrence for the Tampa Member. North of this area, the Tampa has been removed by erosion and only a few, isolated, erosional remnants are present. In some areas its absence may be due to nondeposition. East and south of the area of occurrence, the Tampa grades laterally into the undifferentiated Arcadia Formation. It is important to note that relatively thin beds of Tampa lithology occur within the Arcadia Formation outside the area in which Tampa is mapped. These beds often occur sporadically throughout the lower Arcadia but are not thick enough and are too complexly interbedded with Arcadia lithologies to be mapped as Tampa Member. Characteristically, the Tampa is recognized when there are few beds of Arcadia lithologies interbedded with Tampa lithologies and the sequence of Tampa lithologies is sufficiently thick. Further data may permit more accurate definition of the limits of the Tampa Member.

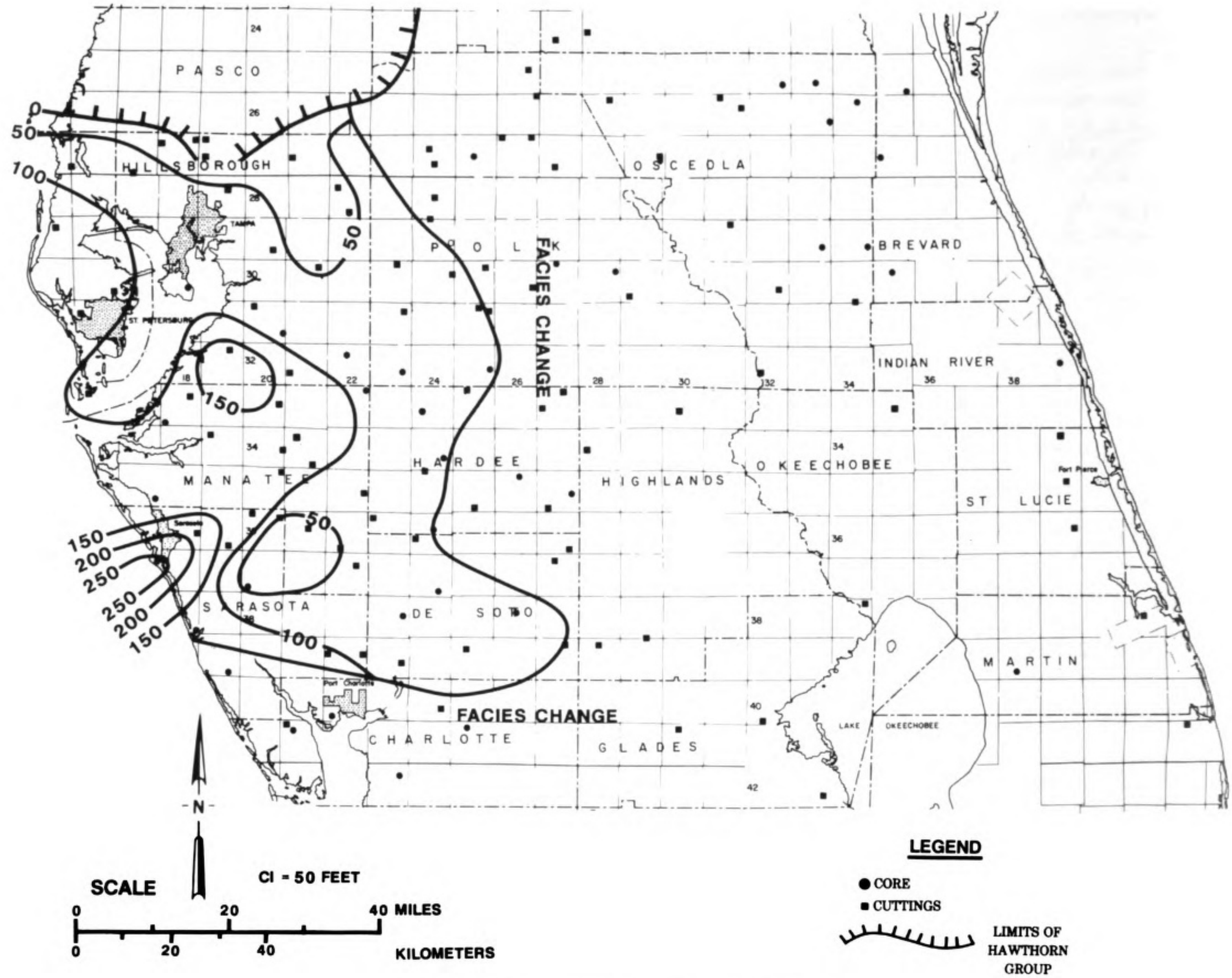


Figure 46. Isopach of Tampa Member.

Age and Correlation

The Tampa Member is characteristically variably fossiliferous. Mollusks are most common with corals and foraminifera also present. Despite the presence of these fossils, no age diagnostic species have yet been recognized.

MacNeil (1944) suggested the correlation of the Tampa with the Paynes Hammock Formation of Mississippi based on the mollusk fauna present in each. Poag (1972) dated the Paynes Hammock Formation using planktic foraminifera and suggested a Late Oligocene age (N2-N3 of Blow, 1969). Huddlestun (personal communication, 1984) indicates that the Tampa Member equates with part of the Parachucla Formation in Georgia and straddles the boundary between the Oligocene and Miocene. Hunter (personal communication, 1984) agrees with Huddlestun and correlates the Tampa with part of the lower Parachucla. Hunter also feels that much of what is incorporated into the Tampa Member in this paper is older than the original type Tampa (Silex Beds) at Ballast Point and Six Mile Creek. The Tampa is also correlated with part of the Penney Farms Formation in north Florida (Figure 19).

Discussion

The introduction of the Tampa as a member of the Arcadia Formation represents a status reduction from formation. The reduction is necessary due to the limited areal extent of the Tampa and its interfingering, gradational nature with part of the Arcadia Formation. The historical significance of the Tampa and its widespread use suggest a retention of the name. This revision of the Tampa hopefully will provide an understandable, useable unit of local extent and places it within a regional perspective.

NOCATEE MEMBER OF THE ARCADIA FORMATION

Definition and Type Section

The Nocatee Member is a new name introduced here for sediments at the base of the Arcadia Formation in parts of southwest Florida. Previously, this interval had been informally called the "sand and clay unit" of the Tampa Limestone by Wilson (1977). This unit is recognized only in the subsurface. The Nocatee Member is named for the town of Nocatee in central DeSoto County, Florida. The type core is W-12050, Hogan #1, located in the SE ¼, NW ¼, Section 16, Township 38S, Range 26E, with a surface elevation of 62 feet (19 meters). The type Nocatee occurs between -294 feet (-89.5 meters) MSL and -520 feet (-158.5 meters) MSL (Figure 47). The type core was drilled by the Florida Geological Survey.

Lithology

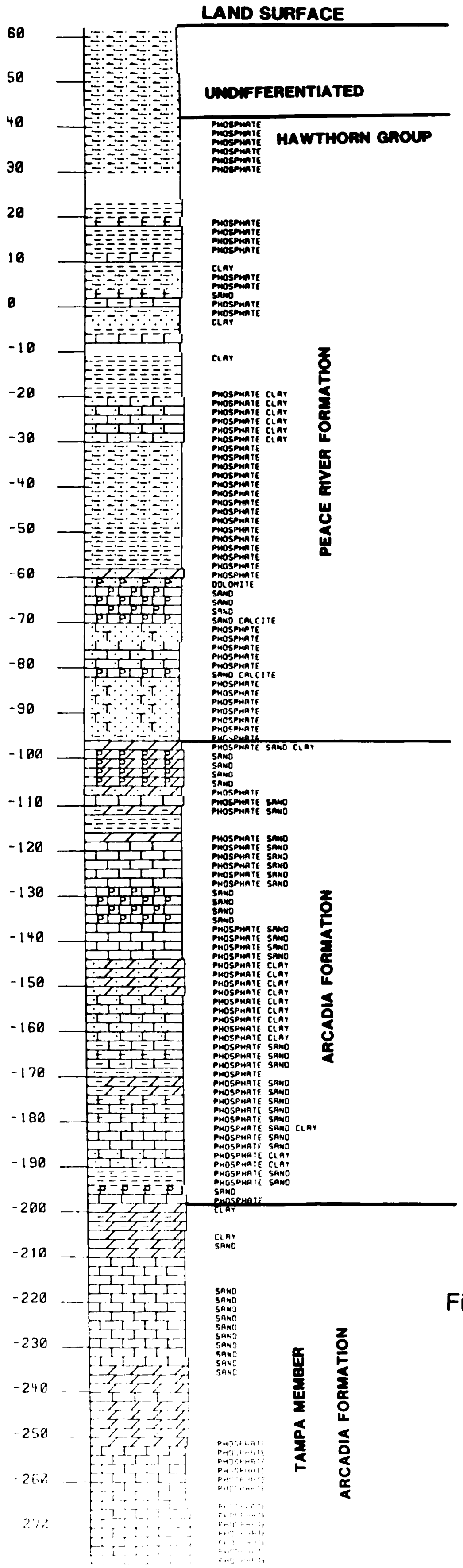
The Nocatee Member is a complexly interbedded sequence of quartz sands, clays, and carbonates, all containing variable percentages of phosphate. Figure 47 shows the nature of the Nocatee in W-12050 in central Desoto County.

The Nocatee is a predominantly siliciclastic unit in the type core (W-12050). This is a noticeable change from the remainder of the Arcadia Formation including the Tampa Member, which are predominantly carbonates with variable percentages of included siliciclastics. The quartz sands in the Nocatee are typically fine to coarse grained, occasionally silty, clayey and calcareous to dolomitic. The quartz sands range in color from white (N 9) to light olive gray (5 Y 6/1). Phosphate grain content is quite variable. In the type core, phosphate grain content is generally low (1-3 percent) with scattered beds with greater concentrations (up to 10 percent). However, in the Nocatee Member in other cores (W-15303, for example, Figure 48), phosphate grains are more common, averaging about 7-8 percent.

Clay beds are quite common in the Nocatee Member and are variably quartz sandy, silty, phosphatic, and calcareous to dolomitic. The colors characteristically range from yellowish gray (5 Y 8/1) to light olive gray (5 Y 6/1) and olive gray (5 Y 4/1). Limited x-ray data suggest that the characteristic clay mineral present is smectite, with palygorskite common. Illite and sepiolite are also present. Further analyses are needed to confirm the identifications and relative abundances of these clay minerals within the Nocatee Member.

Limestone and dolostone are both present in this member. The ratio of limestone to dolostone is variable, as can be seen by comparing W-12050 (Figure 47) with W-15303 (Figure 48). The limestones are generally fine grained, soft to hard, quartz sandy and phosphatic. The percentage of clay present is quite variable and grades into the clay lithology. Colors of the limestone vary from white (N 9) to yellowish gray (5 Y 8/1) and light olive gray (5 Y 6/1), generally in response to clay content. The limestones are usually wackestones with varying degrees of recrystallization and cementation.

The dolostones are quartz sandy, phosphatic, soft to hard, and micro- to very finely crystalline. Variable amounts of clay are present. Colors range from yellowish gray (5 Y 8/1) to light gray (N 7), light olive gray (5 Y 6/1) and grayish brown (5 Y 3/2).



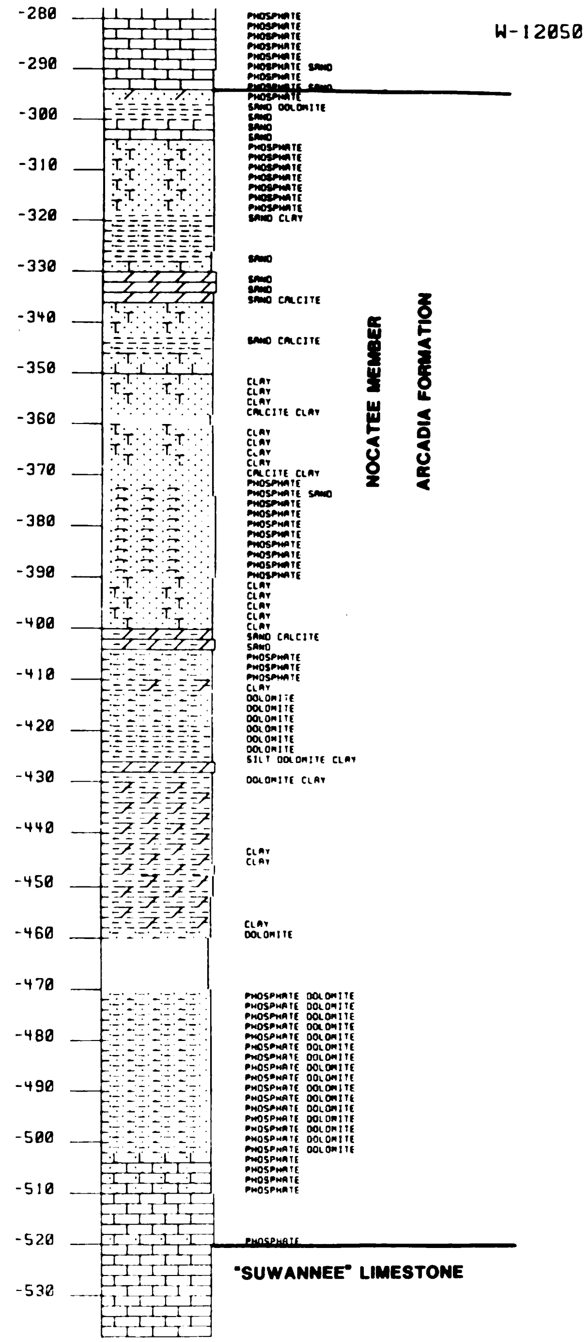


Figure 47. Type core for the Nocatee Member of the Arcadia Formation, Hogan #1, W-12050, DeSoto County (Lithologic legend Appendix A).

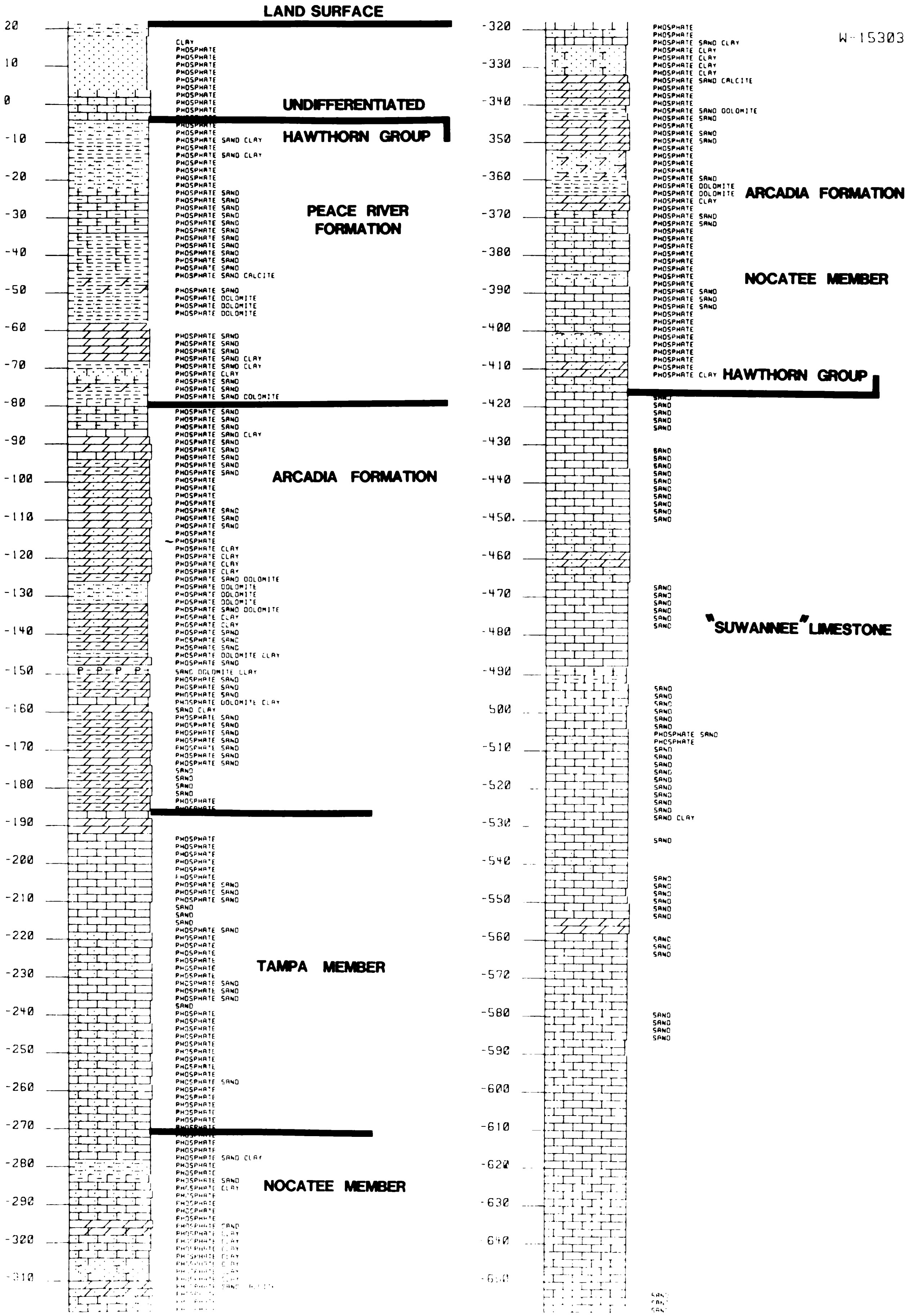


Figure 48. Reference core for the Nocatee Member of the Arcadia Formation, R.O.M.P. 17, W-15303, DeSoto County (Lithologic legend Appendix A).

Fossils are often present in the Nocatee, most often as molds. However, in some of the clay beds diatoms are present but have not been identified. Fossils present include mollusks, algae, foraminifera and corals.

Subjacent and Suprajacent Units

The Nocatee Member overlies limestones currently assigned to the "Suwannee" Limestone. The contact between the units often appears gradational from the basal, quartz-sandy, phosphatic, occasionally clayey carbonates of the Nocatee into the slightly quartz sandy, non-phosphatic limestones of the "Suwannee" (Figures 47 and 48). Occasionally, the basal Nocatee is a siliciclastic unit and it is easily differentiated from the limestones of the "Suwannee." The contact is suggested to be a disconformity based on paleontology (Huddlestun, personal communication, 1984).

The Tampa Member overlies the Nocatee throughout much of the area. The top of the Nocatee is generally placed at the top of the siliciclastic section below the Tampa (as in W-12050, Figure 47). However, occasionally there is a carbonate bed at the top of the Nocatee which contains too much phosphate to be included in the Tampa. This bed is taken as the top of the Nocatee Member. Occasionally, the Nocatee is overlain by carbonates of the undifferentiated Arcadia Formation. The relationships of the Nocatee with the subjacent and suprajacent units are shown in Figures 36, 37, and 39.

Thickness and Areal Extent

The Nocatee Member ranges in thickness up to 226 feet (70 meters) in W-12050 DeSoto County (Figure 49). Other cores in Charlotte County stopped in the Nocatee, in areas where it may be thicker. Further coring or properly sampled cuttings are needed to delinate the thickness and, possibly, the extent of the Nocatee in this area.

The top of the Nocatee ranges in depth from -81 feet (-24.5 meters) MSL in Polk County to -639 feet (-195 meters) MSL in Charlotte County (Figure 50). In general the upper surface dips to the south and southeast at an average of 7.5 feet per mile (1.7 meters per kilometer).

The Nocatee Member is of rather limited areal extent as is the Tampa Member. It has been identified in parts of Polk, Hardee, DeSoto, Charlotte, Manatee, Hillsborough, Sarasota, and possibly Highlands Counties. The lateral limits of this unit in most cases are the result of facies changes (Figures 49 and 50). In portions of the updip area, the Nocatee may be represented by a clay unit present in the Tampa, as discussed by Gilboy (1983). The extent of the Nocatee to the south and east is questionable at this time due to a lack of subsurface data (Figures 49 and 50).

Age and Correlation

The age of the Nocatee Member is based completely on its subjacent positioning to the Tampa Member and its suprajacent position to the "Suwannee" Limestone of south Florida. It is older than part of the Tampa Member, equivalent to part of the Tampa, and younger than the underlying Oligocene carbonates. This suggests an earliest Miocene age for the unit. At the present time there have been no attempts to date the unit paleontologically.

The Nocatee grades laterally westward and southward into very quartz-sandy, phosphatic carbonates of the undifferentiated Arcadia Formation. Eastward the unit grades into a more siliciclastic-rich east coast facies of the undifferentiated Arcadia. Northward, it appears that the Nocatee grades into the basal Tampa Member. The Nocatee correlates with the lower part of the type Tampa Member. It is also correlative with part of the lower Penney Farms Formation of north Florida and the lower Parachucla of southeast Georgia (Figure 19).

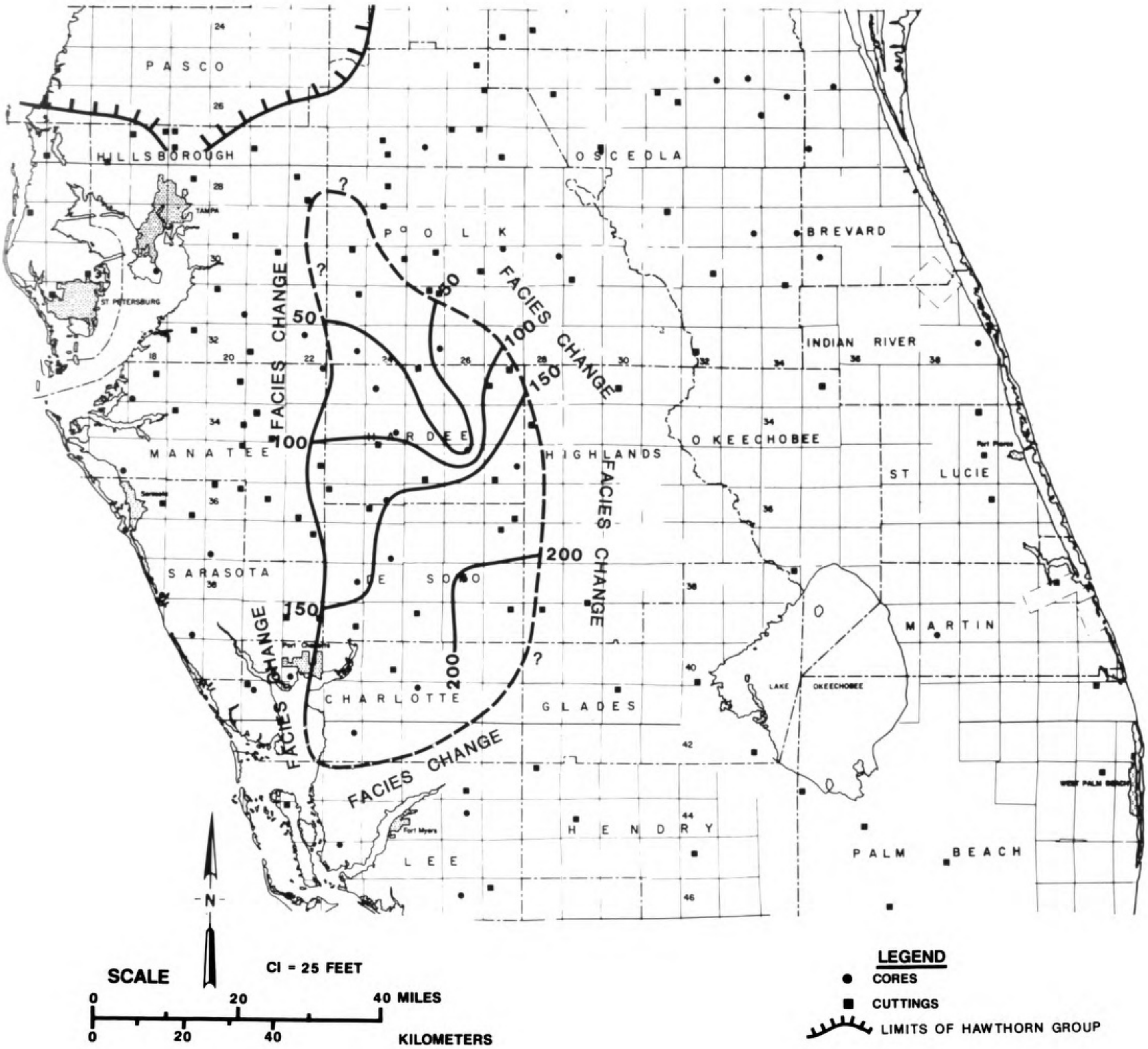


Figure 49. Isopach of Nocatee Member.

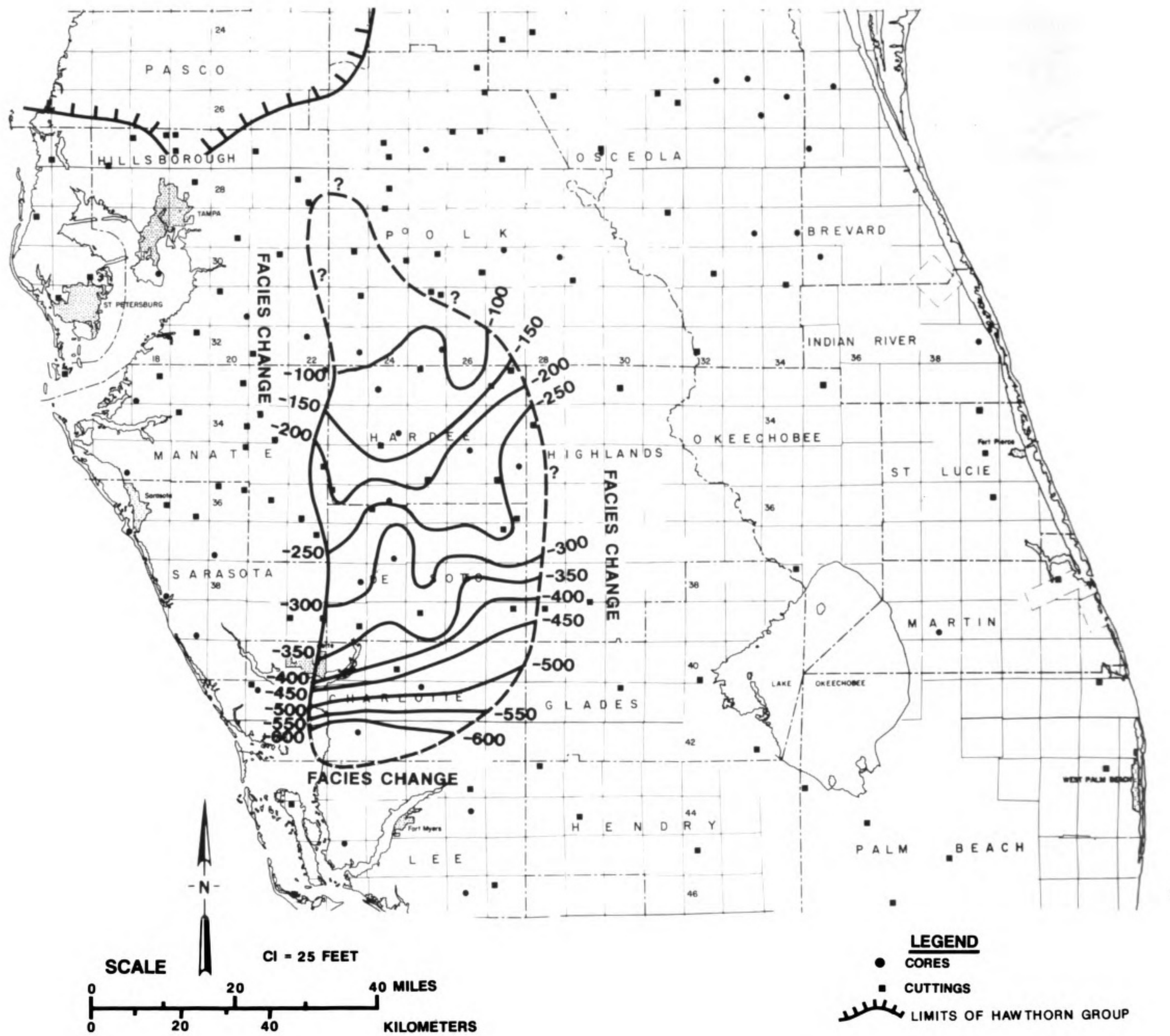


Figure 50. Top of Nocatee Member.

Discussion

The sediments of the Nocatee Member have been recognized for some time. The name "Tampa sand and clay unit" represents the first published name applied to these sediments (Wilson, 1977). Although these sediments are of limited areal extent, their distinctive lithology suggests the formal recognition of these sediments as a member of the Arcadia Formation. Outside the recognized area of occurrence equivalent carbonate sediments of the Arcadia Formation are often very sandy and may contain thin clay beds. The equivalence of the two units is recognized by the stratigraphic position.

PEACE RIVER FORMATION

Definition and Type Section

The Peace River Formation is a new formational rank name proposed for the combined upper Hawthorn siliciclastic strata and the Bone Valley Formation. The upper Hawthorn siliciclastic strata include siliciclastic beds previously placed in the Tamiami Formation (Parker, 1951) and the Murdock Station and Bayshore Clay members of the Tamiami Formation (Hunter, 1968). The formation is named for the Peace River which occurs in the vicinity of the type section in core W-12050.

The type section for the Peace River Formation is designated as core W-12050, Hogan #1, located in east central DeSoto County, Florida (SE ¼, NW ¼ Section 16, Township 38S, Range 26E) with a surface elevation of 62 feet (19 meters). The type Peace River Formation occurs between +41 feet (+12.5 meters) MSL and -97 feet (-29.5 meters) MSL (Figure 51).

W-15303, R.O.M.P. #17, is suggested as a reference section (Figure 48). R.O.M.P. #17 is located west of W-12050 in the west central part of DeSoto County (NE ¼, NE ¼ Section 14, Township 38S, Range 23E, surface elevation 22 feet (6.5 meters)). The Peace River Formation occurs between -3 feet (-1 meter) MSL and -77 feet (-23.5 meters) MSL in W-15303.

Lithology

The Peace River Formation consists of interbedded quartz sands, clays and carbonates. The siliciclastic component predominates and is the distinguishing lithologic feature of the unit. Typically the siliciclastics comprise two-thirds or more of the formation.

The quartz sands are characteristically clayey, calcareous to dolomitic, phosphatic, very fine to medium grained, and poorly consolidated. Their color ranges from light gray (N 7) and yellowish gray (5 Y 8/1) to olive gray (5 Y 4/1). The phosphate content of the sands is highly variable. In the type section (W-12050), the phosphate content is lowest in the upper part of the section and greatest near the base. The same is true for the reference section in W-15303. The phosphate occurs both as sand- and gravel-sized particles. The gravels are most abundant in the Bone Valley Member, although they may occur elsewhere in the unit.

Clay beds are quite common in the Peace River Formation. The clays are quartz sandy, silty, calcareous to dolomitic, phosphatic, and poorly to moderately indurated. Color ranges from yellowish gray (5 Y 8/1) to olive gray (5 Y 4/1). Reynolds (1962) characterized the clay minerals as consisting of smectite (montmorillonite), palygorskite (attapulgite) and sepiolite. Strom (personal communication, 1984) and Barwood (personal communication, 1984) agree that smectite and palygorskite are the dominant clay minerals in the formation.

Carbonates occur throughout the Peace River Formation. Characteristically they comprise less than 33 percent of the Peace River section. The carbonates may be either limestone or dolostone. Updip (northward), dolostone occurs more frequently. The limestones are characteristically variably sandy, clayey and phosphatic, poorly to well indurated, mudstones to wackestones. They vary in color from yellowish gray (5 Y 8/1) to white (N 9). Dolostones are micro- to very finely crystalline, variably sandy, clayey and phosphatic, and poorly to well indurated. Colors range from light gray (N 7) to yellowish gray

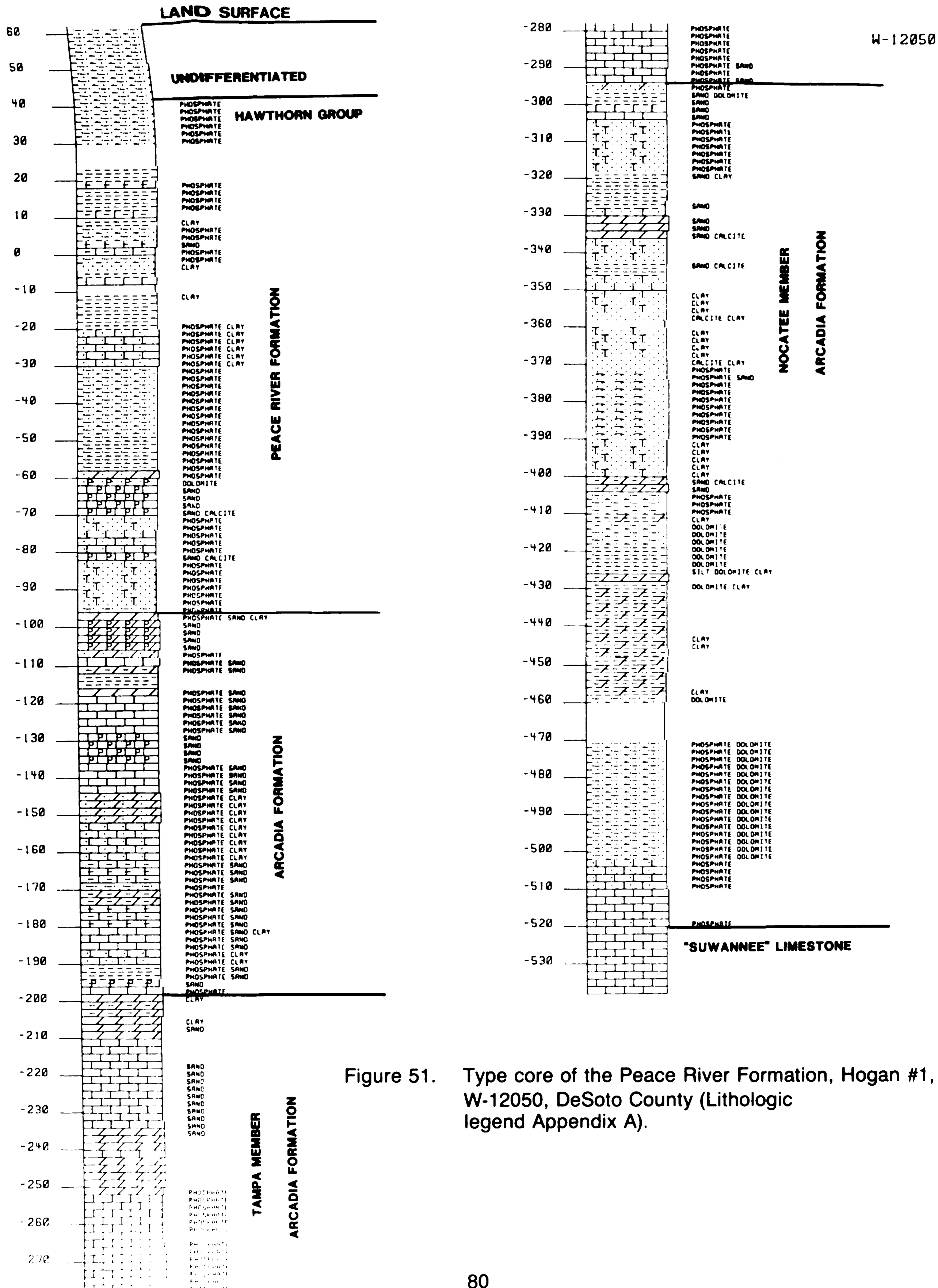


Figure 51. Type core of the Peace River Formation, Hogan #1, W-12050, DeSoto County (Lithologic legend Appendix A).

(5 Y 8/1). Mollusk molds are common throughout the carbonates. Occasionally dolomite occurs as a dolosilt (composed of unconsolidated, silt-sized dolomite rhombs). The dolosilts contain variable amounts of clay, are generally only slightly sandy and phosphatic, and do not contain fossil molds or fragments.

Chert occurs sporadically in the Peace River Formation. Characteristically it appears to be a replacement of the carbonates although silicified clays do occur. The cherts are opaline and are suggestive of localized "alkaline lake" deposition, as described by Upchurch, Strom and Nuckels (1982) and Strom and Upchurch (1983).

Subjacent and Suprajacent Units

The Peace River Formation disconformably overlies the Arcadia Formation throughout its extent. The contact often appears unconformable updip and conformable (gradational) downdip (Figure 35 through 40). The gradational appearance is due to the repetition of similar lithologies in both formations. When the boundary appears gradational the base of the Peace River Formation is placed where the carbonates become dominant over the siliciclastic beds (Figures 48 and 51). As was previously mentioned in the discussion of the Arcadia Formation, the contact may also be marked by a rubble zone.

The sediments overlying the Peace River Formation are assigned to several formations. In the south Florida area and the southern part of east central Florida, the limestone and sand facies of the Tamiami Formation unconformably overlie the Peace River. Sediments disconformably suprajacent to the Peace River Formation in the west central Florida area (Polk, Hillsborough, Manatee, Sarasota, and Charlotte Counties) and parts of east central Florida are generally unnamed, nonphosphatic sands (often surficial) and unnamed fossiliferous sands and shell beds. The contact with the surficial sands is often obscure due to leaching of the phosphate and clays in the upper portion of the Peace River Formation. In the central and south central section, unfossiliferous non-phosphatic to very slightly phosphatic sands overlie the Peace River. These sands have been called "Citronelle" Formation (Cooke and Mossom, 1929; Cooke, 1945) and "Fort Preston" Formation (Puri and Vernon, 1964). In Georgia, these sands are currently assigned to the Cypresshead Formation by Huddlestun (personal communication, 1984). These sediments are assigned here, for convenience, to the post-Hawthorn sediments.

Problems in identifying the upper limits of the Peace River arise in areas of extensive reworking of the sediments. In such a case the sediment may be completely reworked and the resultant lithology only slightly different than the unreworked sediments. When this occurs minor changes in lithology such as an increase in shell material, change in clay mineralogy, or change in sorting provide the necessary lithologic criteria for separating the units.

Thickness and Areal Extent

Sediments assigned to the Peace River Formation occur over much of the southern half of the Florida peninsula. The top of the unit ranges from a maximum known elevation of +175 feet (+53 meters) MSL in Polk County to greater than -150 feet (-46 meters) MSL in part of Collier, Dade, Broward, and Palm Beach Counties (Figure 52). The thickness of this unit varies to more than 650 feet (198 meters) in parts of Martin and Palm Beach Counties (Figure 53). This thickness, which is taken from several sets of cuttings in the area, seems anomalously thick. Thicknesses of 400 feet (122 meters) or greater occur in eastern Glades County along the western edge of Lake Okeechobee (Figure 53).

Although the Peace River Formation occurs over most of the southern portion of the state, it is absent from the Ocala Platform and the Sanford High (Figures 4, 52 and 53). It is also absent, possibly due to erosion, from portions of Hillsborough, Pinellas, Manatee and Sarasota Counties (Figures 52 and 53). It dips east, south and west off the southern nose of the Ocala Platform (an area referred to as the Central Florida Platform by Hall [1983]). South of this area, the dip is primarily south and southeast at approximately 8 feet per mile (1.3 meters per kilometer) (Figure 52). Local variations of dip direction and degree are common.

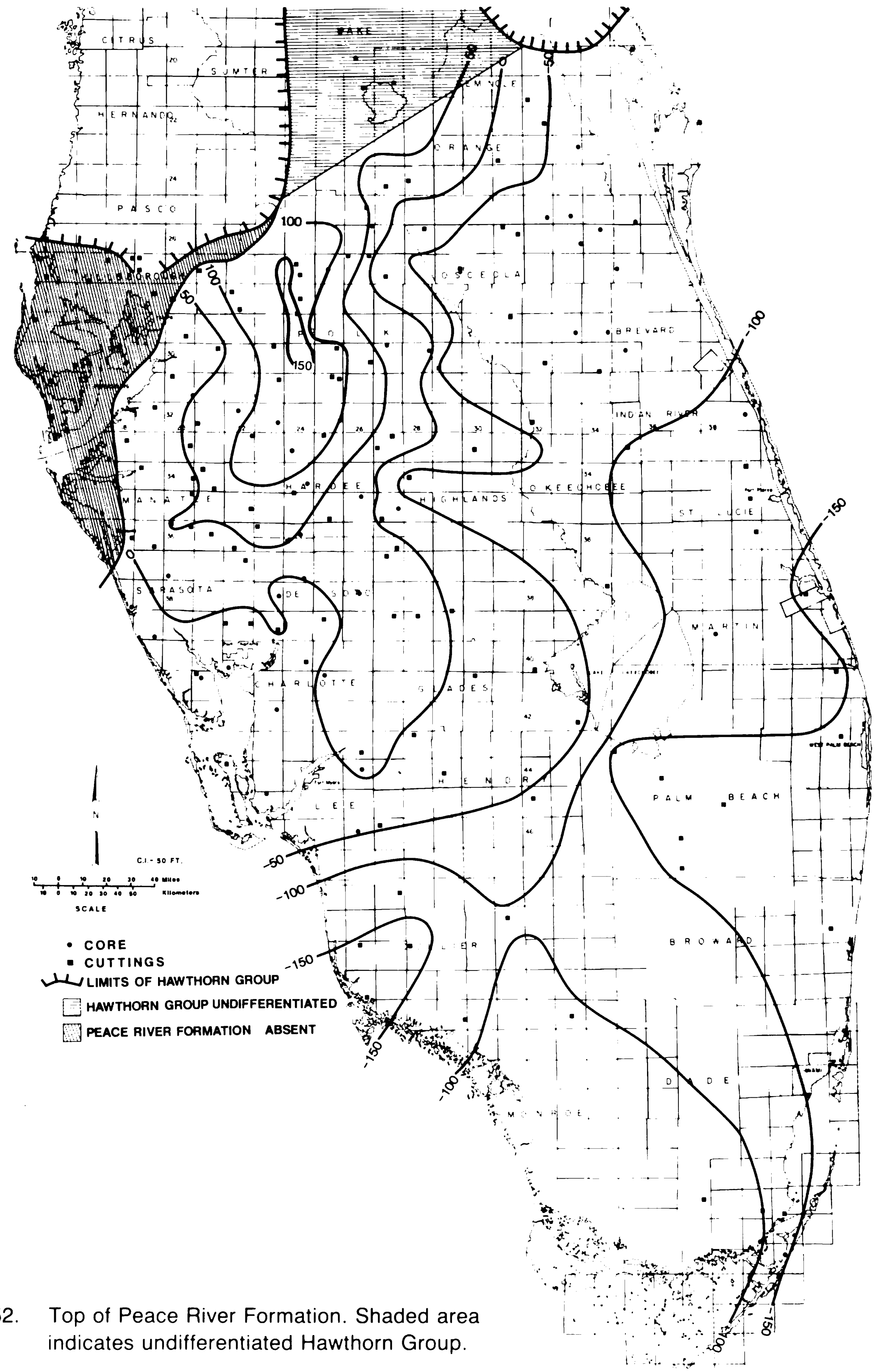


Figure 52. Top of Peace River Formation. Shaded area indicates undifferentiated Hawthorn Group.

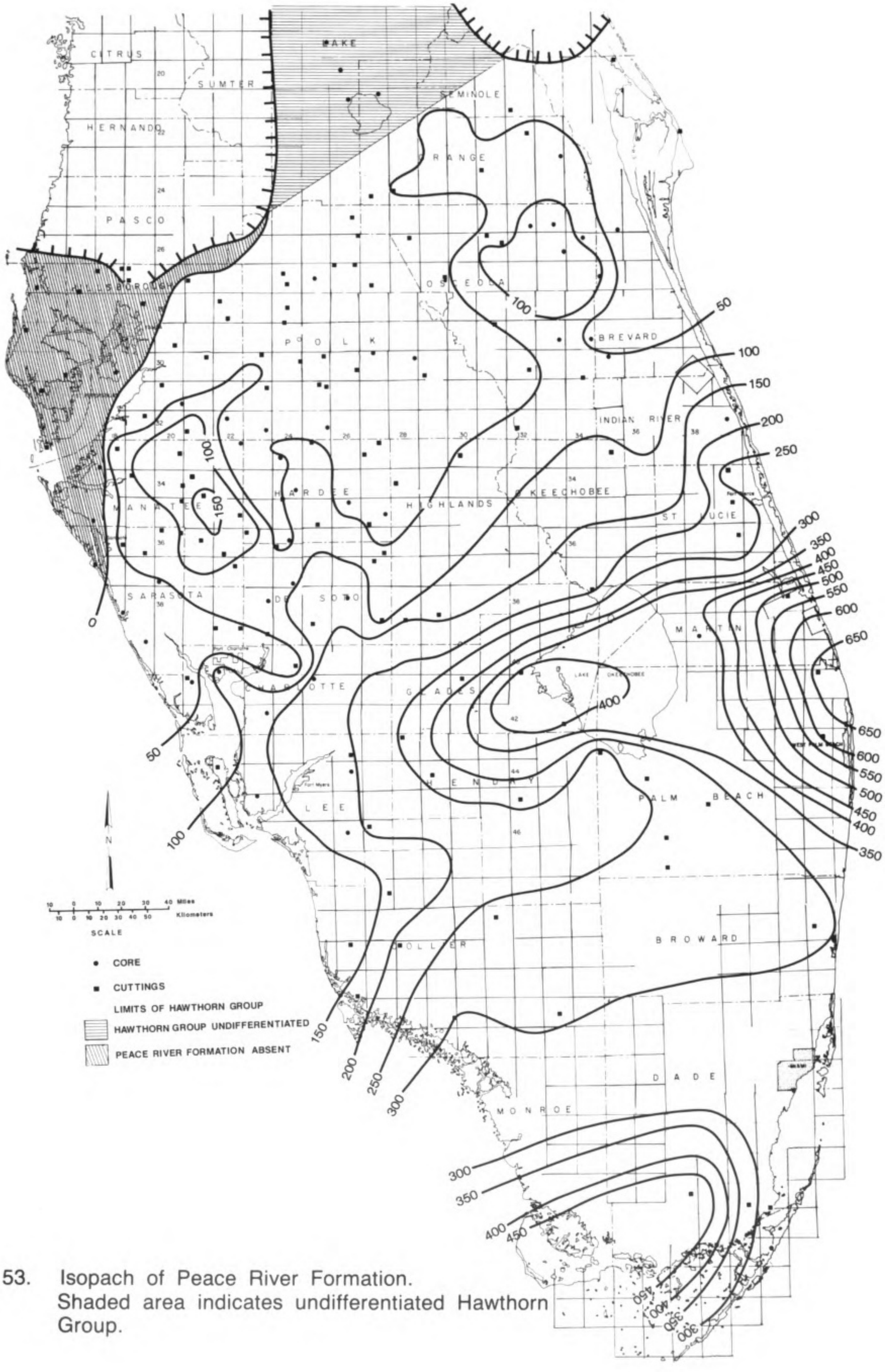


Figure 53. Isopach of Peace River Formation. Shaded area indicates undifferentiated Hawthorn Group.

Age and Correlation

The Peace River Formation often contains well preserved fossils that include vertebrates, diatoms, and foraminifera. As a result, the range of ages that this unit encompasses can often be documented.

Vertebrate fossils are frequently exposed during mining operations in the central Florida phosphate mines. The oldest, a limited fauna tentatively assigned an early to middle Barstovian age (late Early to late Middle Miocene) (Webb and Crissinger, 1983), was collected from the lowest strata of the Peace River Formation, just above its contact with the older Arcadia Formation. These fossils suggest a possible latest Early to early Middle Miocene age for the lowest part of the Peace River. This author has found no record of Late Barstovian or Clarendonian vertebrate sites in the Peace River Formation of southern Florida. The next younger vertebrates from the phosphate mining area are those known as the Lower Bone Valley fauna. These are regarded as being of Early Hemphillian age (medial to late Late Miocene) according to MacFadden and Webb (1982). The Bone Valley Member, also contains the Upper Bone Valley Fauna, for which a Late Hemphillian age has been assigned. This fauna is discussed further in the section of the Bone Valley Member. Another assemblage of vertebrate fossils, known as the Manatee local fauna, was collected *in situ* at the Manatee River Dam site, just east of Bradenton in Manatee County. These fossils, assigned an early Late (or medial) Hemphillian age, came from beds only 6 to 10 feet (1.8 to 3.0 meters) above present sea level (MacFadden and Webb, 1982, p. 197).

Marine invertebrates provide additional information about the age of the Peace River Formation in other parts of southern Florida. Diatoms identified by Hoenstine (personal communication, 1979) from core W-10761 in Charlotte County indicate a Middle Miocene age for Peace River sediments at -92 feet (-28 meters) below present sea level. According to Huddlestun (personal communication, 1983), foraminifera in W-15286 in Lee County suggest an age no younger than earliest Pliocene for sediments at -132 feet (-40.5 meters) MSL. Huddlestun also suggests a Late Miocene age (early to middle Tortonian age) for Peace River sediments at -405 to -417 feet (-124 to 127.5 meters) MSL in W-15246 in Martin County. He also indicated an earliest Pliocene age for the Peace River sediments between -175 feet (-53.5 meters) MSL and -437 feet (-133.5 meters) MSL in W-15493 in Monroe County.

When considering the depths from which some of these invertebrates are reported, the reader should bear in mind that the southern half of the peninsula is known to be a subsiding area, with the degree of subsidence varying from minimal in the northern area to maximum at the southernmost tip of the peninsula and in the Florida Keys. The present subsea elevation of the strata that contain these marine invertebrates is therefore not necessarily the same as the elevation of the strata in relation to sea level at time of deposition.

From the preceding records, the Peace River Formation is thought to range in age from possibly latest Early or early Middle Miocene for the oldest sediments to early Pliocene for the youngest.

Huddlestun et al. (1982) informally proposed the name "Indian River beds" of the Hawthorn Group (later changed to Wabasso beds) for an interval of sediments in core W-13958, Indian River County. They reported diatoms and planktonic foraminifera indicative of a late Early Pliocene age for the strata. Their age assignment suggests that the Wabasso beds may be slightly younger than the uppermost Peace River strata.

The lower part of the Peace River Formation is here correlated with the Coosawhatchie and Statenville formations of northern Florida (Figure 19). This is based partly on stratigraphic position, and partly on ages suggested by the Middle Miocene diatoms, and the tentative Early to Middle Barstovian age for the vertebrates in the lowest beds of the Peace River.

Huddlestun (personal communication, 1983) suggests that the upper strata of the Peace River are slightly older than the Jackson Bluff Formation in the Panhandle. They are also slightly older than the Tamiami Formation of southern Florida as restricted herein.

Discussion

For years the Peace River Formation has been identified and mapped as the upper siliciclastic unit of the Hawthorn Formation in south Florida. It is simply the phosphatic quartz sands and clays that overlie

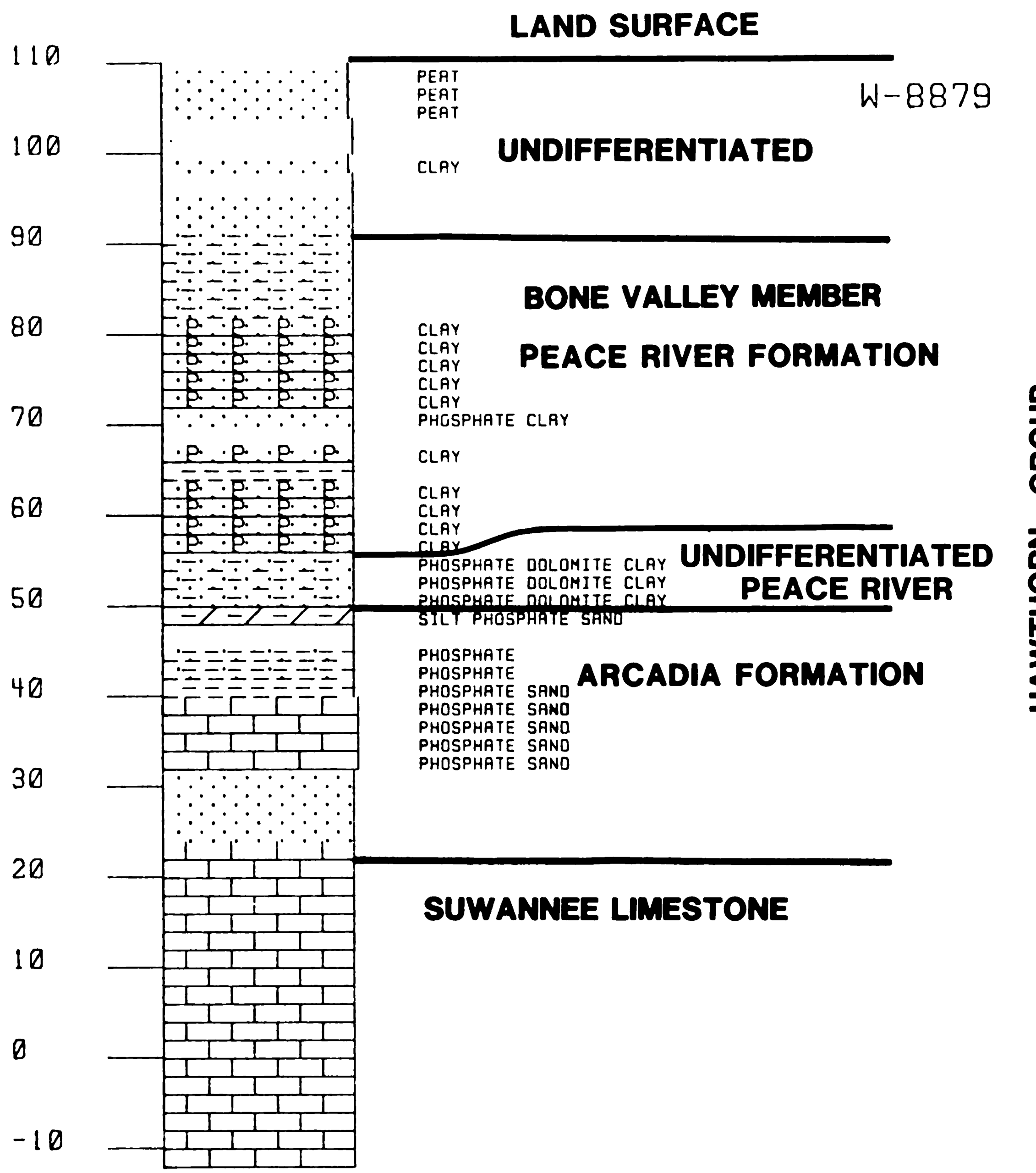


Figure 54. Reference core for the Bone Valley Member of Peace River Formation, Griffin #2, W-8879, Polk County (Lithologic legend Appendix A).

and grade into the Hawthorn carbonate section (here referred to as the Arcadia Formation). In this report the name Peace River Formation is formally proposed for this section including the Bone Valley Formation of former usage, the lower Tamiami Formation of Parker, et al. (1955) and the Murdock Station and Bayshore Clay members of the Tamiami of Hunter (1968).

Strata currently assigned to the Peace River Formation in southernmost Florida and along the southeastern coast include sediments that are Messinian to Zanclian, latest Miocene to earliest Pliocene in age. These sediments may be age equivalent with the uppermost bed of the Bone Valley Member. Admittedly the data base in these areas is relatively poor. Future investigations may provide the core data necessary to further describe the sections.

BONE VALLEY MEMBER OF THE PEACE RIVER FORMATION

Definition and Type Locality

The Bone Valley Formation of former usage is demoted herein to member status within the Peace River Formation of the Hawthorn Group. The status reduction is suggested due to the limited areal extent of this unit, to the gradational nature of its boundaries (both lateral and vertical) with the Peace River Formation, and to its lithologic similarities to the Peace River Formation. This unit directly overlies the Arcadia Formation in some areas but overlies and interfingers with the upper Peace River Formation in other areas (Figure 55).

The type area designated by Matson and Clapp (1909) consists of phosphate mines west of Bartow in Polk County, but no individual type section was proposed. More complete sections of the Bone Valley Member are presently available in present-day phosphate mines than were accessible when the unit was

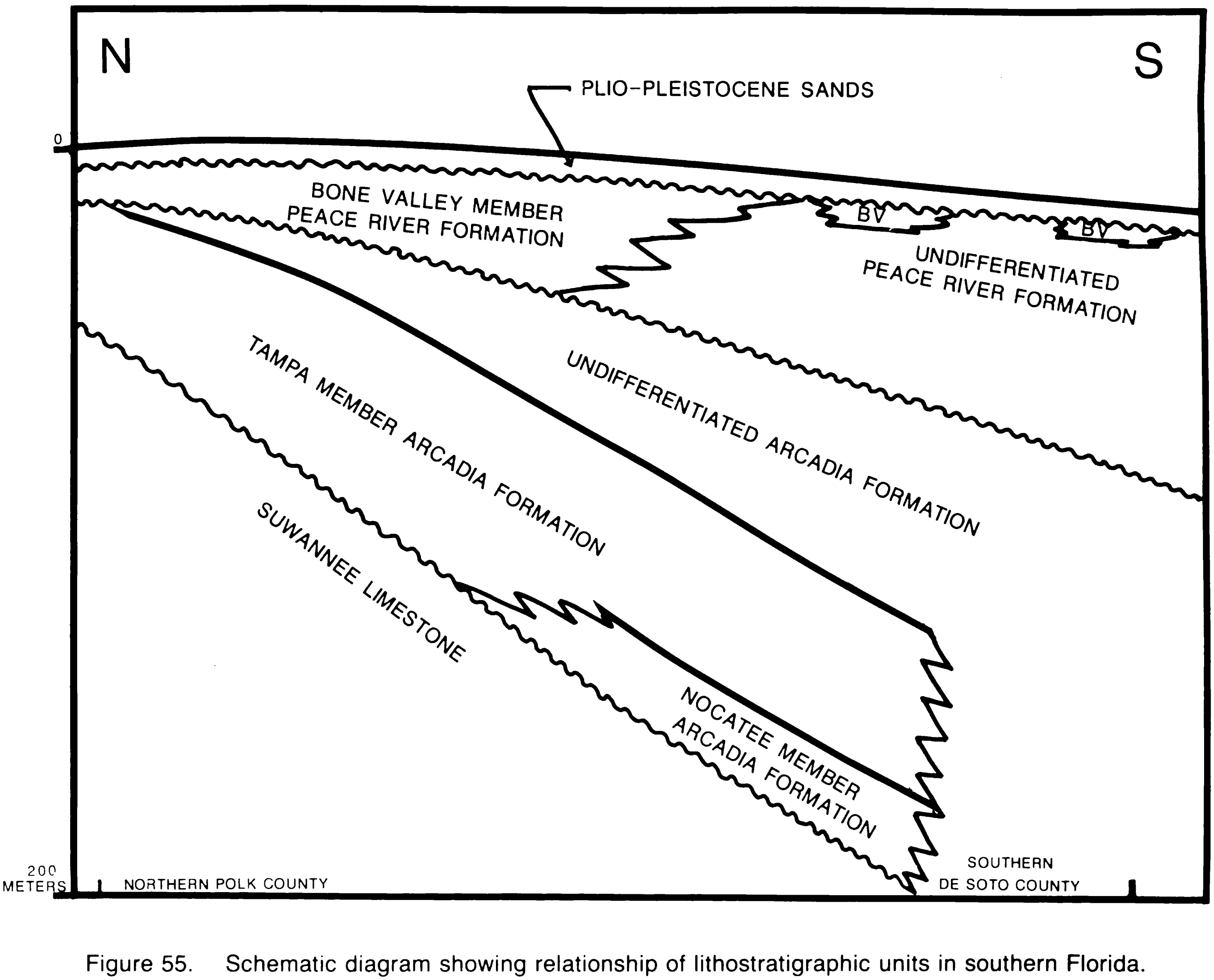


Figure 55. Schematic diagram showing relationship of lithostratigraphic units in southern Florida.

described. Unfortunately, the mine sections are constantly being changed by the mining operations and a definite type section is impossible to erect. As a result, the Bone Valley Member type area remains designated the current exposures in mines west of Bartow in Polk County.

It is interesting to note that the original "Bone Valley Gravel" of Matson and Clapp (1909) was probably limited to only the uppermost gravel bed of the Bone Valley Formation as it is currently used in the phosphate district. As mining methods improved deeper pits were dug exposing more of the phosphorite section and the accepted definition of the Bone Valley was expanded to include these sediments.

A principal reference section in a core, W-8879 (NE ¼, SW ¼ Section 24, Township 29S, Range 24E, Polk County), near Bartow is suggested as being representative of this unit. In this core the Bone Valley Member occurs between 91.5 feet (28 meters) MSL and 56 feet (17 meters) MSL (surface elevation is 110 feet [33.5 meters]) (Figure 54).

Lithology

Throughout its extent, the Bone Valley Member is a clastic unit. It consists of pebble- or gravel-sized phosphate fragments and sand-sized phosphate grains in a matrix of quartz sand and clay. Percentages of the various constituents vary widely.

The occurrence of phosphate gravels in the Bone Valley is the most lithologically important factor in the separation of the member from the remainder of the Peace River Formation. Phosphorite sands are also present, often as the most abundant phosphate size fraction. The phosphate grains range in color from white (N 9), where they have been leached, to black (N 1). Commonly the larger phosphate clasts appear to be replacement of carbonate by phosphate.

The quartz sands occur intimately mixed with the phosphate and clays in the Bone Valley Member. Only in part of the leached zone are phosphate grains absent from the sands. A leached zone develops where the phosphate grains are removed by groundwater dissolution. Other phosphate minerals are often deposited in the sands, weakly cementing them. Clays in this zone are also altered. The sands range from very fine grained to very coarse with some zones containing quartz pebbles and cobbles. Colors of the sands range from white (N 9) and light brown (5 YR 6/4) in the leached zone to light olive gray (5 Y 6/1) in the more clayey sections and to dark gray (N 3) in the highly phosphatic sections.

Clays characteristically occur as matrix materials but also occur as discrete beds. The clay beds vary in the amount of accessory minerals present, occasionally occurring as relatively pure clay with very little sand or phosphate grains. The clay beds often occur at the base of the Bone Valley and are referred to in the phosphate district as "bed clays." The "bed clays" have been interpreted by some as being the "residuum of the argillaceous carbonate rock of the Hawthorn..." (Altschuler et al., 1964). Other clay occurrences in the Bone Valley have been interpreted as possible products of alkaline lake deposition (Strom and Upchurch, 1983). Colors of the clay beds exposed in the mines range from white (N 9) to yellowish gray (5 Y 8/1), light brown (5 YR 6/4) and blue green (5 BG 7/2). In cores, the colors show a similar range plus olive grays (5 Y 6/1 and 5 Y 4/1). Beds of carbonate rubble often occur at the base of the "bed clay."

Bedding in the Bone Valley Member varies from faintly stratified to strongly cross bedded. Graded bedding is common throughout the unit, although it is often not well developed. The poorly stratified units are typically more clayey and poorly-sorted, while the crossbedded sections are moderately to well sorted and generally lack finer grained materials (silts and clays). A mottled appearance to the sediment is not typical in the Bone Valley Member but becomes apparent in the underlying undifferentiated Peace River sediments.

The very phosphatic section of the Bone Valley Member grades upward into slightly phosphatic to nonphosphatic clayey sands. These clayey sands have been referred to as the Upper Bone Valley (Altschuler et al., 1964). Bedding is typically massive. In this investigation this section is placed in the Bone Valley as the uppermost sediments, but is not given a separate bed name. This section often contains the "leached zone" which has been altered, often intensely, by groundwater, removing all the included phosphate.

Subjacent and Suprajacent Units

The Bone Valley Member disconformably overlies the Arcadia Formation throughout much of its extent. In the areas furthest updip (Figure 55), the lower Arcadia (possibly the Tampa Member in some cases) immediately underlies the Bone Valley. In southernmost Polk and adjacent parts of Hardee and Manatee counties, the Bone Valley grades laterally, and to some extent vertically, into the undifferentiated Peace River Formation. In this area the Bone Valley often lies on the Peace River and the differentiation between the two becomes difficult (Figure 55). These relationships and those with the overlying units are shown in Figures 35 through 40.

The characteristic Bone Valley section (if such could be seen in a single pit wall or core) consists of a basal gravelly unit lying on either undifferentiated Peace River Formation or Arcadia Formation. This is overlain by a "middle feed" unit of sand-sized material with little gravel which, in turn, is overlain by the upper gravels. When the basal gravels are present it is quite simple to separate the Bone Valley from the undifferentiated Peace River Formation. However, if the basal gravels are absent and the middle unit of the Bone Valley lies on the Peace River sediments, it often is not possible to accurately separate the two beds, and placement of the boundary becomes arbitrary.

The Bone Valley Member is unconformably overlain throughout its extent by unnamed sands. These sands often appear to grade into the Bone Valley due to the obliteration of the contact by ground-water leaching and reworking. The unnamed sands have often been referred to as Pleistocene or Plio-Pleistocene in age.

Thickness and Areal Extent

The Bone Valley Member occurs at elevations as high as 175 feet above sea level (53 meters) in southwestern Polk County (Figure 56). Over the majority of its areal extent the Bone Valley member occurs above 100 feet (30.5 meters) MSL. The lowest elevations of the upper surface of the Bone Valley occur near the limits of the member on the east, south and west (Figure 56). This unit attains a maximum thickness of just over 50 feet (15 meters) in southwest Polk County, from which it thins in all directions (Figure 57). Locally, the Bone Valley may thicken abruptly into karst features.

The upper surface of the Bone Valley Member dips in all directions away from the highest area at less than 5 feet per mile (0.9 meters per kilometer). Individual beds within the Bone Valley appear to have a slight "seaward" dip (Matson and Clapp, 1909).

This unit extends over much of the western half of Polk County, the eastern one-third of Hillsborough County, northeast Manatee County and northwest to north-central Hardee County (Figures 56 and 57). Outside this area individual beds of Bone Valley lithology occur intermixed with undifferentiated Peace River sediments, but are not differentiated.

Age and Correlation

Vertebrate remains are frequently exposed during mining operations in the central Florida phosphate mines, and are probably the source of the name, Bone Valley. The ages assigned to the Bone Valley Member are derived entirely from these vertebrate fossils.

The oldest, a limited fauna tentatively assigned an early to Middle Barstovian age (Webb and Crissinger, 1983), was collected from the lowest strata of the Bone Valley Member, just above its contact with the older Arcadia Formation. These fossils suggest a possible latest Early to early Middle Miocene age for the lowest part of the Bone Valley. This author has found no record of Late Barstovian vertebrate sites in the Bone Valley Member of southern Florida. The next younger vertebrates from the phosphate mining area are those known as the "Lower Bone Valley Fauna." These are regarded as being of Early Hemphillian age (medial to late Late Miocene) (MacFadden and Webb, 1982). The youngest vertebrate assemblage, known as the Upper Bone Valley Fauna, occurs in marine sediments deposited above an unconformity thought to represent the Messinian regressive event. MacFadden and Webb (1982) indicate a Late Hemphillian age for these animals. Because of the unconformity, it is suggested that the

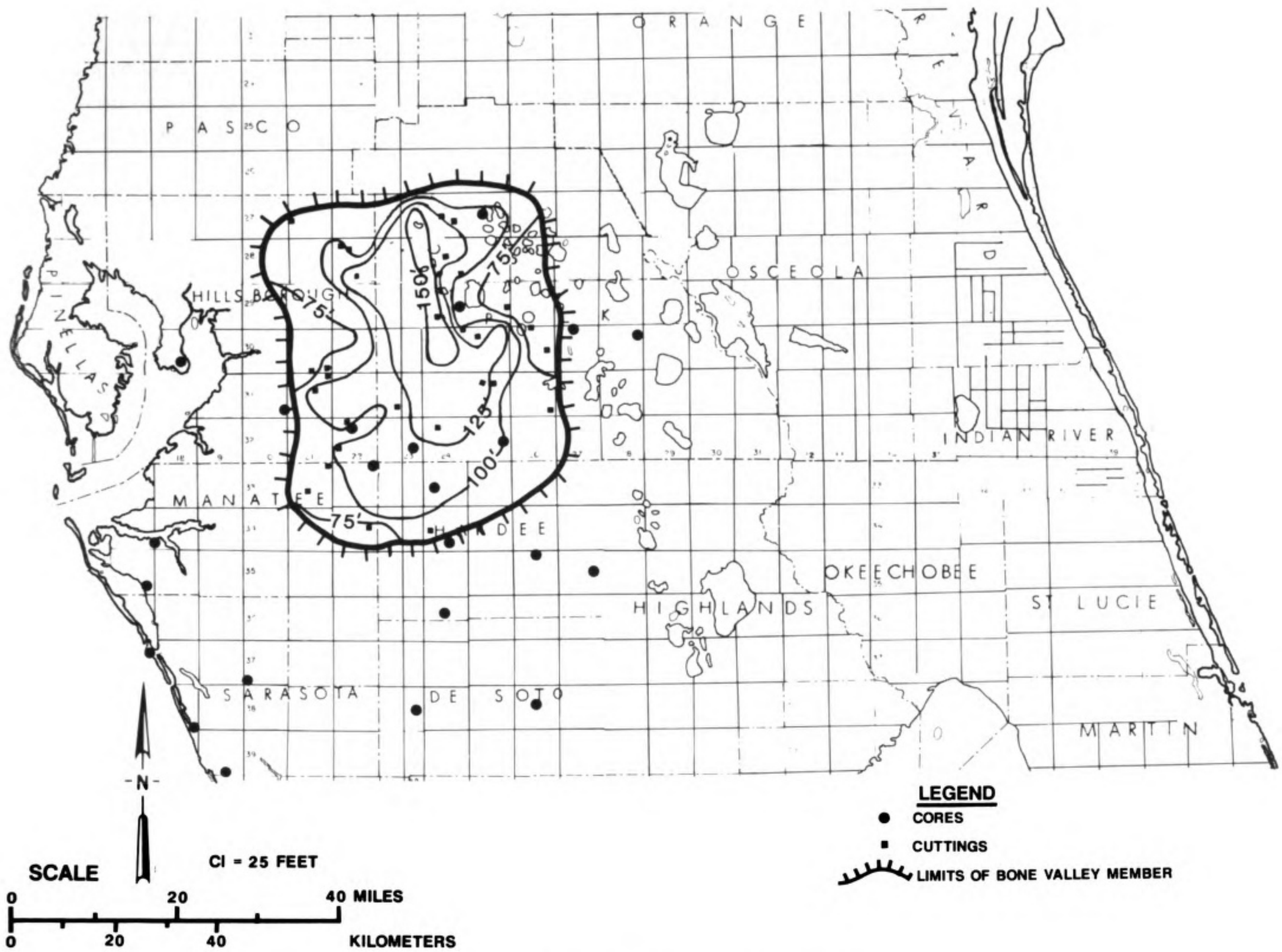


Figure 56. Top of Bone Valley Member.

age of the uppermost Bone Valley strata is probably Early Zanclian (very Early Pliocene; see Figure 73). These sediments are discussed by Webb and Crissinger (1983) as reworked channel deposits (''drift rock'' of phosphate mining terminology), also being of Late Hemphillian age. They further reported that Pleistocene vertebrates have been collected from younger channel fills that contain reworked parts of the Bone Valley Member.

The Early Pliocene strata of the Bone Valley Member that occur above the unconformity seem to have no exact correlatives that have been identified with certainty in Florida or the Southeast Georgia Embayment.

Huddlestun (personal communication, 1983) suggests a correlation of the Bone Valley Member to the hard rock phosphates of central Florida based on vertebrate faunas. The Bone Valley also correlates to part of the Intracoastal Formation in the Apalachicola Embayment (Schmidt, 1984). Part of the Bone Valley Member correlates with the Coosawhatchie and Statenville Formations of North Florida and Georgia and the Pungo River Formation of North Carolina. A portion of the Bone valley correlates with Huddlestun's (in press) Screven Formation in the Georgia Coastal Plain.

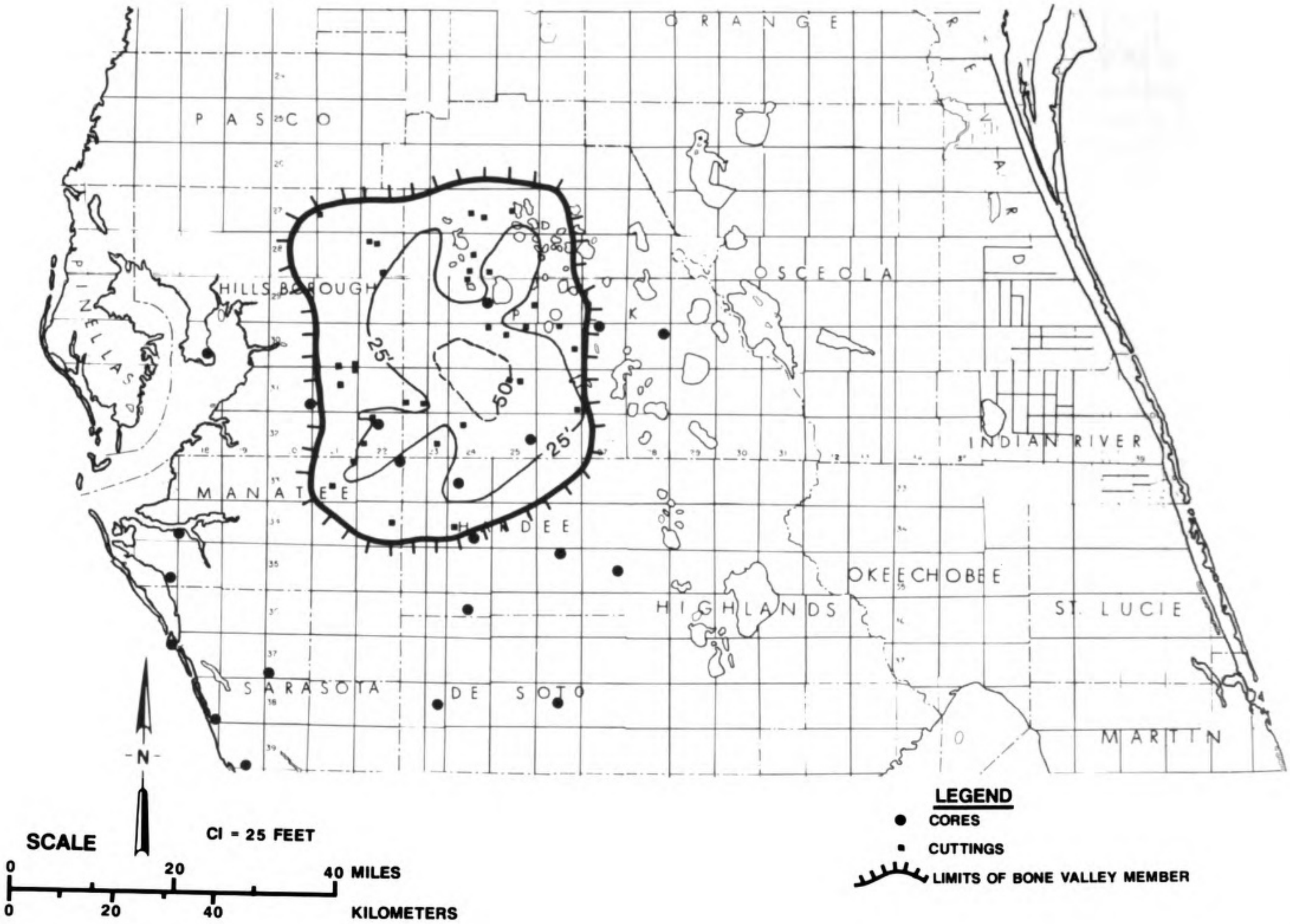


Figure 57. Isopach of Bone Valley Member.

Discussion

The Bone Valley section has been recognized for years due to its economic importance. However, as previously mentioned, its limited areal extent does not warrant formational status. The preceding discussion of the Bone Valley indicates distinct similarities between parts of the Bone Valley Member and the undifferentiated Peace River Formation. Geologists familiar with the geologic section in the phosphate district readily recognize the similarities and many have accepted the association of these units.

One source of discussion concerning the placement of the entire Bone Valey in the Peace River Formation and the Hawthorn Group is the occurrence of a major unconformity within this section. The unconformity spans much of the Late Miocene. Without the aid of dateable fossils, it is normally not possible to separate the pre-unconformity gravels from the post-unconformity gravels. The argument has been presented that the post-unconformity Bone Valley sediments should not be included in the Peace River Formation or the Hawthorn Group. However, based on lithologic similarities on either side of the nonconformity and their stratigraphic position it is perfectly acceptable under the North American Stratigraphic Code, Article 23d (NACSN, 1983) to place all these sediments in a single unit.

In light of this argument it is interesting to note that the classical Bone Valley "Formation" as originally described by Matson and Clapp (1909), included only the post-Messinian gravels. This was the only portion of the section normally exposed as a result of the old mining methods. As flotation methods began being used to concentrate the phosphate, mining went deeper into the phosphate-bearing strata. As the deeper lithologies were exposed, most were incorporated into the Bone Valley "Formation" thereby expanding the time frame and the definition of the unit.

EASTERN FLORIDA PANHANDLE

The Hawthorn Group extends northwestward from the Ocala Platform across the eastern portion of the Florida panhandle as far west as the Apalachicola River in Gadsden and Liberty Counties. Sediments of the Hawthorn Group have not been identified west of the Apalachicola River on the west side of the Gulf Trough (Huddlestun and Hunter, 1982). These sediments are thickest in the Gulf Trough and thin dramatically on the flanks.

Lithologically, much of the Hawthorn Group in the eastern panhandle is quite different from the Hawthorn sediments of the peninsular area. The most obvious difference is the decreased phosphate content throughout the section. In Madison, Jefferson and part of Leon Counties the dominant lithology is sandy clay to very clayey sand. Carbonate content increases in the Gulf Trough area, where the lithologies become more similar to those of the northeastern peninsular area in many respects.

Stratigraphically, the sediments under consideration here are assigned to the Torreya Formation of the Hawthorn Group (Figure 58). Unfortunately, core data to further refine the stratigraphy of these sediments in the eastern panhandle do not exist at this time either in northern Florida or southern Georgia.

TORREYA FORMATION

Definition and Type Section

The Torreya Formation was described by Banks and Hunter (1973) as consisting of post-Tampa, pre-Chipola (Early Miocene) age deposits in the eastern Florida panhandle. In defining this unit Banks and Hunter (1973) restricted the use of the Hawthorn Formation by removing from it the sediments of the Torreya. However, they did not clearly distinguish between the two units lithologically due to the paucity of data available at the time.

Huddlestun and Hunter (1982) suggested the revision of the definition of the Torreya to include all deposits previously referred to the Hawthorn Formation in the eastern Florida panhandle. They regarded the Torreya as identical to the Hawthorn Formation of former usage. The Torreya is the only formation currently recognized as part of the Hawthorn Group in this area. It includes two named members: the Dogtown and the Sopchoppy (Figure 58).

The type section designated by Banks and Hunter (1973) is located at Rock Bluff, Liberty County, Florida, in the Torreya State Park from which the formational name is derived. Rock Bluff is located on the Apalachicola River in the SW¼, Section 17, Township 2 North, Range 7 West. A complete description of this outcrop is available in Banks and Hunter (1973). For the purpose of this study, reference sections are designated in cores W-6611, SE¼, NE¼ Section 23, Township 2N, Range 7W, Liberty County (Figure 59); W-7472, NW¼, SE¼ Section 19, Township 2N, Range 3W, Gadsden County (Figure 60); and W-6998, SE¼, NW¼ Section 8, Township 2N, Range 2E, Leon County (Figure 61).

Lithology

The Torreya Formation of the eastern Florida panhandle is typically a siliciclastic unit with increasing amounts of carbonate in the lower portion of the section, particularly in the Gulf Trough area. The siliciclastic portion varies from a very fine to medium grained, clayey quartz sand to a variably quartz-sandy, silty clay often containing a minor but variable carbonate component (either calcareous or

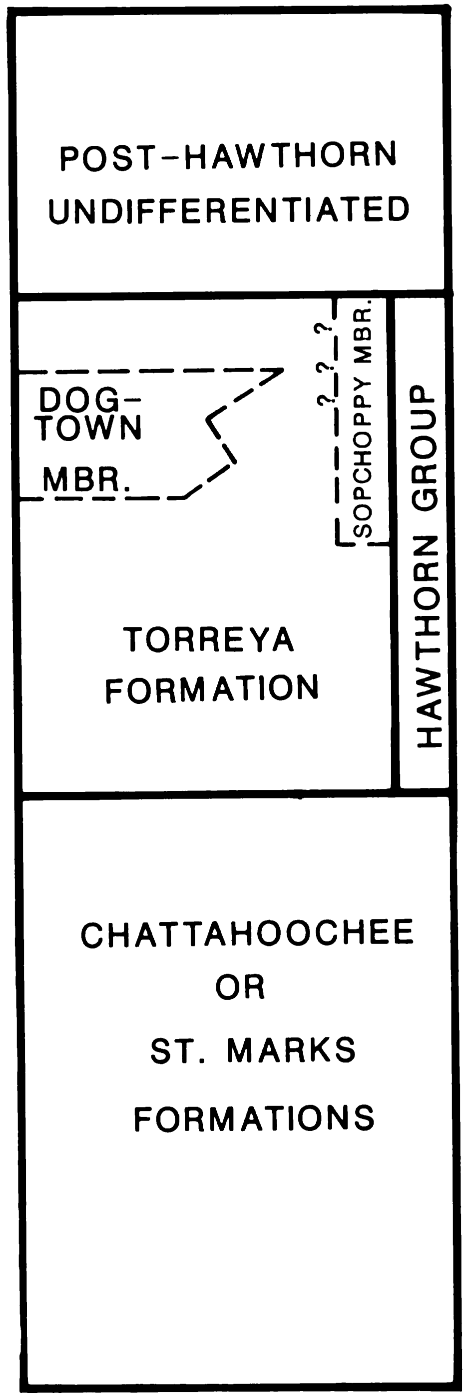


Figure 58. Lithostratigraphic units of the Hawthorn Group in the eastern Florida panhandle.

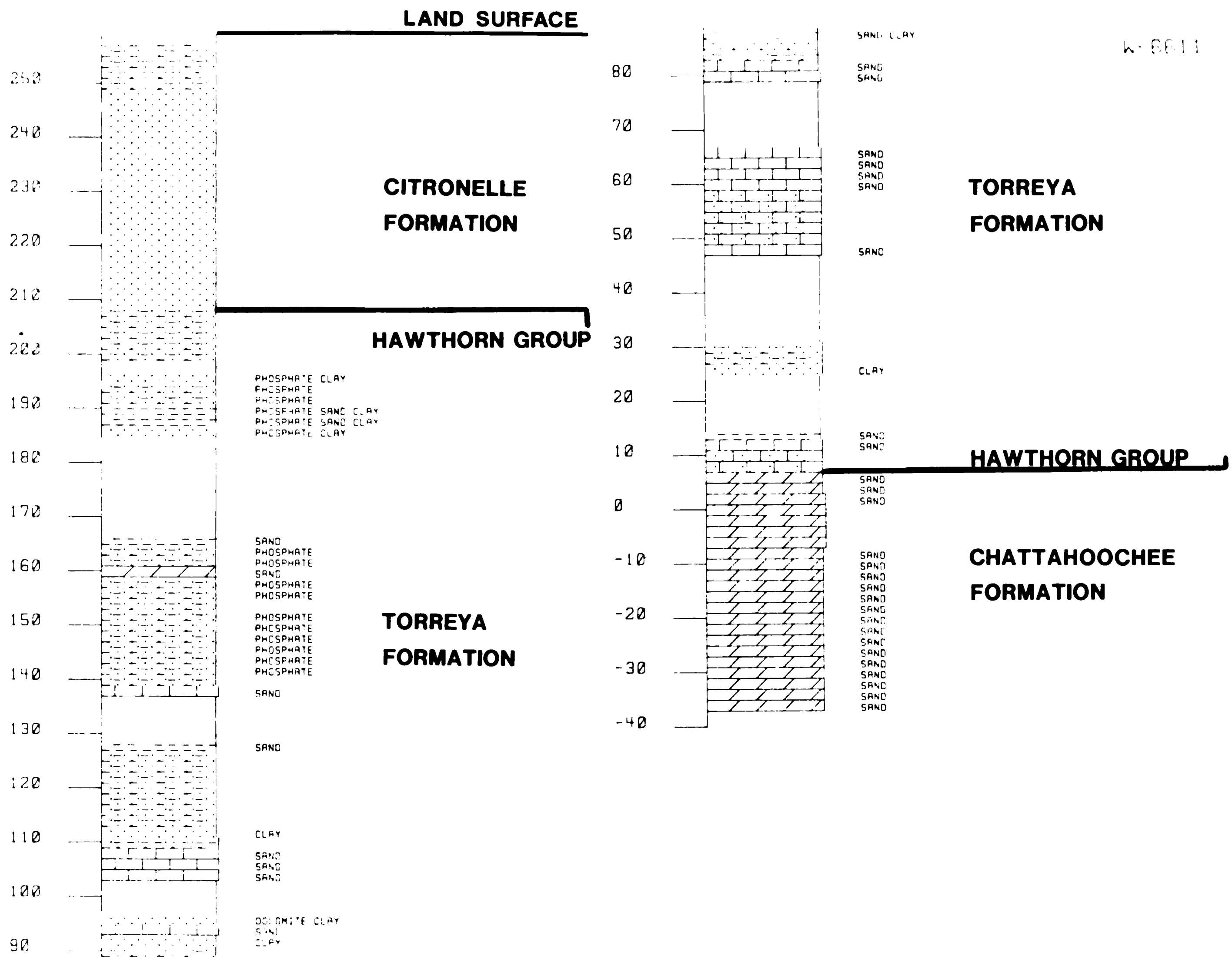


Figure 59. Reference core for the Torreya Formation, Rock Bluff #1, W-6611, Liberty County (Lithologic legend Appendix A).

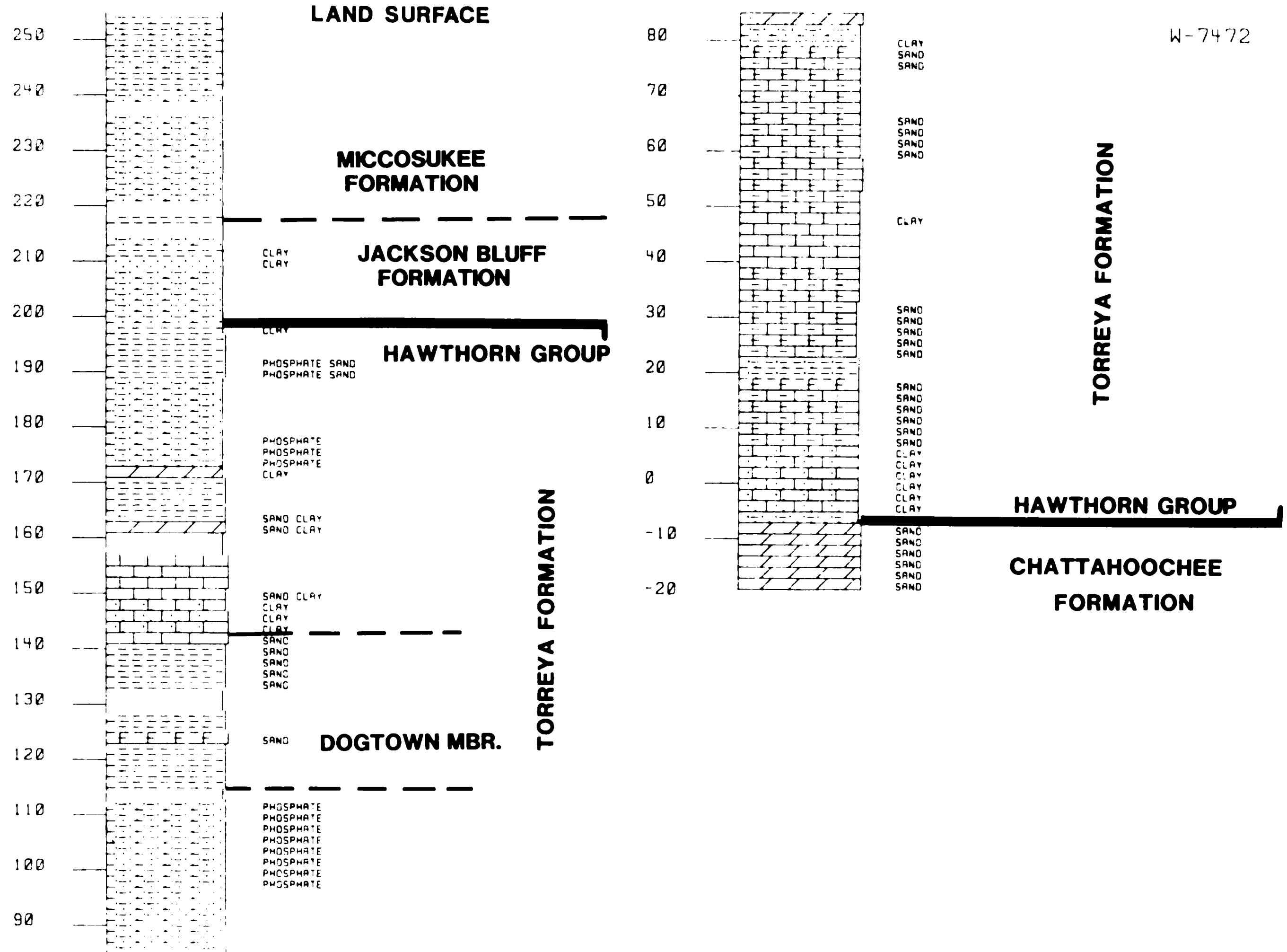


Figure 60. Reference core for the Torreya Formation, Owenby #1, W-7472, Gadsden County (Lithologic legend Appendix A).

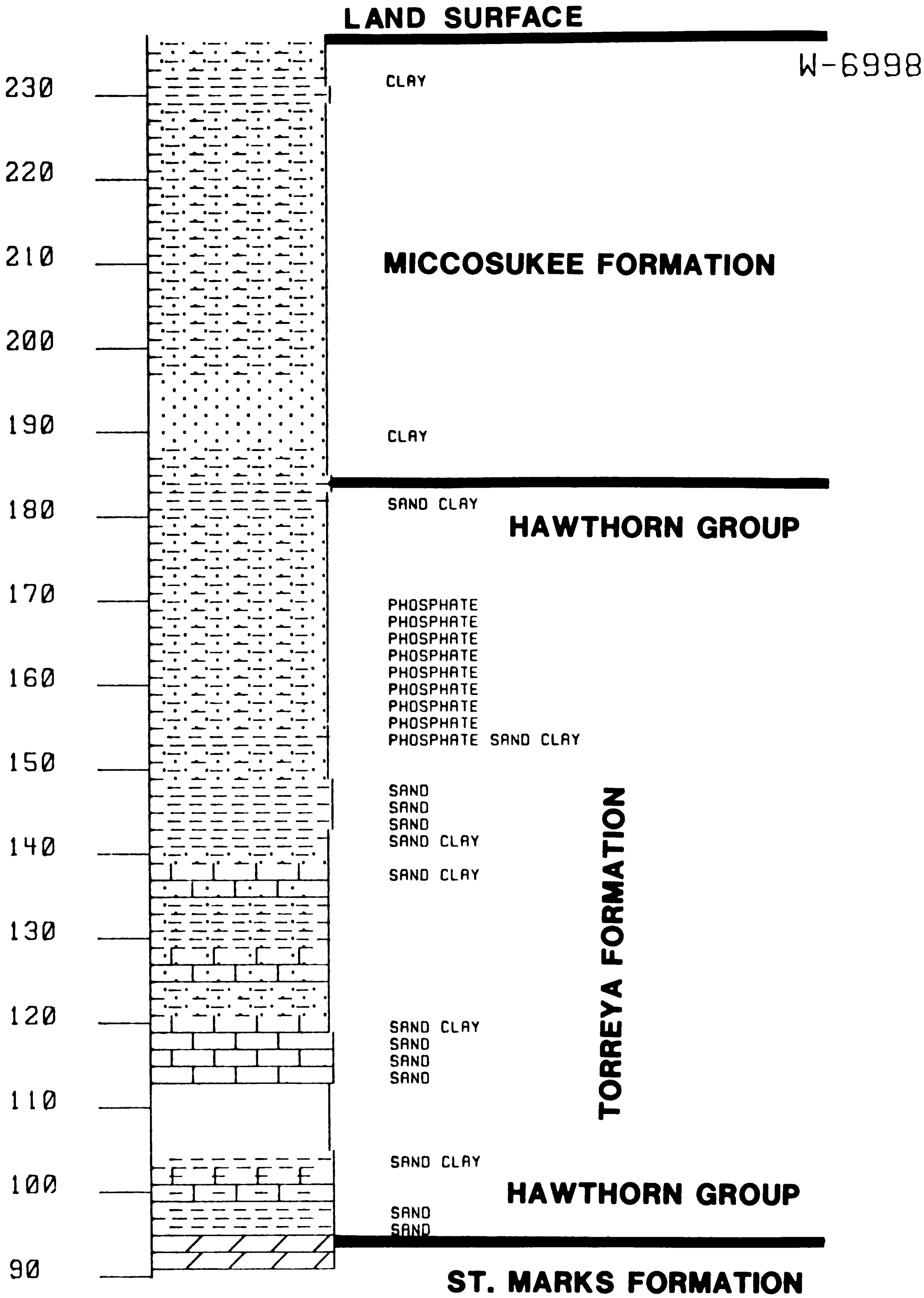


Figure 61. Reference core for the Torreya Formation, Goode #1, W-6998, Leon County (Lithologic legend Appendix A).

dolomitic). Phosphate grains are a common but minor lithologic component of the siliciclastic beds and are often absent. Induration varies from poor to moderate, generally in direct relation to the relative amounts of clay and/or carbonate present. The colors in the unweathered siliciclastic beds range from white (N 9) and yellowish gray (5 Y 8/1) to light olive gray (5 Y 6/1). In a more weathered section the sediments appear mottled and are grayish-red (10 R 4/2) to grayish orange (10 YR 7/4) in color.

The carbonate portion of the Torreya Formation typically is a variably quartz-sandy, clayey limestone which occasionally may be dolomitic. As noted by Huddlestun and Hunter (1982), the Torreya is the only formation of the Hawthorn Group in north Florida and Georgia where limestone is an important and consistent component of the lithology. Minor amounts of phosphate are present in limestones of the upper Torreya. Quartz sand content varies drastically and grades into calcareous quartz sands. Induration is usually moderate but is variable. Color ranges from white (N 9) to light olive-gray (5 Y 6/1). The carbonate sediments are often fossiliferous and commonly have abundant molds and casts of mollusks.

Clays are an important lithologic component of the Torreya Formation particularly in the upper part of the unit. The clays are predominantly palygorskite and smectite with minor sepiolite, illite and kaolinite (Weaver and Beck, 1977). Weaver and Beck (1977) recognized the variability of the clay mineralogy in that some intervals may be dominated by palygorskite while others may be predominantly smectite or, more rarely, sepiolite. Ogden (1978) recognized that palygorskite was the major and occasionally the sole clay mineral constituent in the southern portion (Florida) of the fuller's earth mining district. Other minor lithologic components recognized in the Torreya Formation include feldspar, pyrite, opal-CT, and mica.

Bedding in the Torreya Formation ranges from thin laminae to more massive beds up to 5 feet (1.5 meters) thick (Huddlestun and Hunter, 1982). Bioturbation has had a widely variable effect on the bedding, which ranges from undisturbed to highly bioturbated.

Huddlestun and Hunter (1982) recognized the occurrence of intraformational breccias in the Torreya sediments. The intraclasts are composed of clay or carbonate and are enclosed in a clayey or carbonate matrix. They suggest that the intraclast beds are characteristic of the inner Apalachicola Embayment and the Gulf Trough area, and are a local occurrence, not correlatable throughout the area.

Lithologic variation in the Torreya occurs both laterally and vertically. The lateral variations include 1) more carbonate in the Apalachicola Embayment-Gulf Trough area and 2) the carbonates become dolomitic eastward and northwestward (Huddlestun and Hunter, 1982). Vertical variations recognized within the Torreya Formation include in ascending order 1) a basal carbonate-rich zone; 2) a siliciclastic (quartz sand) sequence that often contains phosphate grains; 3) a clay-rich facies which contains the commercial fullers earth beds (this is the Dogtown Member); 4) a calcareous facies of sandy limestone or calcareous quartz sands (Sopchoppy Member?); and 5) uppermost beds of noncalcareous clays and quartz sand (Huddlestun and Hunter, 1982).

Subjacent and Suprajacent Units

The Torreya Formation is underlain by carbonates that have been referred to as the Chattahoochee Formation and/or St. Marks Formation. Huddlestun and Hunter (1982) refer to these sediments as Chattahoochee. Other investigators, such as Hendry and Sproul (1966) and Yon (1966), placed the sediments in the St. Marks. The contact between these units appears gradational in portions of the Gulf Trough-Apalachicola Embayment area but is disconformable in other areas.

Throughout much of its extent, the Torreya Formation is disconformably overlain by the Citronelle and Miccosukee formations. The Citronelle Formation occurs in the western portion of the area, in parts of Liberty and Gadsden Counties, and grades eastward into the Miccosukee Formation. Near Alum Bluff (W-6901), on the Apalachicola River, the Torreya is overlain disconformably by the Chipola Formation (Banks and Hunter, 1973; Huddlestun and Hunter, 1982). Further south, in Wakulla County, erosional outliers of Jackson Bluff Formation disconformably lie on the Torreya (Banks and Hunter, 1973). Huddlestun and Hunter (1982) state that elsewhere in the eastern panhandle the Torreya Formation is overlain by undifferentiated surficial sands. These relationships are shown in Figure 62.

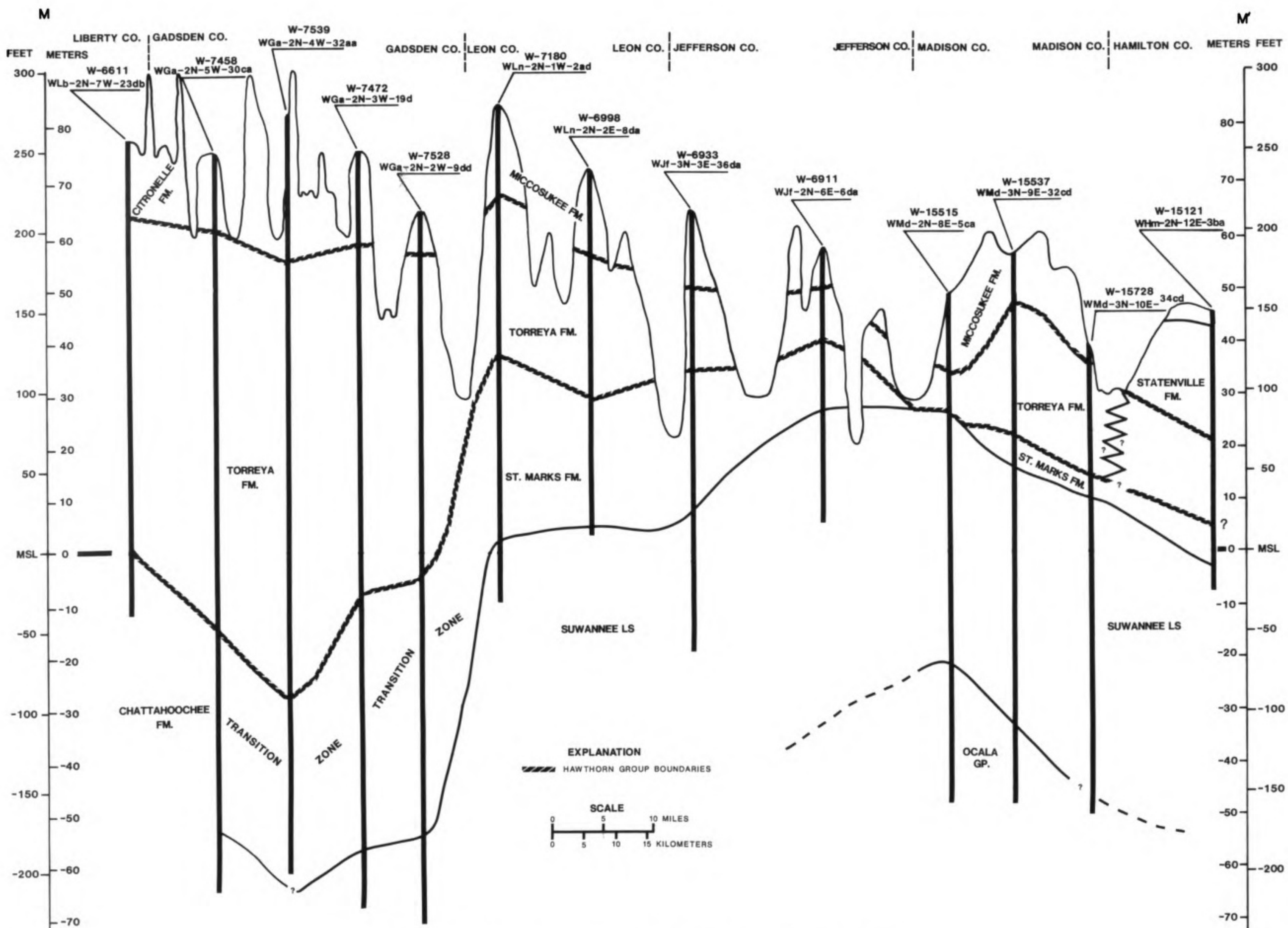


Figure 62. Cross section M-M' (see figure 3 for location).

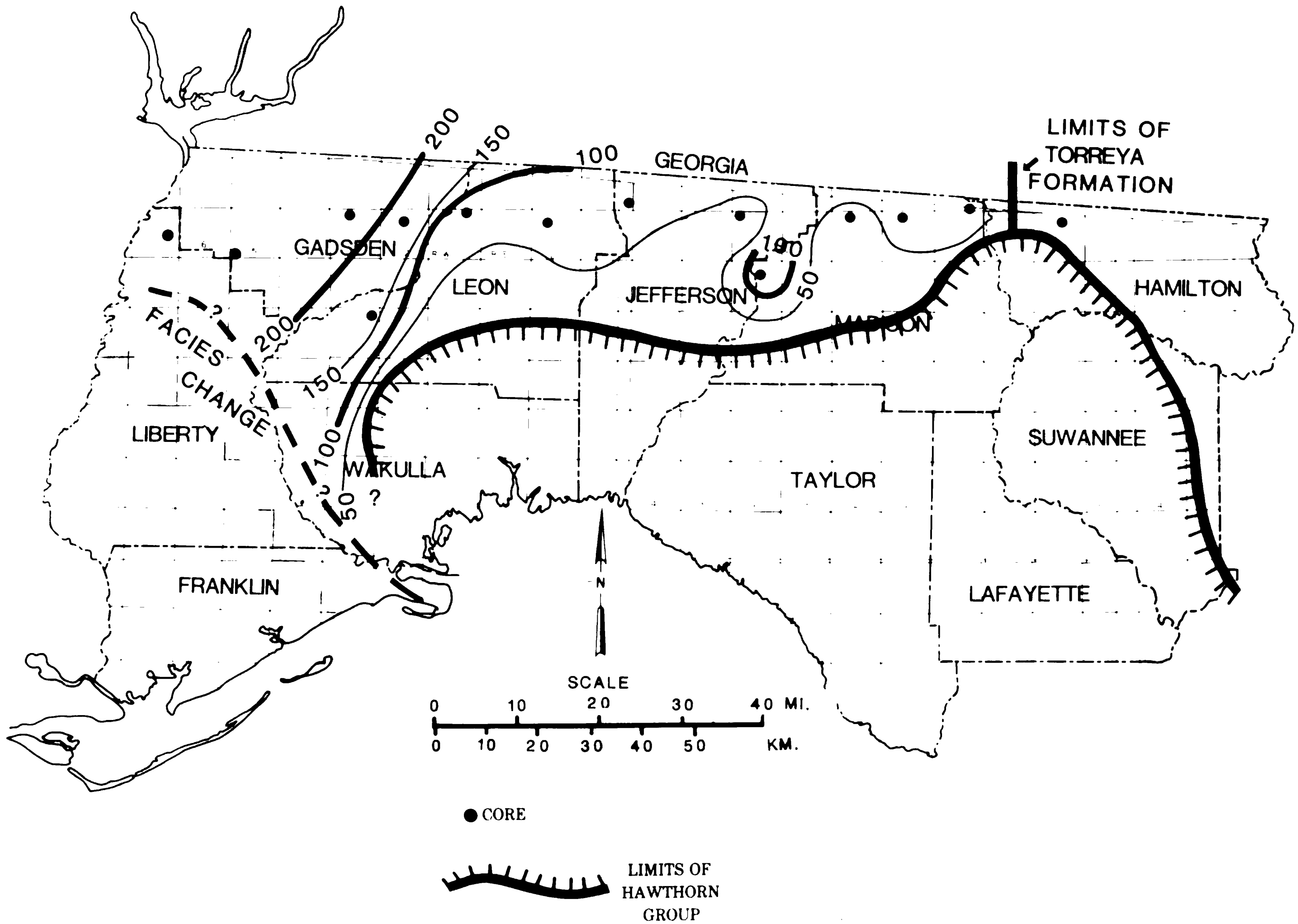


Figure 63. Isopach of the Torreya Formation.

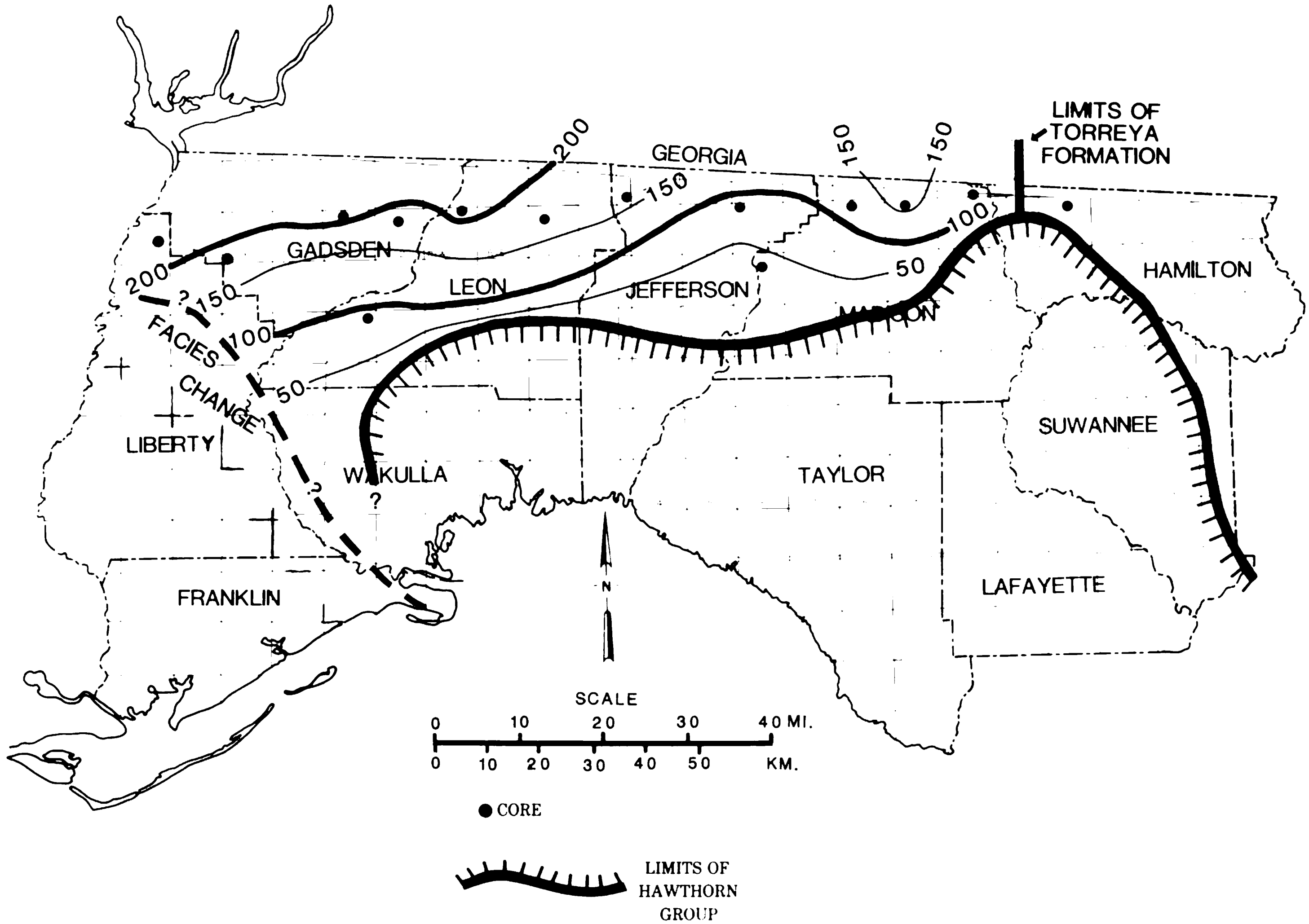


Figure 64. Top of the Torreya Formation.

Thickness and Areal Extent

The Torreya Formation varies considerably in thickness with a maximum of 227 feet (69 meters) in W-7539, Suber #1, Gadsden County, Florida near the axis of the Apalachicola Embayment (Huddlestun and Hunter, 1982). Characteristically, through the eastern panhandle, the thickness varies from 50 feet (15 meters) to 100 feet (30 meters) (Huddlestun and Hunter, 1982) (Figure 63).

The Torreya Formation underlies much of the eastern panhandle as shown in Figures 64 and 65. It occurs in parts of Madison, Jefferson, Leon, Wakulla, Liberty and Gadsden Counties. The Torreya extends northward into south Georgia (Huddlestun and Hunter, 1982), but its full extent is not known. Elevation of the upper surface of the Torreya ranges from less than 50 feet to greater than 200 feet above MSL (Figure 64).

Age and Correlation

Hunter and Huddlestun (1982), Huddlestun and Hunter (1982) and Huddlestun (in press) suggest that the Torreya Formation is middle Early Miocene (early to middle Burdigalian) in age (Figure 19). The age determination is based on correlation with the Marks Head Formation by molluskan faunal zones and the occurrence of two vertebrate faunas (Huddlestun, in press).

The Torreya Formation correlates with the Marks Head Formation of northeast Florida and southeast Georgia. It also correlates with the upper part of the Arcadia Formation of southern Florida (Figure 19). Northward into North Carolina the Torreya equates with the lower Pungo River Formation based on relative ages.

Discussion

It is obvious from this discussion that future investigations, as more data become available, may allow the Torreya Formation of the Hawthorn Group to be further subdivided or revised.

DOGTOWN MEMBER OF THE TORREYA FORMATION

Definition and Type Locality

The Dogtown Member of the Torreya Formation was suggested by Huddlestun and Hunter (1982) for the clay-rich interval in the upper Torreya in parts of Liberty, Gadsden and Leon Counties, Florida, and Decatur County, Georgia. Commercial fuller's earth deposits occur within the Dogtown Member.

The type locality of the Dogtown Member is the La Camelia Mine of Engelhard Corp., located in Section 15, Township 3 North, Range 3 West, Gadsden County, Florida. The Owenby #1 core (W-7472) located in SE ¼, Section 4, Township 2 North, Range 3 West is suggested here as a reference section (Figure 60).

Lithology

The Dogtown Member, as described by Huddlestun and Hunter (1982), and Huddlestun (in press) consists largely of clay. The clays are often quartz sandy, silty and occasionally dolomitic (Weaver and Beck, 1977). The commercial clay beds are quite pure clay but these do not make up the entire unit. Induration is generally moderate. The color of the unweathered, freshly exposed sediment varies from very light gray (N 8) to pale greenish-yellowish (10 Y 8/2) and light bluish-gray (5 B 7/1). Bedding in the clays ranges from thinly bedded (laminated) and somewhat fissile to massive, blocky, poorly bedded units. Where the clay is shaley, there is often silt or fine sand along bedding planes (Huddlestun and Hunter, 1982). The clay beds often contain clay intraclasts and show desiccation cracks (Weaver and Beck, 1977).

Associated with the clay beds are sand and carbonate beds which often separate the clay zone into two beds. The sands are very fine to fine grained, variably clayey, dolomitic or calcareous and poorly to moderately indurated. Colors range from light gray (N 7) to yellowish-gray (5 Y 7/2). The carbonate beds are clayey, sandy, dolostones to limestones with varying percentages of phosphate. Induration varies from poor to good. Colors range from white (N 9) to light olive-gray (5 Y 6/1). Mollusk molds are common in this unit.

The clay minerals associated with the Dogtown Member are predominantly palygorskite and smectite with minor but variable percentages of illite and sepiolite (Weaver and Beck, 1977). The relative percentages of individual clay minerals vary from bed to bed in the section. Lithologically, the Dogtown Member grades vertically both upward and downward into undifferentiated Torreya Formation.

Subjacent and Suprajacent Units

At this time, utilizing limited core and outcrop data, it is difficult to accurately determine the relationship of the Dogtown Member to the Sopchoppy Member. It appears that, although the Dogtown is not known to directly overlie the Sopchoppy Member in any core or outcrop, the Dogtown Member is younger than the Sopchoppy and could possibly be found in a suprajacent position to it. The Dogtown Member is unconformably overlain by the Citronelle and/or the Miccosukee Formations where the contact has been observed.

Thickness and Areal Extent

The thickness of the Dogtown varies from a maximum recognized thickness of 40.5 feet (12 meters) W-7539 (Suber #1) to a minimum of 15.5 feet (4.7 meters) (Huddlestun, in press).

The Dogtown Member occurs in northern Liberty, northern Gadsden, and northern Leon Counties in Florida and in southern Decatur and Grady Counties, Georgia. Its limits in Georgia have not been accurately defined (Huddlestun, in press).

Age

As discussed under the Torreya Formation, the Dogtown is middle Early Miocene (early to middle Burdigalian) in age. It is included in the *Carolia floridana* Zone of Hunter and Huddlestun (1982). Weaver and Beck (1977) also suggested an Early Miocene age for the fuller's earth beds (Dogtown Member).

Discussion

The Dogtown Member of the Torreya Formation contains economically important fuller's earth clay deposits. Although its areal extent has not been accurately defined, it appears to be mappable in a limited area. As is the case with the Torreya Formation in general, more core data are needed to further define the Dogtown Member.

SOPCHOPPY MEMBER OF THE TORREYA FORMATION

Definition and type Locality

Huddlestun and Hunter (1982) suggested using the "Sopchoppy limestone" of Dall and Harris (1892) as a member of the Torreya Formation. The type locality of the Sopchoppy Member is an exposure of fossiliferous, sandy limstone under a bridge over Mill Creek in the center of Section 34, Township 4 South, Range 3 West, northwest of Sopchoppy, Wakulla County, Florida. No core data is presently available in this area.

Lithology

Dall and Harris (1892) refered to the Sopchoppy Limestone as a very soft limestone with numerous imprints of fossils. In referring the Sopchoppy to the Alum Bluff Formation, Matson and Clapp (1909) did not provide descriptions of the limestone.

Huddlestun (in press) recognizes two lithofacies in the Sopchoppy Member: 1) a sandy, fossiliferous limestone, and 2) a tough, phosphatic, dolomitic sand.

The limestone is moldic, fossiliferous, variably sandy and phosphatic and is coarsely bioclastic with a calcareous mud matrix (Huddlestun, in press). The sand facies is a fine grained, well sorted, dolomitic, phosphatic quartz sand. This sand is often irregularly distributed through the limestone unit. Clays are present as interstitial material and include palygorskite and smectite (Weaver and Beck, 1977).

Subjacent and Suprajacent Units

Thickness and Areal Extent

The only recognized occurrence of the Sopchoppy Member is near the Sopchoppy River in Wakulla County, Florida. Its relationship with the overlying and underlying units, and its thickness and extent are not clearly understood (Huddlestun and Hunter, 1982). However, it appears to grade vertically downward into undifferentiated Torreya Formation. In the type area, the Sopchoppy Member is overlain by undifferentiated sands (Pleistocene?).

Age and Correlation

The age of the Sopchoppy Member is based on macrofaunal similarities with the main portion of the Torreya Formation (Huddlestun, in press). This suggests an Early Miocene age.

Correlations of the Sopchoppy with other units are not well understood at this time. Huddlestun (in press) suggests that it may correlate with the phosphatic sands below the Dogtown Member north of the Sopchoppy Member's type area.

Discussion

Very little is known about the Sopchoppy Member of the Torreya Formation outside of its type area. No core data are presently available to study the extent of the unit. Further study is required to better understand the Sopchoppy.

HAWTHORN GROUP MINERALOGY

The sediments here included in the Hawthorn Group have been of interest for many years due in part to their unusual mineralogy and complex lithostratigraphy. While the Hawthorn contains a variety of common minerals, it also has a number of unusual minerals which developed under special conditions. The genesis of these minerals was related to oceanic chemistry, depositional environments and the effects of post-depositional, diagenetic changes.

The unusual minerals present in the Hawthorn Group include francolite, palygorskite, sepiolite, and dolomite. The phosphates have been the focus of much research due to their economic importance. Development of the phosphate minerals and phosphorite deposits required an unusual set of circumstances that also resulted in the formation and deposition of palygorskite and sepiolite. Related to these conditions is the formation of dolomite in the Hawthorn sediments.

Each of these minerals will be discussed separately to contribute to an understanding of the conditions necessary for their formation. The separate discussions show that similar environmental conditions were responsible for the unusual mineral suite commonly recognized in the Hawthorn sediments.

PHOSPHATE

Occurrence in the Hawthorn Group

Phosphate is present in much of the Hawthorn Group, constituting one of the primary lithologic factors for assigning sediments to the group. In peninsular Florida, phosphate is virtually ubiquitous throughout the Hawthorn sediments. Nonphosphatic lithologies are not common but do occur, usually in the more pure clays and carbonates or as rare, clean, quartz sand beds. However, in the eastern Florida panhandle on the northwest flank of the Ocala Platform (Figures 4, 63 and 64), non-phosphatic sediments in the Hawthorn are quite common.

In the Hawthorn sediments statewide, phospate typically occurs as sand-sized grains disseminated throughout the sediment. Pebble-sized phosphate grains are also common but generally are limited (i.e. Bone Valley Member) to localized areas or very thin zones. The concentration of phosphate within the Hawthorn sediments ranges from zero to greater than 50 percent. Characteristically, however, the average concentration in the Hawthorn sediments is between 2 and 10 percent.

Economically important occurrences of phosphate are known in several areas of the state (Figure 65). The most productive deposit is found in the Central Florida Phosphate District in Polk, Hillsborough, Manatee and Hardee Counties. In this district, the phosphate is produced predominantly from the Bone Valley Member of the Peace River Formation with some production occurring from the undifferentiated Peace River Formation. Pebble phosphorites predominate in the Bone Valley Member while sand-sized phosphorites dominate the undifferentiated section. Southward into the southern extension of the Central Florida Phosphate District (Hardee, Manatee, Sarasota and DeSoto Counties), the production comes from the undifferentiated Peace River Formation.

The southeast Florida phosphate deposit, located primarily in Brevard and Osceola Counties (Figure 65) contains phosphorite in the undifferentiated Peace River Formation. This deposit occurs on the flank of the Brevard Platform (Figure 4). There has been no mining in the southeast Florida deposit.

Phosphate production in north Florida is limited to an area in eastern Hamilton County. The Northern Florida deposit extends eastward and southward as shown in Figure 65. Production in north Florida is from the Statenville Formation. This deposit is located on the northeast flank of the Ocala Platform (Figures 4 and 65). The northern Florida deposit is associated with the lower grade south Georgia deposit (Figure 65).

Further east in north Florida is the northeast Florida deposit (Riggs, 1984) (Figure 65). This deposit is unique in that it is much deeper in the section, occurring more than 200 feet (61 meters) below land surface. These sediments are tentatively placed in the Marks Head Formation of the Hawthorn Group based on very limited core data. If the formational assignment is correct, the phosphorites may represent the oldest Miocene phosphorite deposit in the southeastern United States. Currently, experimental borehole mining techniques are being used to test the feasibility of mining this deposit (Scott, L.E., 1981).

One other important phosphate deposit, the Hard Rock Phosphate District, occurs in northern Florida. It is not currently considered part of the Hawthorn Group although weathering of the Hawthorn Group sediments was probably responsible for the formation of the hard rock phosphates. The Hard Rock District lies west of the present erosional scarp of the Hawthorn Group and occurs on the eastern flank of the Ocala Platform (Figures 4 and 65). Currently the hard rock deposits are not being mined.

Phosphate Genesis

The abundance of phosphate in the Hawthorn sediments is anomalous when compared to the remainder of the Tertiary sediments. Many questions arise concerning the genesis of phosphate in Florida including: 1) What was the source of the phosphate?; 2) How was it deposited?; 3) What role did topographic or structural features play? Research worldwide is producing a greater insight into the processes involved in the formation of marine phosphates. However, the problem is still far from being thoroughly understood.

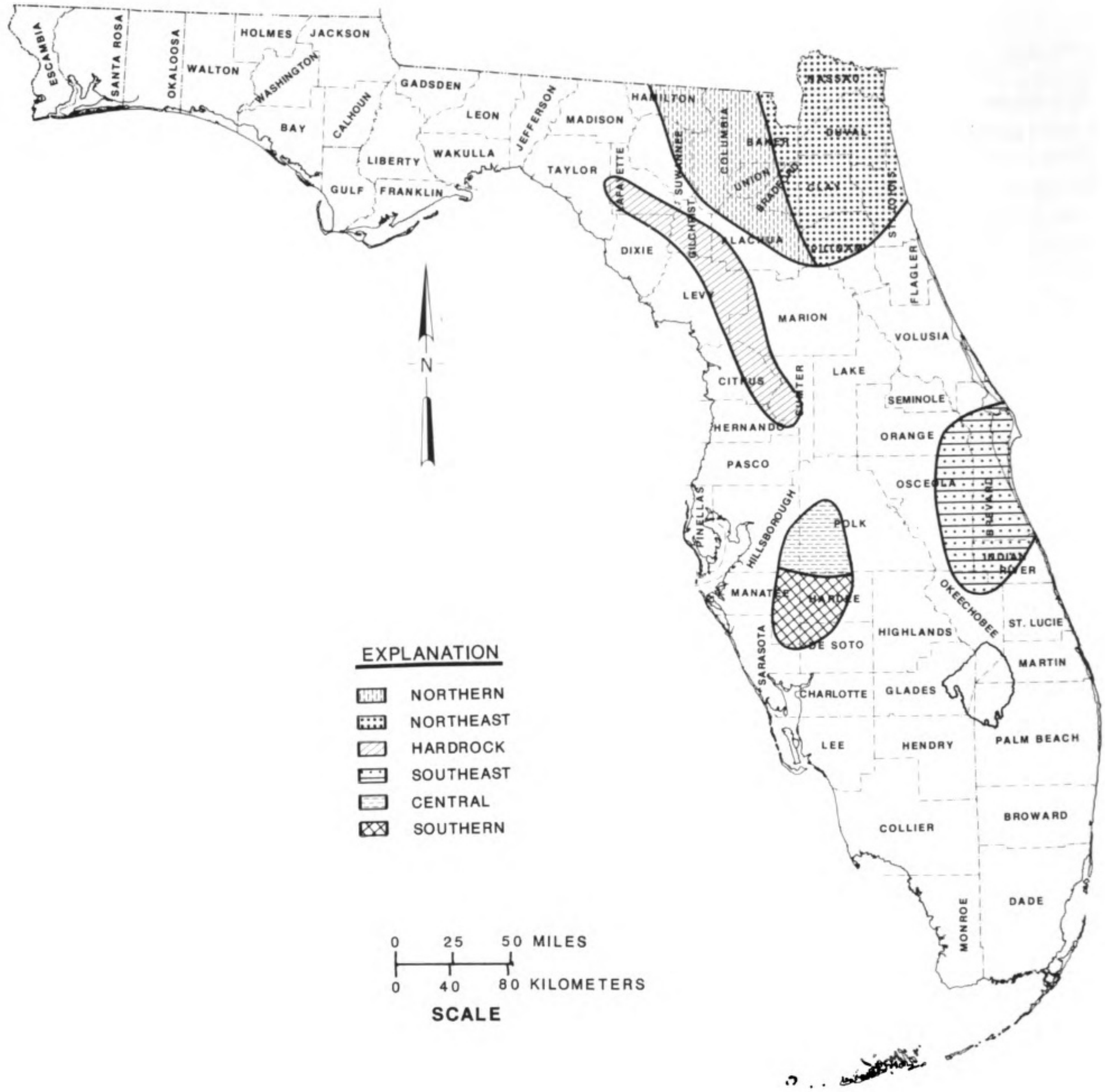


Figure 65. Location of phosphate deposits in Florida.

The phosphorite deposits in the southeastern United States are enigmatic when compared to other occurences of marine phosphorites in the world (Riggs, 1984). Most marine phosphorite deposits occur on western continental shelves where upwelling is associated with trade wind belts, or along east-west seaways characterized by equatorial upwelling. The southeastern United States deposits do not fall into these categories. More recent research indicates, however, that similar mechanisms (upwelling and currents) may be involved in the phosphorite formation in the southeast (Riggs, 1984).

Kazakov (1937) originally suggested that marine phosphorites were precipitated inorganically from upwelling, cold, phosphorus-rich water. The inorganic mechanism for phosphorite precipitation has been suggested to be unlikely by more recent research (Bentor, 1980).

Upwelling, however, remains an important mechanism in the formation of these deposits. Upwelling currents provide the nutrients necessary for the production of large amounts of organic matter (Sheldon, 1980). Subsequent concentration of the phosphorus may result from the action of bacteria at or above the sediment-water interface (Riggs, 1979b), or in interstitial pores within the sediment (Burnett, 1977).

An oceanographic event of global extent was responsible for the formation of the Miocene phosphorite deposits in the southeastern United States (Riggs, 1984). The deposition of the phosphorites and associated phosphatic sediments was controlled by the regional structural framework and the effects of the impinging upwelling currents (Riggs, 1984). Figure 66 shows the structural features of the southeastern coastal plain from North Carolina to Florida that probably controlled phosphate deposition. Only Florida's structural framework will be discussed here.

The dominant positive structural features in the peninsula are the Ocala Platform and the Sanford High including the Sanford High's northern and southern extensions, the St. Johns Platform and the Brevard Platform, respectively (Figure 66). The negative features include the Jacksonville Basin and the Osceola Low. These structures are all considered as pre-Miocene features (Vernon, 1951). Riggs (1979b) considered the structural framework to be one of the most important variables in the development of the phosphogenic system. He outlined three criteria for the development of the phosphogenic system. First is the appropriate regional setting which defines the limits of the system. Second, shoaling environments associated with structural or topographic highs and adjacent basins must occur. Third, the highs must have the appropriate topography to produce the phosphorite and accumulate it in associated topographic lows. Florida's regional structural setting meets these criteria.

According to Riggs (1984), optimum production of phosphate occurred on the flanks of the highs in Florida while significantly less formed elsewhere in the marine environment. Gulf Stream-associated upwellings resulting from bathymetric (topographic) influences impinged on the flanks of the structures providing the necessary constant supply of phosphorus required for phosphate deposition. Miller (1982) suggested that the upwellings associated with north Florida phosphate deposition were related to a south-flowing cold-water current that Gibson (1967) identified during a faunal study of the phosphorites in North Carolina. Hoenstine (1984) also recognized a cold water diatom flora in portions of the Hawthorn Group in an investigation of the group in northeast Florida.

Riggs (1979b) believed that phosphate deposition occurred as a biochemically precipitated mud in the shallow water environments on the positive structural features. The microcrystalline phosphate mud (microsphorite) is not commonly preserved; however, remnants of the microsphorite beds may be present in the Hawthorn Group sediments. Many of the zones suggested to be microsphorite appear to be 1) phosphatized carbonate hard grounds; 2) phosphatic subaerial crusts; and 3) secondary deposits of phosphate by groundwater. The microsphorite beds were reworked into pelletal and intraclastic grains that were deposited in topographic lows on the flanks of the positive features. Riggs (1979a) suggested that many of the pelletal grains originated from the ingestion of phosphate mud by organisms and the excretion of phosphatic fecal pellets. Miller (1982) suggests that gentle currents were responsible for the formation of the pelletal phosphorites in north Florida. Intraclastic and lithoclastic fragments could have resulted from the erosion and reworking of semilithified to lithified microsphorite beds and possibly phosphatized carbonate beds.

Burnett (1977) suggested that the phosphorites forming off the coast of Peru and Chile are inorganically precipipated in the pore waters of anoxic sediments. Phosphorus-rich waters upwell onto the shelf pro-

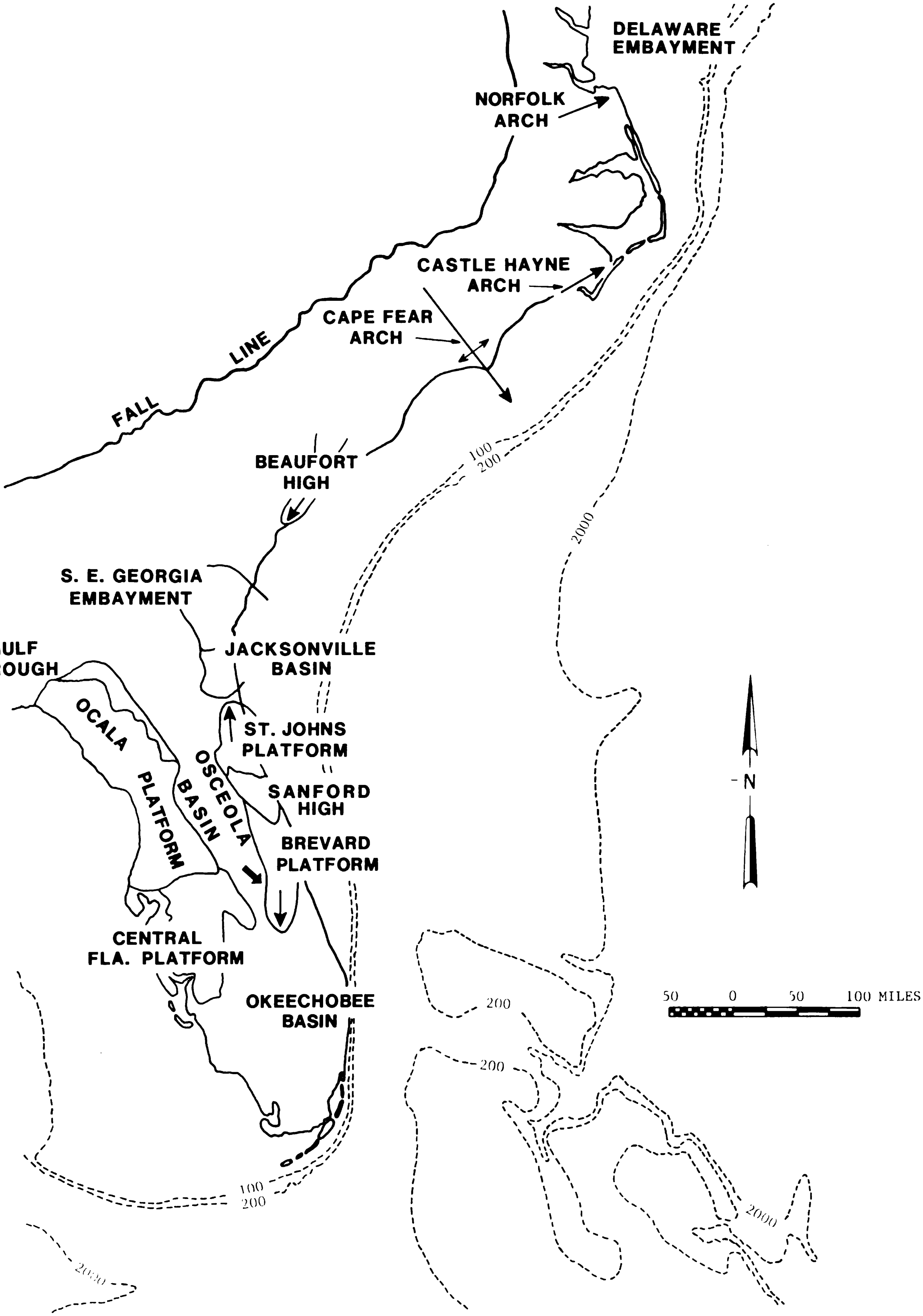


Figure 66. Structural features of the southeast United States (after Riggs, 1979).

viding the necessary nutrients for high biologic productivity resulting in an increased accumulation of organic material in the bottom sediments. Burnett et al. (1980) indicated that the highest concentration of phosphate in the sediments occurred in the zone of oxygen minimum. The phosphate is provided to the pore waters by the decomposition of the incorporated organic matter. The precipitation of phosphate in the pores results in the growth of nodules and, presumably, various sizes of pellets in the sediment.

The resultant phosphate grains range from silt-sized to pebble-sized with the size range becoming coarser and identifiable intraclastic fragments becoming more common toward the phosphate source area. Riggs (1979b) has noted this occurrence on the flanks of the Ocala Platform. Away from the areas of primary phosphate deposition, the percentage of phosphate present in the Hawthorn sediments generally decreases as does the ratio of pebble to sand-sized phosphate.

Riggs (1979b) suggested that, away from the highs or positive structural features, fine sand-sized and silt-sized phosphates formed from a loose colloidal suspension of orthochemical phosphate occurring above the bottom. As the aggregates formed they trapped other sediments in them including silts, dolomite rhombs, organic debris and clays. The resulting aggregates were subsequently incorporated in the bottom sediments.

It is the author's opinion that the vast majority of phosphate grains in Florida have been transported, or at least reworked, from their original depositional area. Throughout the Hawthorn Group, the occurrence of phosphate appears related to the occurrence of quartz sand. It is uncommon for the percentage of phosphate to exceed the percentage of quartz sand in a clay or carbonate sediment except in the case of a phosphorite such as those currently being mined. The lack of phosphate grains in relatively pure carbonates (lacking quartz sand or other siliciclastic particles) in the Hawthorn is very common even though these units may be overlain and/or underlain by quartz sandy carbonates containing phosphate. The same relationship applies to relatively pure clays and sandy clays. These relationships suggest that, although phosphate in Florida is a precipitate, it most often becomes a clastic particle which is subsequently deposited at varying distances from the source areas. Phosphorite deposits result when sufficient quantities of phosphate are available and wave and/or current energies are sufficient to winnow and concentrate the phosphate grains. Sedimentary features, including graded bedding and cross bedding, are indicative of the higher energy conditions present during phosphorite deposition. Grain size and shape of the phosphate particles may also be indicative of reworked materials, since the grains vary from rounded and sand-sized to subangular or rounded and pebble-sized.

Post-Depositional Modification

Post-depositional weathering and reworking of the Hawthorn sediments have been relatively widespread. The best documented effects are those that affect the sediments of the major phosphorite deposits. Leaching, redeposition and reworking have all played a role in the modification of the original phosphatic material in the Hawthorn sediments.

Throughout much of northern and central Florida, part of the Hawthorn Group (Figure 5) has been subjected to the effects of groundwater migration. Leaching of the soluble phosphates has been one of the major effects of this process, resulting in the total loss of phosphate in extreme cases. The post-depositional development of the "leached zone" in the Central Florida phosphorite deposits has been discussed by a number of authors including Altschuler and Young (1960), Altschuler et al. (1964), Riggs (1979a) and Hall (1983).

Supergene weathering of the phosphorite tends to upgrade or increase the phosphate content by removing the included carbonates and organic material. The deveopment of the aluminum phosphate zone is the direct result of weathering of the carbonate fluorapatites. Riggs (1979a) recognized seven zones ranging from unaltered to completely leached. These zones were gradational and all zones may not be fully developed in any one section. The typical zonation trends from: unaltered carbonate fluorapatite to mixed calcium-aluminum phosphates to aluminum phosphates and, finally, to phosphate free. As the phosphate grains are leached the color changes from shiny black and dark brown to earthy-textured light colors and white. This same process of supergene weathering alters and removes clays as well. The net result is the development of a clean quartz sand which constitutes part of the overburden (Altschuler and Young, 1960).

Elsewhere in the state, where the upper Hawthorn sediments do not constitute an economic phosphorite deposit, weathering follows a similar sequence but without the extensive development of the aluminum phosphate zone. As the phosphate and carbonate are removed, a vesicular sandstone develops.

Hard Rock Phosphate Deposits

Hard rock phosphate deposits are found scattered along the eastern flank of the Ocala Platform west of the present limits of the Hawthorn Group (Figure 65). Cooke (1945), Vernon (1951) and Puri and Vernon (1964) considered these deposits as part of the Alachua Formation. The phosphate occurs as "plates or large boulder like masses" (Cooke, 1945) resting on the surface of the underlying limestones of the Ocala Group or Suwannee Limestone. Cooke (1945) also reported that the phosphate has replaced portions of this underlying carbonate. These deposits were mined from 1890 until the mid-1960s, when the last operation closed.

The origin of the hard rock phosphate is intimately related to the development or occurrence of a phosphorite deposit in the Hawthorn Group. Sellards (1913) believed that the phosphate was derived from overlying phosphatic sediments by dissolution and was subsequently reprecipitated to form the hard rock deposits. Cooke (1945) also supported this theory. Sellards (1913) discussed theories proposed by other authors, many of whom felt the source of the phosphate to be guano. Vernon (1951) believed guano to be the source of the phosphate, citing the fact that he did not believe the phosphatic materials of the Hawthorn Group were deposited that high on the Ocala Platform.

The Hawthorn Group was postulated to have extended over much of the Ocala Platform (Scott, T.M., 1981) based on the occurrence of cherts in the upper part of the Ocala Group and Suwannee Limestone. The occurrence of phosphatic sands associated with the hard rock phosphates also suggests the former presence of the Hawthorn Group in the Hard Rock Phosphate District.

Based on these assumptions, the present author agrees with Sellards (1913), Cooke (1945) and Upchurch and Lawrence (1984) that phosphates present in the Hawthorn Group on the east flank of the Ocala Platform were probably the source of the phosphorus which developed the hard rock phosphate deposits. It is suggested here that the original Hawthorn phosphorite deposit formed in the manner described for other Florida deposits. It then underwent extensive leaching, erosion and reworking to develop the hard rock phosphates and the residual Hawthorn sediments previously placed in the Alachua Formation. It is interesting to note here that recent research on the erosional scarp of the Hawthorn Group in Columbia County indicates that groundwater in the Floridan aquifer system under the Hawthorn Group near the scarp is supersaturated with respect to PO_4 (Upchurch and Lawrence, 1984). Upchurch and Lawrence believe that the development of karst features penetrating the Hawthorn sediments allows the phosphorus-bearing water to enter the aquifer system. They also feel that this mechanism may have allowed the development of the hard rock deposits and may explain the discontinuous nature of their occurrence.

PALYGORSKITE AND SEPIOLITE

Palygorskite and sepiolite are not generally considered common clay minerals. Their sedimentary origin is not well known, although it is generally assumed that restricted conditions are often required for their formation. Their occurrence in the Hawthorn Group of the Florida, Georgia and South Carolina coastal plain, where they often are the dominant clay mineral, is well documented (Reynolds, 1962; Heron and Johnson, 1966; Weaver and Beck, 1977; Reik, 1982; Hetrick and Friddell, 1984). The occurrence of these clays in association with dolosilts and phosphate indicates unusual depositional environments for the Miocene sediments in the southeastern United States.

Palygorskite and sepiolite are magnesium silicate clay minerals belonging to the 2:1 layer group and possessing an amphibole-like chain or fibrous structure. While the two minerals differ slightly in structure, they have very similar chemical formulas. The major difference is that palygorskite contains some aluminum substituted for magnesium while sepiolite does not (Hathaway, 1979). For a complete discussion of the mineralogy and chemistry of palygorskite, see Gremillion (1965), Grim (1968), Weaver and Beck (1977), Ogden (1978), and Hathaway (1979).

Palygorskite and sepiolite occur throughout the Hawthorn Group mixed with variable proportions of smectite, illite, chlorite and some kaolinite. Hetrick and Friddell's (1984) study of the Hawthorn Group clay mineralogy indicated a highly variable clay-mineral composition that is not obviously related to stratigraphic position. However, statistical evaluation of this data indicated that the formations of the Hawthorn Group are significantly different from each other in smectite, palygorskite and sepiolite content (Hetrick and Friddell, 1984). They indicate that palygorskite and sepiolite are the dominant clay minerals in the Marks Head Formation of northern Florida and Georgia, while smectite dominates in the Coosawhatchie and Penney Farms (Parachucla) formations.

Palygorskite and sepiolite are often closely associated with dolomitic sediments (Reynolds, 1962; Weaver and Beck, 1977; Reik, 1982). The dolomite in these sediments is commonly the limpid dolosilt discussed in the dolomite section of this paper.

The modes of formation and depositional environments of palygorskite and sepiolite have been studied by a number of authors (McClellan, 1964; Gremillion, 1965; Millot, 1970; Weaver and Beck, 1977; Ogden, 1978; Strom and Upchurch, 1985) resulting in a number of depositional models. The formation of these clays has been postulated to have resulted from: 1) weathering (Kerr, 1937), 2) alteration of volcanic ash (Gremillion, 1965), 3) transformation from clay mineral precursor (Weaver and Beck 1977, Ogden, 1978), and 4) neoformation or precipitation from sea water (Millot, 1970). Currently, the transformation of a clay mineral precursor such as montmorillionite by the addition of silicon and magnesium is the accepted mode of formation for palygorskite and sepiolite. It should be noted here that a minor amount of palygorskite probably precipitated directly from solution (Weaver and Beck, 1982).

The development of palygorskite and sepiolite was thought to occur primarily in restricted, brackish water (schizohaline) lagoons and tidal flats by Weaver and Beck (1977, 1982) and Ogden (1978). Weaver and Beck (1977) suggest that sepiolite formed under more fresh water conditions in this environment. The transformation of the precursor clay minerals to palygorskite and sepiolite requires a relatively high pH (8-9) as suggested by Weaver and Beck (1977), and a supply of silicon and magnesium. The pH increases in response to evaporation in the restricted environments, and, perhaps seasonally, reaches the required high pH levels. As the pH levels increase, the solubility of biogenic opal (found in diatoms and siliceous sponge spicules) increases, supplying the silicon required. Magnesium is concentrated due to the evaporation of the brackish waters. Given these conditions, and a supply of a suitable precursor clay mineral such as smectite, Weaver and Beck (1977) and Ogden (1978) postulate the development of palygorskite and sepiolite clays.

Weaver and Beck (1977) also discuss the development of limpid dolomite in association with palygorskite genesis. They suggest that dolomite forms both prior to palygorskite formation and after it. This may also indicate a seasonality to the critical nature of the depositional environments.

Restricted, alkaline lagoons probably occurred over a wide area during Hawthorn deposition. The flanks of the Ocala Platform possibly provided ideal environments for palygorskite formation as did parts of the St. Johns and Brevard Platforms and the Sanford High. The reworking of these palygorskite-rich deposits during transgression could provide vast amounts of clay that could be incorporated in the more normal marine portions of the Hawthorn Group downdip. The association of dolomite in both the environment of the reworked palygorskite indicates the possibility that the silt-sized dolomites were transported into depositional basins.

Upchurch et al. (1982) and Strom and Upchurch (1983) discuss the development of palygorskite and opaline chert in perimarine, alkaline-lake environments. Their discussion of the palygorskite and opal-forming environments suggests a somewhat more restricted environment than that discussed by other authors. It seems to this author that the more restricted environment of Upchurch, et al. (1982) may have occurred in conjunction with less restricted, palygorskite-producing, brackish water (alkaline) lagoons. However, the ephemeral lakes of these authors were less common and of smaller areal extent than the lagoonal environments. The net result is the large scale production of palygorskite with a more limited creation of opaline sediments and subsequent reworking of the palygorskite into the depositional basins.

DOLOMITE

Dolomite, like phosphate, is a rather enigmatic mineral in nature. A number of different types of dolomite are known to exist, suggesting that there is not a single, unique process by which dolomite forms or dolomitization occurs. As a result, there is no unique model to explain dolomite genesis (Zenger and Dunham, 1980). It is important to attempt to understand the occurrence of dolomite in the Hawthorn Group, due to the association of dolomite with phosphate and palygorskite. The knowledge resulting from attempts to determine the origin of one mineral may shed light on the origin of the other minerals.

Carbonate rocks dominate the Hawthorn sediments in a large portion of southern Florida. Northward, the carbonate content decreases as the terrigenous component increases. Even in the northern area, however, carbonate remains an important constituent, both as a primary lithology and as an accessory mineral.

Dolomite is the most common carbonate component in the Hawthorn Group throughout much of the state. Only in portions of southern Florida does dolomite assume a subordinate position with respect to limestone in the group. Dolomite occurs in several different modes; the predominant types are dolomitized limestones or secondary dolomites and dolosilts. It also is present as an accessory mineral in clays, clayey sands, limestones and many phosphate grains.

Secondary dolomites are present in the carbonates of the Hawthorn Group throughout the state. These dolomites are characterized by a coarse, anhedral dolomite replacing the original limestone. Most original depositional features are destroyed by the dolomitization, although ghost structures of pellets and fossils have been observed in thin section. Molds of mollusk shells are common and are often lined with later-phase dolomite and/or sparry calcite druses. It appears that the original carbonate rock was a wackestone to a mudstone that contained a variable siliciclastic component, including phosphate. This type of dolomite is most common in the basal Hawthorn Group Penney Farms Formation in northern Florida.

The dolomites of the basal Hawthorn Group in much of northern and part of southern Florida lie directly on undolomitized Eocene (Oligocene in a few cases) limestones. The development of the dolomite was restricted to the Miocene carbonates by some mechanism. The occurrence of a recrystallized low permeability zone in the upper few feet of the undolomitized limestones below the pre-Hawthorn unconformity may have provided enough of a permeability barrier to groundwater movement to limit dolomitization to the Miocene carbonates. Further study is required to determine if the dolomitization is an early or later diagenetic event.

Dolosilt is a term applied to unconsolidated, silt-sized, euhedral, rhombic, often limpid crystals of dolomite. This type of dolomite has also been referred to as microsucrosic dolomite when more lithified (Prasad, 1983). Dolosilts are extremely common in the sediments of the Hawthorn Group ranging from a minor accessory mineral to a nearly pure dolosilt sediment. The dolosilts range from fine silt-sized (10 microns) to fine sand-sized (greater than 62 microns). The individual crystals show sharp crystal faces and often have hollow centers.

Lithologically, dolosilts are present in a wide variety of sediment types. Clays and clayey sands of the Hawthorn Group very commonly contain dolosilts in widely varying amounts. A complete gradation between the clays and dolosilt-rich sediments often occurs, causing some problems in identifying the components of the sediment, since minor amounts of clay in a fine-grained dolosilt may present the appearance of a siliciclastic, silty clay lithology.

The carbonate portions of the Hawthorn Group contain variable percentages of dolosilt. Beds vary lithologically from nearly pure dolosilt and dolostone to limestones with minor percentages of dolosilt floating in a carbonate mud matrix. Prasad (1983) has identified two types of dolomite in the Hawthorn of southern Florida. First, he recognized a dolomite fraction of microsucrosic, silt-sized rhombs (dolosilts) that show no replacement textures. Second, Prasad identified fine grained dolomite associated with dolosilts that exhibited a replacement texture. The dolomite replaced metastable fossil fragments often with a syntaxial dolomite rim (Prasad, 1983). Prasad also noted that there is an inverse relationship between micrite and dolosilt in the carbonate beds suggesting a replacement of the micrite by dolosilt.

In northern parts of central Florida, dolosilts are significantly more abundant than in south Florida. This suggests that dolomite genesis (and perhaps dolomitization) was more intense or complete in these areas than in the southern area discussed by Prasad (1983). It is also interesting to note that the northern and central Florida dolomites are associated with greater amounts of palygorskite and, in general, phosphate.

Silt-sized dolomite rhombs and occasionally clasts of dolomite are often incorporated in phosphate grains. Riggs (1979a) states that it is not unusual if as much as 90 percent of the phosphate grains in a deposit contain inclusions of dolomite. This association is important since the two mineral phases do not form in the same geochemical environment. The magnesium concentration is a controlling factor in the development of phosphate in that magnesium inhibits the formation of phosphate in normal seawater (Bentor, 1980). Riggs (1979a) recognizes evidence of transportation of the dolomite rhombs. He suggests that the dolomite and phosphate developed in adjacent areas and that the dolomite was transported then mixed with the phosphate muds.

The origin of dolomite is a confusing and enigmatic question. Even though it is a common rock-forming mineral and an accessory mineral, the various modes of formation are not well understood. With respect to the dolomites in the Hawthorn Group, there appears to have been several types of dolomite development. These types include replacement of limestones (secondary dolomite), dolomitization of metastable fossil material, and dissolution of aragonite and high-Mg calcite mud with co-precipitation of dolomite (dolosilt or microsucrosic dolomite).

The replacement of limestone by dolomite is virtually complete in the carbonates of the Hawthorn Group's Penney Farms and Marks Head Formations in northern Florida. Dolomitization on this broad scale is suggestive of a mixing zone mode of formation for the dolomites. As described by Badiozamani (1973), dolomite may be formed by the replacement of limestone by groundwaters of mixed fresh and marine origins. It is suggested here that these dolomites in the Hawthorn Group resulted from the migration of mixed-water zones through the carbonate sediments as sea levels fluctuated during the Late Miocene. The timing of this event is purely speculative based on proposed sea level curves (Vail and Mitchum, 1979). Further research is needed to fully understand the timing and mode of formation of the replacement dolomites.

Dolosilts, or microsucrosic dolomites, may also form from the effects of mixing-zone waters on fine grained carbonate sediments and fossil debris. Prasad (1983, 1985) studied the microsucrosic dolomites of the Arcadia and Peace River Formations in southern Florida. He concluded that dolomitization of the metastable fossil material (echinoderm plates) occurred prior to freshwater diagenesis. The dolosilts appear to have precipitated from dilute solution in the interstital pores. The source for the calcium carbonate to form the dolomite in the mixed waters is inferred to have come from dissolution of fine grained lime mud (Prasad, 1983, 1985). The fine grained, limpid, euhedral, rhombic nature of the dolosilts is considered indicative of growth from dilute solutions in mixed waters (Folk and Land, 1975). Based on the belief that these dolomite crystals form in a brackish water environment, Weaver and Beck (1977) believed that the dolosilts formed in the same environment as the palygorskites.

Very small (1 micron), well-formed, rhombic dolomite crystals have been recognized cementing aragonitic muds on portions of Andros Island (Gebelein, et al. 1980). Growth of these dolomite crystals concurrently with dissolution of the aragonite results in limpid, inclusion-free dolosilts. These sediments may form in two ways, both of which are related to mixing of fresh and marine water. First, they may form in an intertidal or tidal flat environment as recognized by Gebelein, et al. (1980). Secondly, they can develop in migrating mixed water zones in buried sediments (very shallow burial in this case) due to sea level fluctuations (Prasad, 1983, 1985). Both origins seem to be represented in the dolosilts of the Hawthorn Group.

GEOLOGIC HISTORY

Sedimentation in peninsular Florida throughout the Paleogene was dominated by carbonate deposition. Only minor percentages of siliciclastic materials are present in the pre-Miocene sediments. At the beginning of the Neogene, the influx of siliciclastic materials increased dramatically, flooding the carbonate environments and pushing these environments southward. Carbonate deposition continued perhaps as late as early Middle Miocene in parts of south-central Florida to Late Miocene (?) in the Keys. Within the carbonate units, siliciclastic material occurring as both accessory minerals and the dominant sediment type in thin beds generally increased in percentage with decreasing age.

Chen (1965) believed that the Gulf Trough (his Suwannee Channel) (Figure 4) acted as a natural barrier to the southward movement of siliciclastic material until near the end of the Eocene. However, a large influx of siliciclastic material is not recognized until Miocene time. The assumed source for the siliciclastics is the southern Appalachian Mountains and the Piedmont. The reason for the dramatic increase in the supply of siliciclastics has not been documented. However, it is possibly the result of a renewed uplift in the southern Appalachians in the late Paleogene or early Neogene.

The geologic history of the Hawthorn Group is directly related to the Miocene fluctuations of global sea level. An understanding of the global sea levels such as those proposed by Vail and Mitchum (1979) aid in determining the depositional controls exerted by features such as the Sanford High and the Ocala Platform. Since the proposed sea level curves are thought to be free from local tectonic influence, comparison of these curves to the present position of the Hawthorn Group sediment may shed light on the possibilities of tectonic influence on the Florida platform.

Throughout the Tertiary, the Florida platform has been subjected to numerous fluctuations, transgressions and regressions of the sea. The effects of these variations in sea level have been most dramatic from the latest Oligocene through the Pleistocene. Coastal onlap curves published by Vail and Mitchum (1979) reflect these changes along with the apparent relative magnitudes of the fluctuations based on relative coastal onlap (Figure 67).

In contrast to the Vail and Mitchum (1979) sea level curves is the classical idea of fluctuating sea levels expressed by Cooke (1945). According to Cooke (1945), there is a three-fold subdivision of the Miocene present in Florida. Each subdivision was the result of a sea level rise from a previous low stand and a subsequent withdrawal of the sea at the end of each division. The subdivisions were referred to as the Early, Middle and Late Miocene. Cooke (1945) believed that sea level rose to its greatest height during the Middle Miocene.

The relationships of the formations of the Hawthorn Group to the proposed sea level are shown in Figure 67. The formations of the Hawthorn Group in the peninsular area (north and south Florida of Figure 1) are predominantly related to the sea level stands of the earliest Miocene through middle Late Miocene. In the panhandle, Hawthorn Group deposition is thought to be restricted to the Burdigalian as recognized in the Torreya Formation.

Correlations of the Hawthorn Group sediments to the Vail and Mitchum (1979) sea level curve indicate the following sequence of events. The earliest marine transgression that is suggested to have affected the deposition of the Hawthorn Group began in the Early Miocene (Aquitanian). At least part of the Penney Farms Formation was deposited at this time as was the lower portion of the Arcadia Formation (Tampa and Nocatee Members and undifferentiated Arcadia). Deposition was interrupted when the sea level dropped in mid-Early Miocene (Early Burdigalian). As sea level continued to rise through the Early Miocene, Hawthorn deposition resumed. Although it is not yet documented, the upper portion of the Penney Farms Formation may have been deposited during this period. Much of the upper part of the Arcadia Formation was also deposited during this transgression. In the panhandle, the deposition of the Torreya Formation of the Hawthorn Group began during this transgression. However, the documented age for the Torreya Formation is Early to Middle Burdigalian (Huddlestun, in press).

As sea level rose in Late Burdigalian, the Marks Head Formation, the Torreya Formation and the upper portion of the Arcadia Formation were deposited. Sea level continued the rising trend into the Middle Miocene as Marks Head and Torreya deposition ceased. In peninsular Florida the Coosawhatchie was deposited on the Marks Head in northern Florida during the Serravalian. In southern Florida, the Arcadia Formation deposition ended in Serravalian and later Miocene deposition in the panhandle Hawthorn Group has not been recognized. This is due either to non-deposition or erosional removal of these

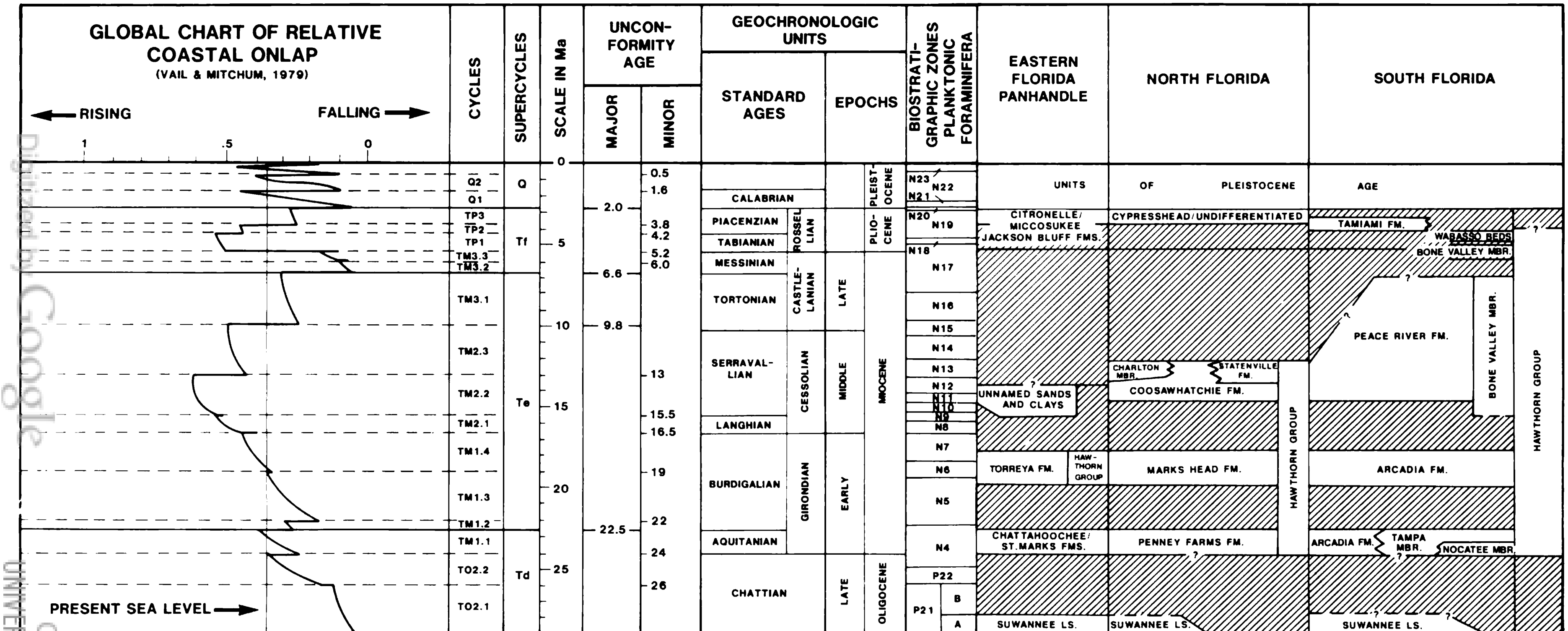


Figure 67. Lithostratigraphic units in relation to proposed sea level fluctuations (after Vail and Mitchum, 1979).

sediments. Post-Serravalian (Tortonian) deposition appears to be limited to southern Florida and perhaps some of the central east coast area where sediments assigned to the Peace River Formation have been identified. Most Hawthorn sedimentation ended by the end of the Tortonian upon the sea level drop of the Messinian. Huddlestun et al. (1982) recognized an informal unit of the Hawthorn Group which was deposited in late Early Pliocene (Tabianian). These beds, referred to as the Indian River beds (later changed to Wabasso beds by Huddlestun (personal communication 1984)) were deposited during the post-Messinian sea level rise. The unit is recognizable only faunally and its extent in Florida is not presently known. During this time the upper bed of the Bone Valley Member of the Peace River Formation developed in part of Polk, Hillsborough, Hardee and Manatee Counties. This bed is the classic Bone Valley Gravel of the earliest usage.

Vail and Mitchum's (1979) sea level curve also lists a number of major and minor unconformities recognized in the seismic sections. Although there are a number of unconformities visually recognizable within the Hawthorn Group (particularly in northern Florida), their correlation with those of Vail and Mitchum (1979) is highly speculative. The difficulty in correlating the unconformities may arise from the very poor biostratigraphic record of the Hawthorn Group in much of Florida or from problems associated with the Vail and Mitchum curve. At this time no attempt is made to correlate the minor unconformities. If future biostratigrahic investigations identify more complete, correlatable faunas or a refinement of Vail and Mitchum's sea level curve occurs, the minor unconformities may be recognized and correlated.

The major unconformities relating to the base of the Hawthorn Group in peninsular Florida are the pre-Hawthorn to post-Ocala unconformity (the Oligocene absent), and the pre-Hawthorn to post-Suwannee unconformity (Latest Oligocene).

Fluctuating sea levels caused varying amounts of land area to be exposed subaerially during the Late Oligocene through Early Pliocene. During the periods of exposure terrestrial vertebrates inhabited the area. The fossil remains found in sinkholes, stream channels and nearshore sediments provide a means of determining the age of the enclosing sediments and therefore the age of the terrestrial episodes.

The series of hypothetical cross sections shown in Figures 68 to 72 suggest a possible geologic history of the Hawthorn Group in Florida. The line of section extends from northern Madison County southeastward to eastern Marion County then south-southeast to Palm Beach County. This series of sections takes into account erosion of sediments during low sea levels and the slow downwarping of southern Florida from a hinge line in Osceola County south. The erosional removal of sediments is shown on the sections as erosional vacuities from several different periods.

The earliest Neogene exposure of the platform occurred during Late Oligocene into Early Miocene (Figure 68). It is very probable that much of the Florida Platform was exposed during this time. Following this low stand, sea level rose but probably did not cover the entire platform. The deposition of the basal Arcadia, the Penney Farms, and the St. Marks Formations occurred during the early Early Miocene. Following this event there was a minor regression then continued transgression. During this period, as the sea levels rose, the Martin-Anthony fauna (MacFadden, 1980) and a terrestrial fauna collected along the Tampa By-Pass Canal (Dale Jackson, personal communications, 1984) were deposited. Both sites contain associated marine fossils indicating a close proximity to land. Upchurch (personal communication, 1986) notes that the Tampa By-Pass Canal exposed some "Tampa" sediments containing a freshwater component to the fauna. These sites are 25 to 22 million years old and are of Arikareean age (North American Land Mammal Age, NALMA) (Chattian and Aquitanian, Figure 73).

Following an earliest Miocene decline in sea level, the sea level began a rise which continued with only minor interruptions through the Early Miocene. Deposition of the upper part of the Arcadia, the Marks Head and the Torreya Formations occurred in the later part of the Early Miocene. During this time (Hemingfordian NALMA; Burdigalian and possibly Aquitanian) a diverse land mammal fauna developed. A number of localities containing this fauna occur in north central and panhandle Florida (see MacFadden and Webb, 1982). The number of sites and their distribution indicate that in the latter part of the Early Miocene, there was a considerable area above sea level (Figure 69). As sea level continued to rise these areas were eventually covered.

Sea level continued to rise reaching its maximum height in the mid-Middle Miocene (Figure 70), when

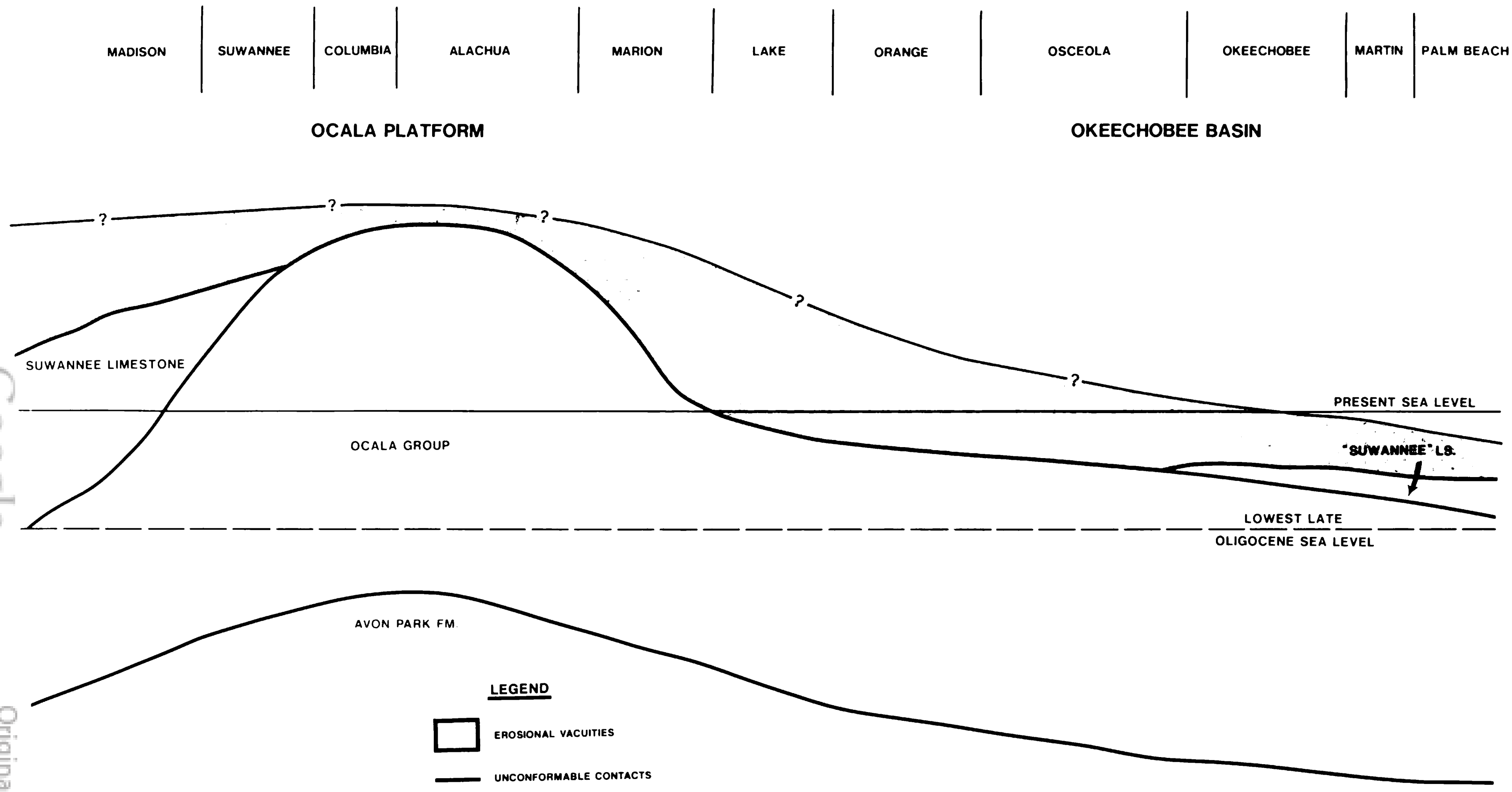


Figure 68. Cross section showing reconstructed stratigraphic sequence at the end of Late Oligocene.

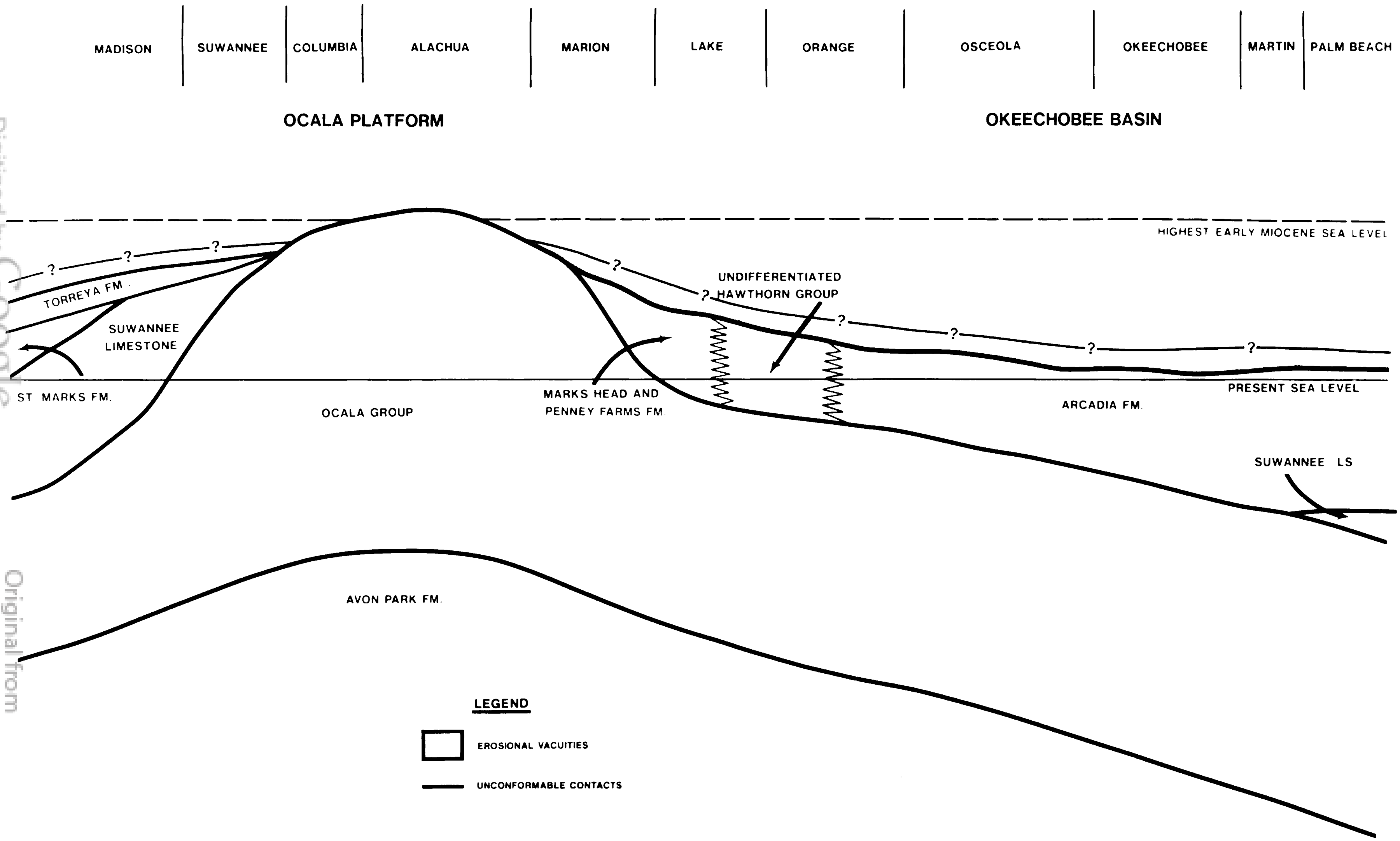


Figure 69. Cross section showing reconstructed stratigraphic sequence at the end of the Early Miocene.

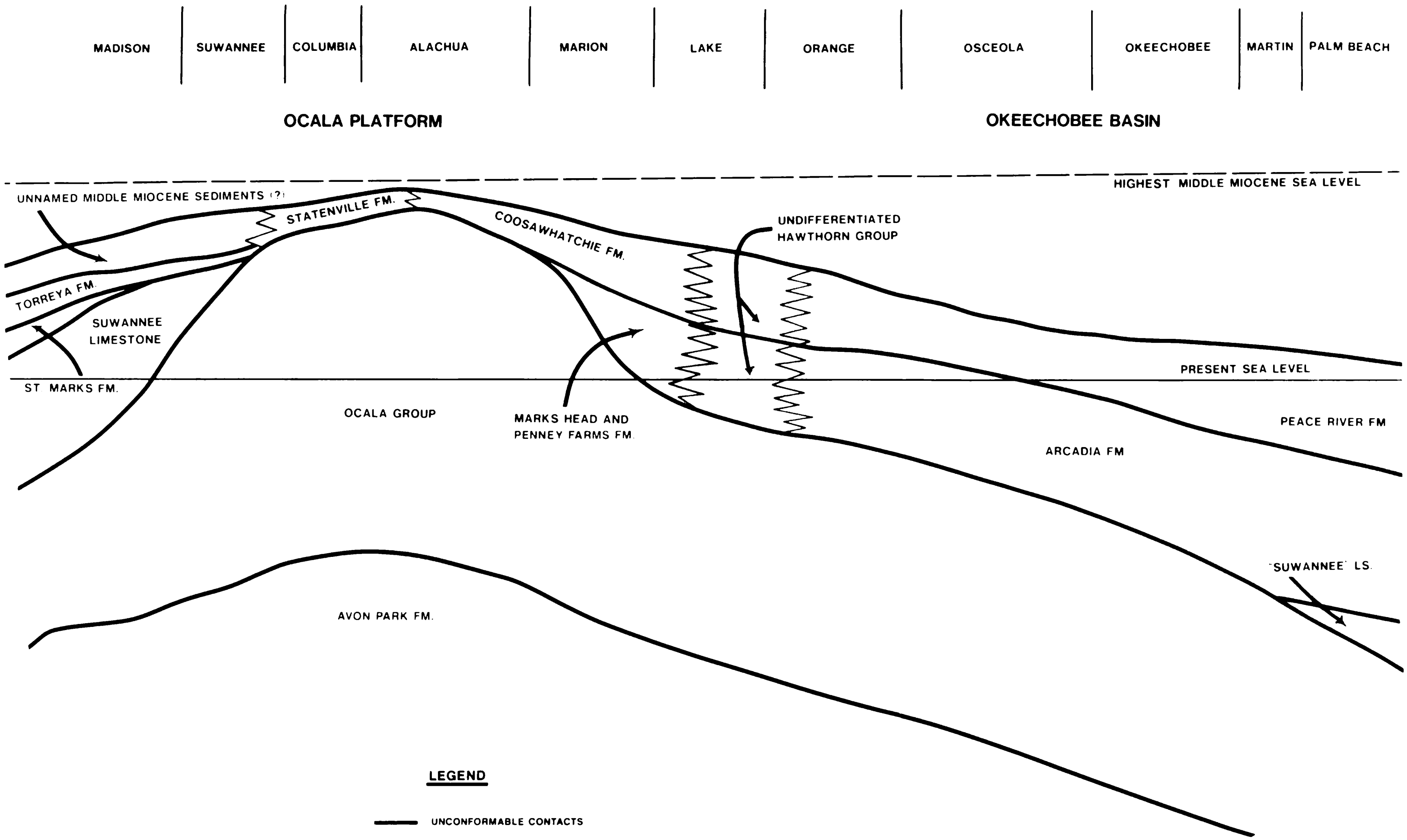


Figure 70. Cross section showing reconstructed stratigraphic sequence at the end of Middle Miocene.

the peninsula was probably entirely submerged. The Peace River and Coosawhatchie Formations were deposited in the peninsular area while an unnamed unit was deposited in the eastern panhandle. Mammal faunas from this time are not well represented. MacFadden and Webb (1982) note sites in Jefferson and Alachua Counties that may be Barstovian age NALMA (Langhian and Serravalian) with possible Barstovian faunas from the Central Florida Phosphate District. In the Central Florida Phosphate District this fauna was collected from sediments immediately above the Arcadia Formation. These sediments were subsequently covered by estuarine and marine sediments of the Peace River Formation (Webb and Crissinger, 1983).

Following the mid-Middle Miocene high stand, sea level began to decline and more of the Florida Platform was exposed. The land area continued increasing into the Late Miocene as the seas continued to recede (Figure 71). There is no record of deposition during this time in the eastern panhandle or the northern peninsular area. In the southern peninsula the upper most portions of the Peace River Formation (incuding the Bone Valley Member) were deposited. The highest sea levels of the Late Miocene and Early Pliocene did not inundate much of the peninsula. During the Late Miocene and Early Pliocene, terrestrial vertebrates were abundant, as indicated by the fauna at the Love Bone Bed in western Alachua Cunty (the only Clarendonian [Tortonian] site) and the faunas at many other Hemphillian (latest Miocene and Early Pliocene) sites.

During the Pliocene and Pleistocene sea levels fluctuated but, judging from data presently available, did not completely cover the state. Deposition appears to have been limited to the southern one-third of Florida and the coastal areas. Erosion breached the Hawthorn Group overlying the Ocala Platform and removed significant amounts of sediment from the peninsula (Figure 72). This erosional episode continues today.

There are problems associated with comparing the Vail and Mitchum (1979) sea level curve to the distribution of Hawthorn Group sediments in Florida. These problems arise when attempting to correlate the occurrence of some Hawthorn sediments presently well above sea level with a paleo-sea level represented as being at or very near present sea level. Further research is required concerning the actual elevations of paleo-sea levels in order to understand the relationships of these levels to the lithostratigraphic units onshore.

PALEOENVIRONMENTS

The Miocene sediments of Florida were apparently deposited in a number of complex depositional environments. Environments range from prodeltaic to open, shallow marine, carbonate bank. Previous workers (Puri 1953; Puri and Vernon, 1964) referred to continental (terrestrial), deltaic, and marine conditions. However, the sediments assigned to the Hawthorn Group by this investigation were deposited only under marine or peri-marine conditions that seemed to have ranged from prodeltaic and shallow to subtidal marine, to intertidal and supratidal. Terrestrial sediments occur only as paleosoils and weathered residuum of the Hawthorn sediments.

In northern peninsular Florida the Penney Farms and Marks Head Formations appear to have been deposited under shallow marine conditions. This is based on the occurrence of a shallow water fauna of *Balanus, Ostrea* and other mollusks (*Pecten, Cardium, Chione,* etc). Intraclasts are commonly recognized in the Penney Farms and Marks Head, which suggests deposition in a shallow water environment with periodic episodes of storm- or tidally-induced high energies. That the shoreline was located west of the present outcrop is indicated by the occurrence of the vertebrate remains in the Penney Farms described by MacFadden (1980). The presence of palygorskite-rich beds within the two formations suggests a nearshore, coastal-lagoonal environments (Weaver and Beck, 1977).

The Coosawhatchie Formation is also thought to have been deposited in a subtidal, shallow marine environment. The Coosawhatchie contains significantly fewer carbonate beds and is much more sandy than the underlying units. Sea level seems to have risen to its Miocene maximum height in the Middle Miocene, during Coosawhatchie deposition. As the sea transgressed, the palygorskite-producing zones of the peri-marine environment were reworked, incorporating palygorskite throughout the unit.

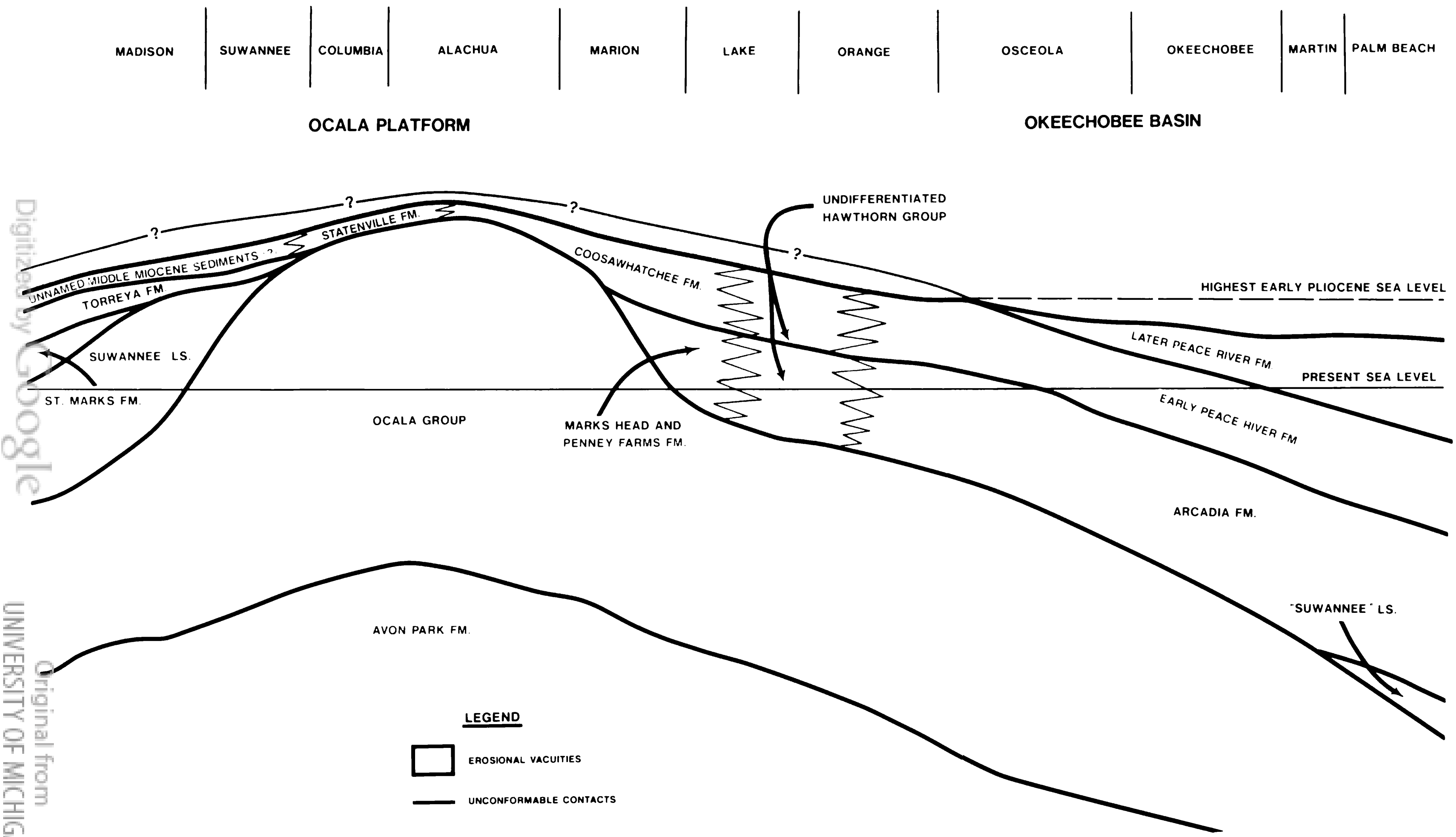


Figure 71. Cross section showing reconstructed stratigraphic sequence at the end of the Early Pliocene.

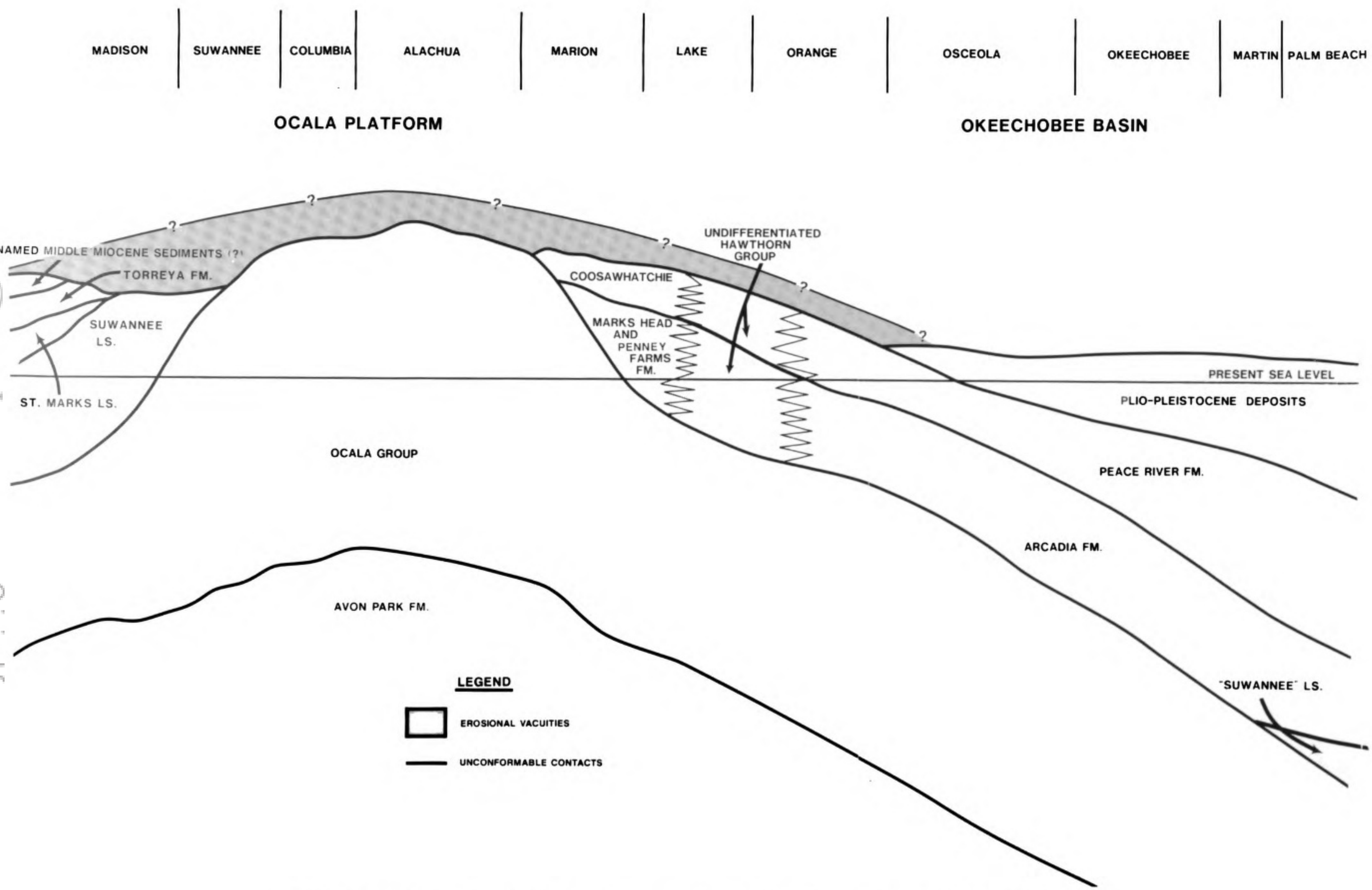


Figure 72. Cross section showing stratigraphic sequence occurring at present.

Sediments assigned to the Statenville Formation crop out along parts of the Suwannee and Alapaha Rivers. These sediments are often strongly crossbedded and contain thin dolomite laminae. Puri and Vernon (1964) thought that the laminae represented algal layers. Associated with the thin dolomite layers are mudcracks, palygorskite beds and opaline cherts. These features suggest a supratidal environment for some of the sediments, while the crossbedded zones suggested nearshore, shallow subtidal to, possibly, intertidal conditions. The occurrence of the opaline cherts is interesting since their occurrence and association with palygorskite and dolosilt (McFadden, 1982) is suggestive of the development of evaporative conditions and highly alkaline waters (Upchurch et al., 1982).

In southern Florida a shallow marine carbonate platform existed throughout a large portion of the Miocene. Siliciclastics were transported onto this carbonate bank from the north and east by southward flowing longshore currents. The Arcadia Formation developed in this environment. King (1979) suggested a quiet water lagoon, much like the present Florida Bay, for the deposition of the Tampa Member of the Arcadia. Similar depositional environments probably continued throughout the deposition of the Arcadia, although the water depths may have increased towards the southeast in response to subsidence of the platform in southern Florida. The Nocatee Member represents a higher energy, more open, near-shore marine environment that occurred on the southeast edge of the carbonate bank during Tampa deposition. The Nocatee grades westward into a very sandy facies of the undifferentiated Arcadia and northwestward into the Tampa Member.

The Peace River Formation represents the flood of siliciclastics that entered southern Florida during the Middle Miocene. The carbonate bank environment was overrun by the siliciclastics, which restricted the deposition of carbonate beds to limited areas. This change was, in part, a response to the rise in sea level in the Middle Miocene and the continued influx of large amounts of siliciclastics from the north. In the northern portion of the area of its occurrence, the Peace River was deposited in a shallow marine to brackish water environment as indicated by the occurrence of shallow water forms of *Balanus* and *Ostrea* in the carbonate beds. Further south (particularly southeasterly) open marine conditions prevailed as suggested by the abundance of planktonic foraminifera in Peace River sediments in Martin County.

The Bone Valley Member of the Peace River Formation is a most interesting unit not only from the standpoint of its phosphate resources but also from the depositional environments it represents and the questions it raises. Early investigators (Eldridge, 1893; Matson and Clapp 1909; Matson and Sanford, 1913; and others) believed that the Bone Valley resulted from the reworking of pre-existing Hawthorn residuum by rivers and the advancing Pliocene sea. Cooke (1945) believed that it was in part residual from the Hawthorn and in part estuarine. Webb and Crissinger (1983) indicate a marine depositional environment for much of the Bone Valley Member. Portions of the Bone Valley were deposited in a more nearshore, higher energy environment while others were laid down in a quieter, shallow marine environment such as an embayment or lagoon. The proximity to land is demonstrated by the occurrence of terrestrial vertebrates mixed with marine vertebrates. This author believes that the Bone Valley Member contains reworked (pre-existing) phosphate derived updip from the older parts of the Hawthorn, gravel sized clasts of phosphatized dolomite, and phosphate formed in the marine environment during Bone Valley deposition. The late phase (very Late Miocene or very Early Pliocene) gravel bed that was classically called the Bone Valley Formation or Gravel is reworked from pre-existing phosphorites. This bed was deposited in freshwater rivers to brackish water, tidally influenced environments.

The depositional environment of sediments assigned to the Torreya Formation of the Hawthorn Group in the eastern panhandle has been discussed by Weaver and Beck (1977). They suggest that these sediments and correlative sediments in southwest Georgia were deposited in a tidally influenced perimarine environment. The environments present ranged from variably brackish to more normal marine waters. This interpretation is based on the occurrence of palygorskite and dolomite, which they believe required more brackish water conditions to form and the occurrence of marine to brackish water diatoms. There were periodic episodes of high energy (perhaps storms) which could have developed intraclast beds within the unit. Limestones present in the lower Torreya suggest a shallow, subtidal marine environment during deposition.

The Hawthorn Group of the Gulf Trough contains a greater abundance of carbonate beds than is present eastward in the panhandle. It appears that this accumulation of carbonate with incorporated

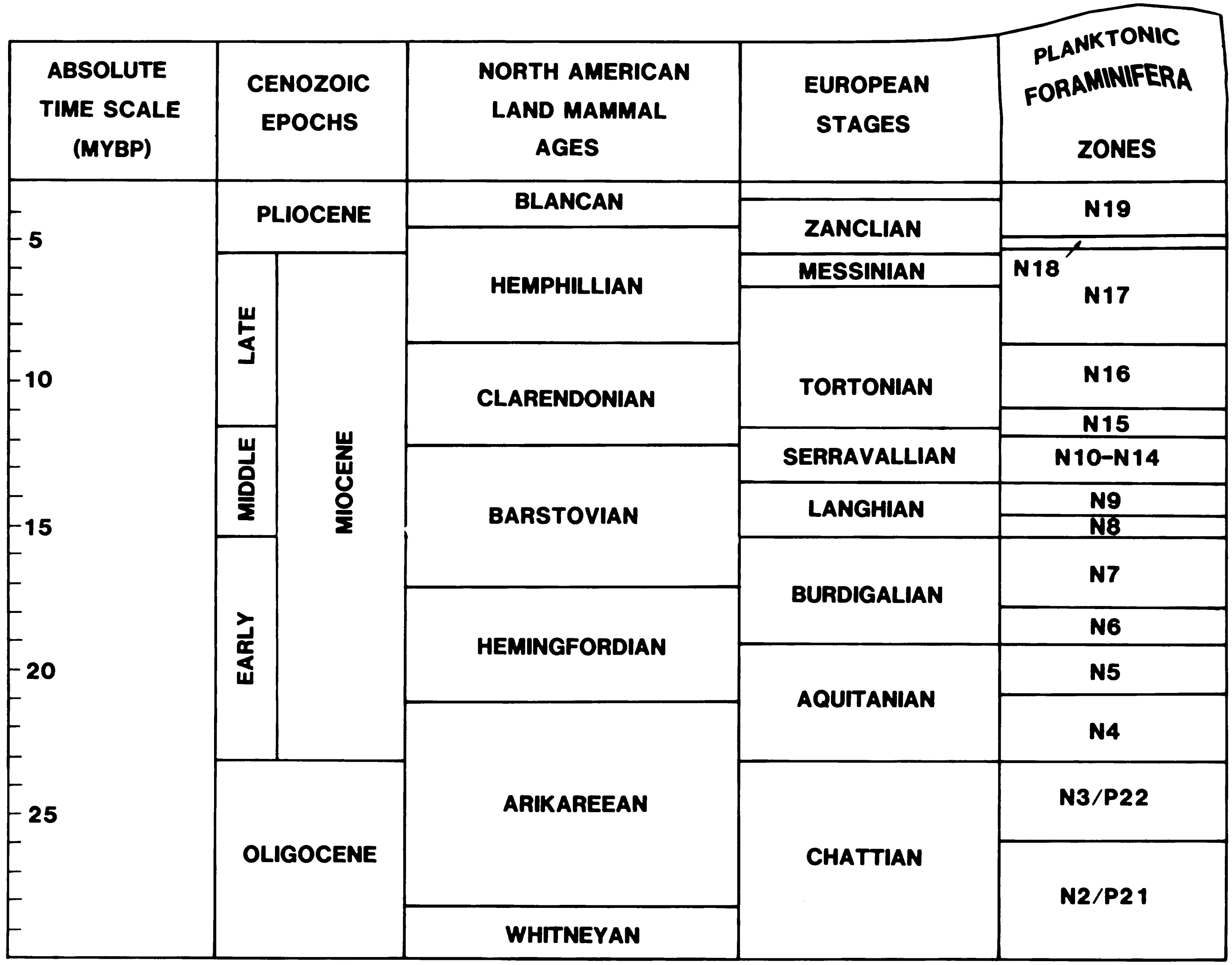


Figure 73. Relation of Mammal ages to planktonic foraminifera time scale (after Webb and Crissinger, 1983).

siliciclastics was deposited in a lagoon or embayment environment prior to the time when siliciclastics flooded the area. When large amounts of siliciclastics entered the area, carbonate deposition was severely limited.

HAWTHORN GROUP GAMMA-RAY LOG INTERPRETATION

Gamma-ray logs are of particular importance to the investigator studying the complex section of the Hawthorn Group. The gamma-ray activity in the Hawthorn Group sediments is generally significantly higher than subjacent or suprajacent formations, thus allowing the delineation of this unit. Also, since these sediments are often partially or entirely cased off during well construction, the ability of gamma-ray probe to obtain information through casing is most important. In the course of this study gamma-ray logs were the only geophysical logs used. For a discussion of resistivity logs of the Hawthorn Group sediments see Johnson (1984).

The Hawthorn Group shows significant stratigraphic and lithologic variation from one area of the state to another. As a result the gamma-ray log discussion is subdivided into sections as shown in Figure 1.

NORTH FLORIDA

The Hawthorn Group of northern Florida consists of a complex sequence of siliciclastics and carbonates containing varying percentages of uranium-bearing phosphate minerals. The resultant gamma-ray log shows widely varying peak intensities (Figure 74). The patterns of peaks are similar throughout much of the area from Duval County west to western Hamilton County and from Nassau County south to southern Putnam County. The Hawthorn thins and the gamma-ray signature changes somewhat south of Putnam County in Marion, Lake and northwestern Orange Counties. This is due both to erosional removal of the upper sediments and to less deposition in the area between the Ocala Uplift and the Sanford High.

A typical gamma-ray log from the north Florida area (Figure 74) consists of five generalized zones. However, the pattern may show significant variation in the intensities of peaks and thicknesses of peak groups. Formational correlation with the gamma-ray signature is relatively consistent. The upper, high intensity zone and part of the subjacent lower intensity zone correlate with the Coosawhatchie Formation and, where it is present, the Statenville Formation. The Marks Head Formation correlates with part of the low intensity zone, the underlying higher intensity zone, and the upper portion of the second low intensity zone. The Penney Farms Formation incorporates the remainder of this low intensity zone and the basal, high to very high intensity zone. The underlying Ocala Group and occasionally the Suwannee Limestone have significantly lower generalized signatures than the sediments of the Hawthorn Group. The formational correlations with the gamma-ray signature are shown in Figure 74. The upper and lower boundaries of the Hawthorn Group are generally easily picked on the gamma-ray logs. However, caution must be exercised in making formational identifications based solely on the signatures.

SOUTH FLORIDA

Intensities of gamma-ray activity in the Hawthorn Group sediments show similar ranges to those recognized in the northern portion of the peninsula. However, the generalized gamma-ray signature is quite different. Figure 75 shows a typical southern Florida gamma-ray log (compare with the northern Florida log, Figure 74). As is the case in northern Florida, the Hawthorn sediments in this area have, in general, significantly higher gamma-ray signatures than the subjacent or suprajacent units.

The Hawthorn Group in southern Florida is somewhat less complex than its northern counterpart. In this area the Hawthorn is generally composed of a siliciclastic upper unit (the Peace River Formation) and a lower carbonate unit (the Arcadia Formation). The Hawthorn becomes more complex to the east due to a greater siliciclastic influx and subsequently the gamma-ray signature changes. These variations are discussed by Gilboy (1983). Several logs showing the more typical range of variations are shown in Figures 76, 77, and 78.

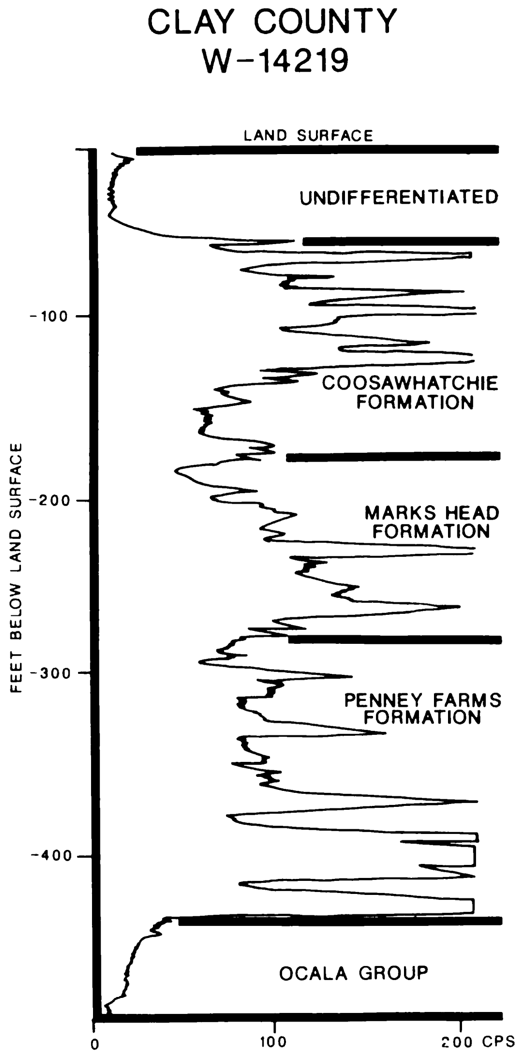


Figure 74. Gamma-ray log, Jennings #1, W-14219, Clay County.

The least complex area is the western half of southern Florida from Polk County southward to Lee and Collier Counties. A typical log for this area, as shown in Figure 79, consists of a number of distinct intensity zones. The uppermost zone is a relatively low intensity zone corresponding to the Peace River Formation. This is underlain by a zone of numerous higher intensity peaks which represent the upper, undifferentiated Arcadia Formation. Below this zone, the intensity drops to the lowest point in the Hawthorn Group. The intensity increases below the low intensity zone to a moderate intensity in basal sediments of the Arcadia Formation. At the base of the Arcadia Formation, the base of the Hawthorn Group, the gamma-ray intensity drops significantly at the contact with the "Suwannee" Limestone.

Variations of the gamma-ray intensity are often greatest in the Peace River Formation. The intensity increases as the phosphate content increases in the phosphate district. The gamma-ray signature of the upper section is most intense when the Bone Valley Member of the Peace River Formation is present (Figure 76). In part of the eastern portion of southern Florida and the extreme southern end of the peninsula, the gamma-ray activity of the Peace River Formation is generally low with only a few high peaks. In parts of Osceola, Brevard and Indian River Counties the Peace River Formation may contain significant phosphate. The resultant gamma-ray signature is high.

DESOTO COUNTY
W-15303

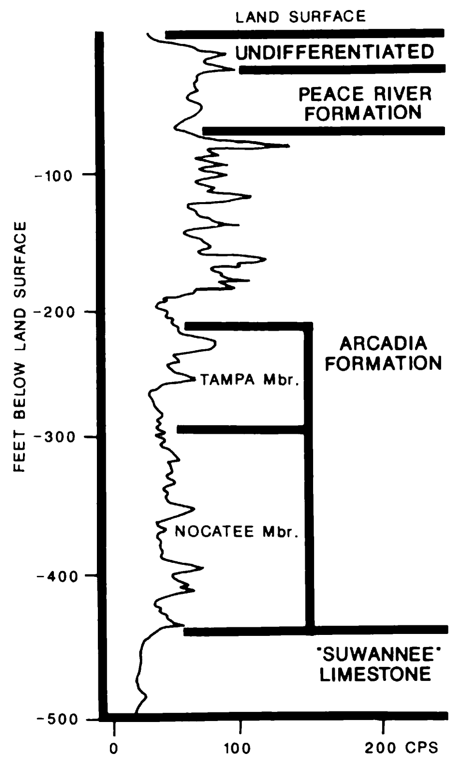


Figure 75. Gamma-ray log, R.O.M.P. 17, W-15303, DeSoto County.

In the eastern portion of southern Florida, south from and including Brevard County and east from the Polk-Osceola County line, the gamma-ray signature is more complex (Figure 77). In the northern part of this area, the Hawthorn is thin and the signature has many high intensity peaks. South from this area the Hawthorn thickens and the generalized signature contains a wider range of intensities (Figure 78). Throughout the eastern half of southern Florida, the Peace River Formation is characteristically of lower gamma-ray intensity than the underlying Arcadia Formation, although a wide variation exists (Figures 77 and 78). The top of the Peace River Formation is usually marked by a peak that is significantly higher than the background. This represents a concentration of phosphate at the post-Hawthorn unconformity. The contact between the Arcadia and Peace River Formations is generally marked by an increase in the abundance of large peaks in the Arcadia. Characteristically, the basal Hawthorn Group sediments contain the greatest number of high intensity peaks and the most intense peaks (Figures 77 and 78).

Underlying the Hawthorn Group throughout the eastern section are sediments with low gamma-ray activities. In portions of the eastern section, the Hawthorn is unconformably underlain by limestones of the Ocala Group which have very low activities. In other areas the Hawthorn is underlain by "Suwannee" Limestone or, in some cases, unnamed Lower Miocene limestones both with gamma-ray signatures much lower than the overlying section.

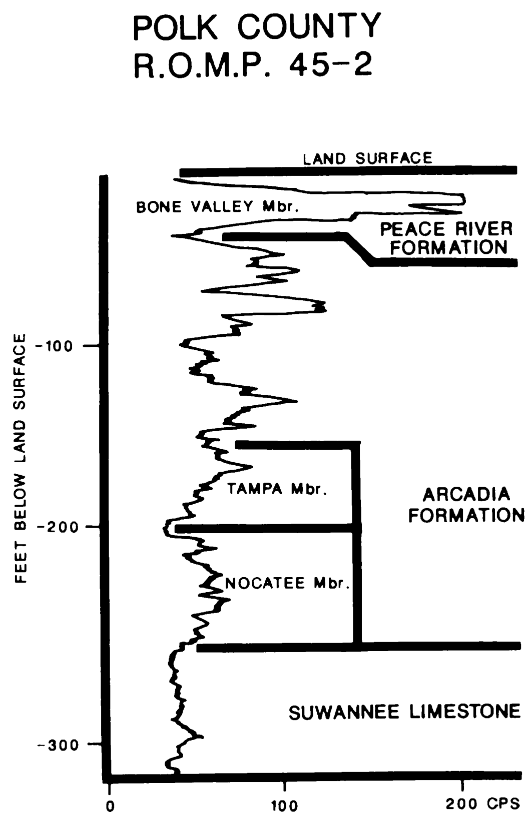


Figure 76. Gamma-ray log, R.O.M.P. 45-2, Polk County.

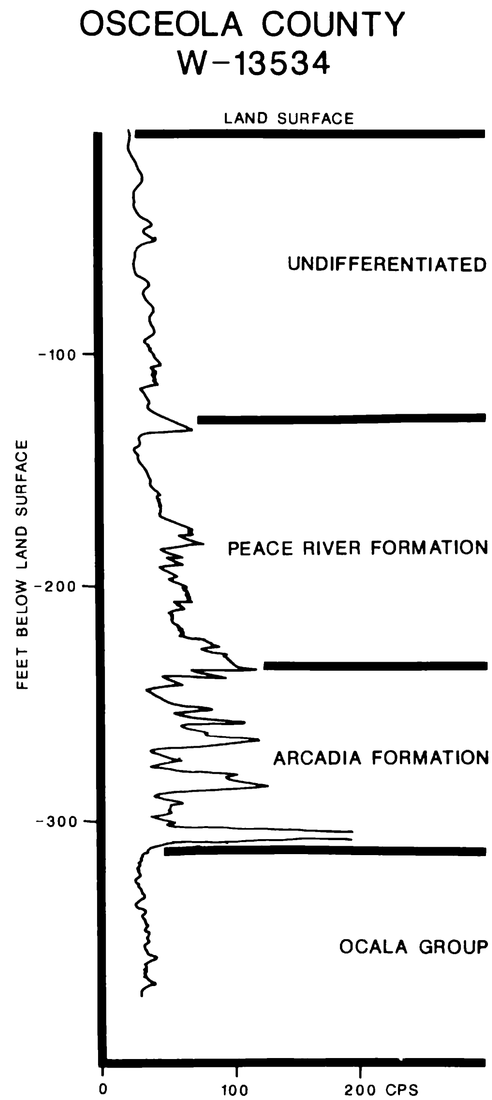


Figure 77. Gamma-ray log, Osceola #7, W-13534, Osceola County.

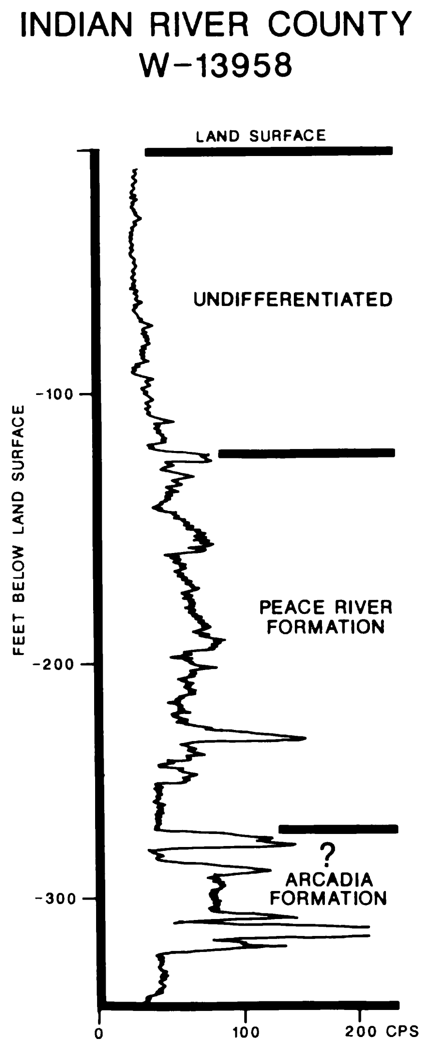


Figure 78. Gamma-ray log, Phred #1, W-13958, Indian River County.

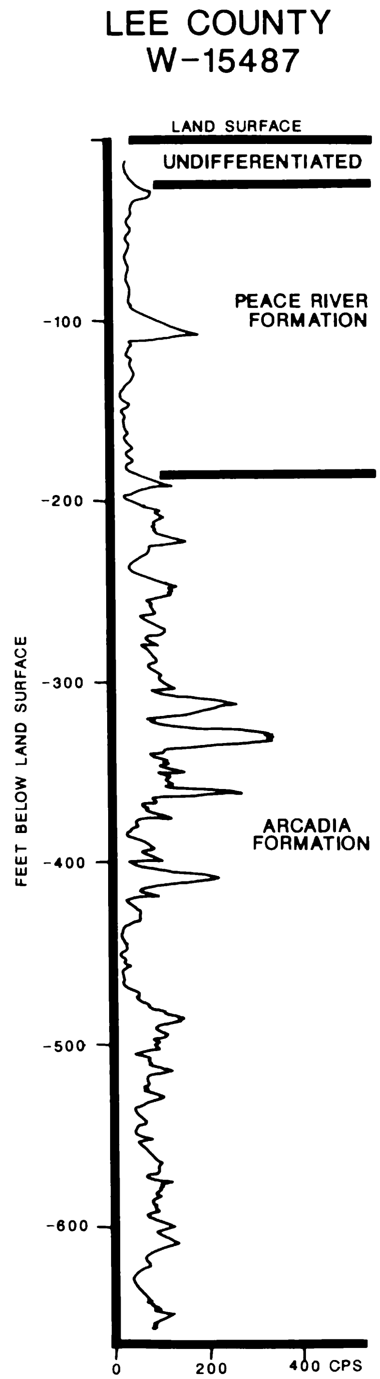


Figure 79. Gamma-ray log, Cape Coral #1, W-15487, Lee County.

EASTERN PANHANDLE

The Hawthorn Group sediments of the eastern Florida panhandle are lithologically different from the Hawthorn in the northern peninsula. This difference is also recognizable when comparing gamma-ray logs from these areas (compare Figure 80 with Figure 74). The northern axis of the Ocala Platform serves as the line separating the two areas, with the Hawthorn Group thickening away from the axis to the east and west. The Hawthorn sediments of the eastern panhandle are predominantly clays, sandy clays and clayey sands with occasional carbonate lenses and contain minor percentages of phosphate. The percentage of carbonate beds increases in western Leon County and westward into the Gulf Trough and Apalachicola Embayment. Figures 80 and 81 show the gamma-ray signature variation in the eastern panhandle.

The typical gamma-ray signature of the Hawthorn Group in the area east of the Gulf Trough is shown in Figure 81. The Hawthorn Group (Torreya Formation) has a gamma-ray signature that is well above the intensity of the subjacent and suprajacent units. In the Gulf Trough the Hawthorn Group thickens. The gamma-ray signature there appears more like that of the peninsular Hawthorn with many higher-intensity peaks separated by low intensity zones.

SUMMARY

1) The Hawthorn Formation has long been considered a complex and unusual unit. The complexity of the strata is the result of interbedding and mixing of carbonate and siliciclastic components in association with the occurrence of phosphate and palygorskite. The complex nature of the Hawthorn can best be understood if the unit is raised to group status and formations are identified within it. This author formally proposes upgrading of the Hawthorn Formation to group status in Florida. New formations are also formally proposed to subdivide the Hawthorn Group.

2) The Hawthorn Group occurs throughout much of Florida and the Coastal Plain of Georgia. In Florida, the Hawthorn is primarily a subsurface unit, although it crops out along the flanks of the Ocala Platform, along the southwest coast of the state, and in limited areas of the eastern panhandle. It is absent from the crest of the Ocala Platform and the Sanford High due to erosional removal.

3) Evidence suggests that sediments of the Hawthorn Group covered the Ocala Platform during Miocene time. The occurrence of outliers of these sediments, the hard rock phosphate and silicified Eocene and Oligocene carbonates, suggests the presence of the Hawthorn over the crest of the platform.

4) The formations of the Hawthorn Group vary from north Florida into south Florida and from north Florida into the eastern panhandle. The Ocala Platform and the Sanford High affected deposition of these sediments, allowing the regional grouping of the formations.

5) The Hawthorn Group in north Florida occurs east of the crest of the Ocala Platform and north of the Sanford High in central Florida. The sediments of the Hawthorn thin in the area between the Ocala Platform and the Sanford High. It appears that the section is thinned due to both erosion and decreased deposition. South of this area the north Florida Hawthorn sediments grade into the south Florida Hawthorn through an area of undifferentiated Hawthorn Group.

6) The area of transition between the Hawthorn Group of north Florida and that of south Florida occurs in an area from central Lake County to northwestern Orange County. This area is between the Ocala Platform and the southern edge of the Sanford High. Within this zone the component formations of the Hawthorn Group are difficult to recognize and as a result, the section remains undifferentiated Hawthorn Group.

7) The north Florida Hawthorn Group consists of (in ascending order) the Penney Farms Formation, the Marks Head Formation, the Coosawhatchie Formation and the Statenville Formation. All of these formational names are new to Florida stratigraphy. The Marks Head, Coosawhatchie and Statenville Formations and the Charlton Member of the Coosawhatchie Formation are extended into Florida from Georgia where their use is currently being formalized (Huddlestun, in press).

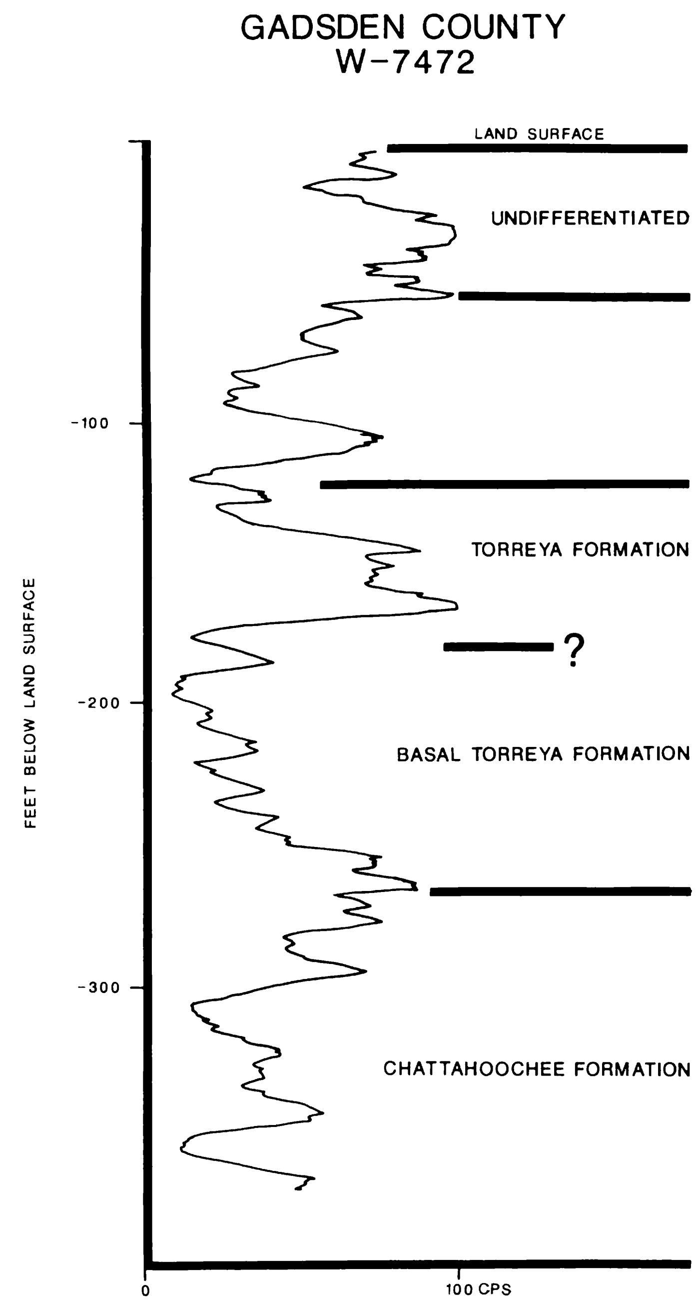


Figure 80. Gamma-ray log, Owenby #1, W-7472, Gadsden County.

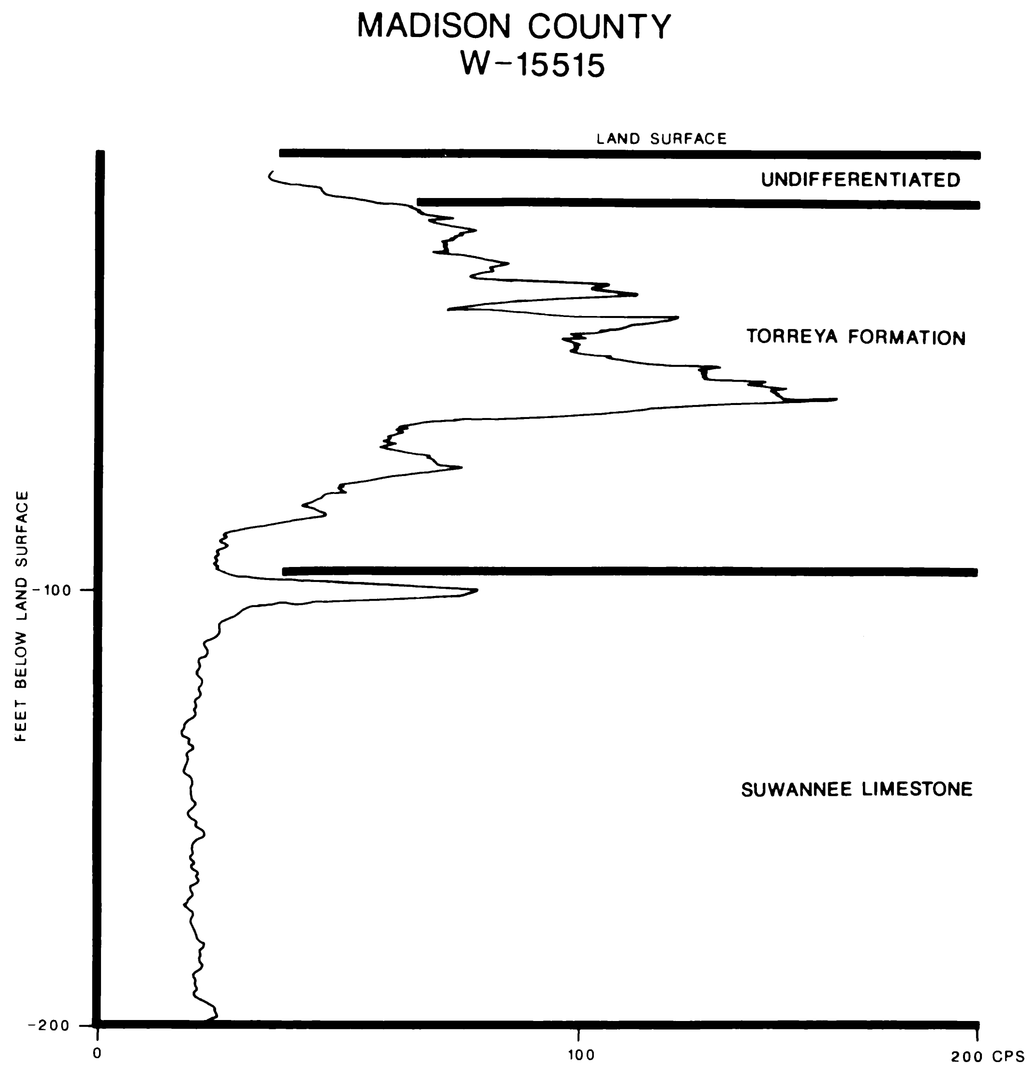


Figure 81. Gamma-ray log, Howard #1, W-15515, Madison County.

8) The Penney Farms Formation is a new name proposed for the basal Hawthorn sediments in north Florida. The type section of the Penney Farms Formation is in core W-13769, Harris #1, located near Penney Farms in central Clay County (SW¼, SE¼ Section 7, Township 6S, Range 25E). It consists of interbedded dolomites and siliciclastics with carbonate being most abundant in the lower portion and siliciclastics in the upper portion. The dolostones are variably quartz sandy, phosphatic and clayey, often containing zones of intraclasts. The siliciclastics vary from clayey sands to sandy clays with varying percentages of phosphate and dolomite. The clays present are smectite, palygorskite, illite and sepiolite.

The Penney Farms Formation unconformably overlies the Ocala Group or, in a few areas, the Suwannee Limestone. It is overlain unconformably by the Marks Head Formation. The top of the Penney Farms in cores ranges from -333 feet MSL (-101 meters) in W-14619 in Duval County to +80 feet MSL (+24 meters) in W-14641 in Alachua County. This unit is thickest in the Jacksonville Basin where more than 155 feet (47 meters) of it are present. The Penney Farms sediments are absent from the crest of the Ocala Platform and the Sanford High. The unit dips generally to the northeast from the Ocala Platform toward the Jacksonville Basin at approximately 4 feet per mile (0.8 meters per kilometer). Local variations in dip are common.

Few fossils are present in the Penney Farms Formation. Dateable faunas encountered indicate an early to middle Aquitanian age (Early Miocene) for this unit. These equate with Zone N.4 and possibly early

N.5 of Blow (1969). The Penney Farms Formation correlates with the Parachucla Formation in Georgia, the lower part of the Arcadia Formation in south Florida and the Chattahoochee Formation in the eastern Florida panhandle. It is slightly older than the Pungo River Formation of North Carolina.

9) The Marks Head Formation is introduced here for sediments of the Florida Hawthorn Group that correlate with the Marks Head Formation in Georgia as recognized by Huddlestun (in press). A reference section in Florida is in core W-14219, Jennings #1, Clay County, Florida (SE¼, SE¼, Section 27, Township 4S, Range 24E).

The Marks Head is the most complexly interbedded unit of the Hawthorn Group. Lithologically, it consists of interbedded clays, quartz sands, and carbonate (usually dolostone), each with varying percentages of quartz sand, clay, carbonate and phosphate. The clays present in the Marks Head are palygorskite, smectite, illite and sepiolite.

The Marks Head unconformably overlies the Penney Farms Formation throughout much of its extent. It is, in turn, overlain unconformably by the Coosawhatchie Formation. The top of the Marks Head ranges from -260 feet MSL (-79 meters) in W-14619, Duval County to +114 feet (35 meters) in W-14641 Alachua County. This unit is absent from the crest of the Ocala Platform and the Sanford High. It reaches a maximum thickness of 130 feet (40 meters) in W-12360, Bradford County.

The Marks Head dips generally to the northeast from the flanks of the Ocala Platform toward the Jacksonville Basin at approximately 4 feet per mile (0.8 meters per kilometer). Local variations are common.

The age of the Marks Head Formation in Florida is inferred from the dateable faunas found in Georgia, since no faunas have been identified in the Florida portion. The Marks Head is Burdigalian age (late Early Zone N.6 or very early N.7 of Blow (1969).

This unit correlates with the Torreya Formation of the Florida panhandle, part of the Arcadia Formation of south Florida, and the lower Pungo River Formation of North Carolina.

10) The Coosawhatchie Formation is introduced here for the upper unit of the Hawthorn Group in northern peninsular Florida. It is a southern extension of the Coosawhatchie Formation of Georgia as introduced by Huddlestun (in press). A reference section in Florida is in core W-13769, Clay County (SW¼, SE¼, Section 7, Township 6S, Range 25E). Lithologically the Coosawhatchie consists of carbonates, quartz sands and clays. The upper part of the formation is characteristically a very sandy, clayey dolostone with interbedded siliciclastics and variable percentages of phosphate. The lower part is characteristically clayey, dolomitic sand with interbedded clay and carbonate and variable amounts of phosphate. Clay minerals present include smectite, palygorskite, sepiolite and illite.

The Coosawhatchie Formation unconformably overlies the Marks Head Formation and unconformably underlies undifferentiated post-Hawthorn sediments. Its upper beds appear to grade laterally into the Statenville Formation. The top of the Coosawhatchie ranges from -93 feet MSL (-28 meters) in W-14477, Putnam County to +168 feet MSL (51 meters) in W-14641, Alachua County. This unit is also absent from the Ocala Platform and the Sanford High. The thickest known occurrence of the Coosawhatchie is in W-14619, Duval County, where it attains a thickness of 222 feet (68 meters). This unit generally dips northeasterly from the Ocala Platform toward the Jacksonville Basin at approximately 4 feet per mile (0.8 meters per kilometer). Local variations in dip are common.

The age of the Coosawhatchie Formation is thought to be Middle Miocene (early Serravalian) based on diatoms and planktonic foraminifera. It is correlated with the Peace River Formation of south Florida, the lower part of the shoal River Formation in the panhandle, and much of the Pungo River Formation in North Carolina.

11) The Charlton Member of the Coosawhatchie Formation represents a reduction of the Charlton Formation to member status, as used by Huddlestun (in press). A reference section for the Charlton Member in Florida is in W-13815, Nassau County (NW¼, NW¼, Section 32, Township 3N, Range 24E). It consists of interbedded carbonates and clays that are variably quartz sandy and slightly to nonphosphatic.

The Charlton overlies conformably and interfingers with the undifferentiated Coosawhatchie Formation. It unconformably underlies the undifferentiated post-Hawthorn sediments. The top of the Charlton ranges from -38 feet MSL (-12 meters) in W-14619, Duval County to +109 feet (33 meters) in W-14283, Bradford County. Its maximum thickness is approximately 40 feet (13 meters) in W-13815, Nassau County. The occurrence of the Charlton Member is spotty throughout the northeasternmost part of the state.

The age of the Charlton Member is considered to be Middle Miocene by Huddlestun (in press), based on the mollusk fauna and the lithostratigraphic relationships.

12) The Statenville Formation is a formational name extended into Florida from Georgia where it was described by Huddlestun (in press). A reference section for Florida is in core W-15121, Hamilton County (NE¼, NW¼, Section 3, Township 2N, Range 12E). The Statenville is characteristically quartz sand with common to abundant phosphate, interbedded with clays and dolostones. One of the diagnostic features of this unit is its thin bedded and cross bedded nature.

The Statenville conformably overlies part of the Coosawhatchie Formation and unconformably underlies undifferentiated post-Hawthorn sediments. In Florida, this formation is recognized only in the limited area of Hamilton and Columbia Counties. The maximum thickness is 87 feet (26.5 meters) in W-15121, Hamilton County.

The age of the Statenville is believed to be Middle Miocene (Serravalian) by Huddlestun (in press). Vertebrate fossils collected from it suggest a late Middle Miocene age. A reworked zone at the top of the Statenville contains Late Miocene vertebrate fossils.

13) The south Florida Hawthorn Group consists of (in ascending order) the Arcadia Formation with the Nocatee and Tampa Members and the Peace River Formation with the Bone Valley Member. The Arcadia and Peace River Formations and the Nocatee Member are new names introduced here. The Tampa and Bone Valley Members are former formational units reduced to member status within the newly proposed Hawthorn Group framework.

14) The Arcadia Formation is a new name proposed here for the lower Hawthorn carbonate section of south Florida. The type section is in the core W-12050, DeSoto County (SE¼, NW¼, Section 16, Township 38S, Range 26E). The Arcadia Formation, with the exception of the Nocatee Member, is predominantly carbonate with varying percentages of quartz sand, clay and phosphate. Thin quartz sand beds and clay beds are present but not abundant.

The Arcadia Formation unconformably overlies the Ocala Group in part of south Florida and the "Suwannee" Limestone in the remainder. In some areas the contact between the Arcadia and the "Suwannee" appears conformable. The Arcadia is usually overlain by the Peace River Formation but, where the Peace River is absent, the Arcadia is overlain by undifferentiated post-Hawthorn sediments. The top of the Arcadia ranges from -440 feet MSL (-134 meters) in W-15493, Monroe County, to +112 feet MSL (34 meters) in W-13269, Polk County. It ranges in thickness up to more than 600 feet (183 meters). In general, the Arcadia dips to the southeast at approximately 5 feet per mile (0.9 meters per kilometer).

The Arcadia Formation has yielded few dateable fossils. Mollusk specimens in the upper portion indicate a correlation with the Torreya Formation of the eastern panhandle and the Marks Head Formation of north Florida and Georgia. This places the Arcadia Formation as no younger than mid-Burdigalian (late Early Miocene). The lower part of the Arcadia appears to equate with the Penney Farms Formation of north Florida, the Chattahoochee Formation in the eastern panhandle and the Parachucla Formation in eastern Georgia.

15) The Tampa Member of the Arcadia Formation represents a reduction in status for the Tampa from formation to member. The reduction is justified based on the limited areal extent of the unit and by its variable nature which is gradational with the undifferented Arcadia Formation. The classical type area occurs around Tampa Bay in Hillsborough County. The type core is W-11541 (SE¼, NW¼, Section 11, Township 30S, Range 18E, Hillsborough County). Reference cores showing regional variation include W-11570 (Section 1, Township 33S, Range 22E, Manatee County) and W-15166 (NW¼, Section 22, Township 35S, Range 17E, Manatee County).

The Tampa Member is predominantly limestone with varying percentages of quartz sand, clay, and minor phosphate. Dolomite is generally a minor component. Phosphate is generally present in amounts less than 3 percent. Individual beds of quartz sand and clay do occur but are infrequent.

The Tampa Member overlies the "Suwannee" Limestone in areas where the Nocatee Member is not present beneath the Tampa. The contact with the "Suwannee" often appears gradational but in the updip areas, the contact is abrupt and unconformable. When the Nocatee Member is present, it underlies the Tampa conformably. The Tampa is overlain throughout much of its extent by the undifferentiated Arcadia Formation. Where the undifferentiated Arcadia Formation is absent due to erosion, the Tampa Member is overlain by either the Peace River Formation or undifferentiated post-Hawthorn sediments. The top of the Tampa ranges from +75 feet (23 meters) MSL in Hillsborough County to -323 feet (-98.5 meter) MSL in Sarasota County. The thickness of the Tampa Member ranges up to 270 feet (82 meters).

The Tampa Member is characteristically variably fossiliferous. Most common are mollusks, with corals and foraminifera also present. Despite the presence of these fossils, no age-diagnostic species have been recognized. It is suggested that the Tampa correlates with the lower part of the Parachucla Formation in Georgia. The Tampa may correlate with the basal Penney Farms Formation in north Florida.

16) The Nocatee Member of the Arcadia Formation is a new name proposed here for the "Tampa sand and clay" unit of Wilson (1977) which occurs entirely in the subsurface. The type core is W-12050 (SE¼, NW¼, Section 16, Township 38S, Range 26E, DeSoto County).

The Nocatee Member is a complexly interbedded sequence of quartz sands, clays, and carbonates, all containing variable percentages of phosphate. It is predominantly a siliciclastic unit but becomes more carbonate-rich near the limits of the member, where it grades into the undifferentiated Arcadia Formation.

The Nocatee Member overlies "Suwannee" Limestone throughout the Nocatee's extent. The contact appears gradational. The Tampa Member conformably overlies the Nocatee throughout much of the Nocatee's extent. Occasionally, the Nocatee is overlain by the undifferentiated Arcadia Formation.

The top of the Nocatee Member ranges from -81 feet (-24.5 meters) MSL in Polk County to -639 feet (-195 meters) MSL in Charlotte County. The thickest section currently recognized is 226 feet (70 meters) in DeSoto County.

The age of the Nocatee is based solely on its relationship to the Tampa Member. This suggests an earliest Miocene age.

17) The Peace River Formation is a new name proposed for the "upper Hawthorn" clastic unit of southern Florida. The type section is in W-12050 (SE¼, NW¼, Section 16, Township 38S, Range 26E, DeSoto County). W-15303 (NE¼, NE¼, Section 14, Township 38S, Range 23E, DeSoto County) is a suggested reference section.

The Peace River Formation consists predominantly of siliciclastics with interbedded carbonate units. Phosphate is present in highly variable percentages that range into the economically important category. The clastics are calcareous to dolomitic, clayey, phosphatic quartz sands to sandy clays.

The Peace River Formation overlies the Arcadia Formation (including the Tampa Member) throughout its extent. The contact appears unconformable in the updip area and gradational downdip. It is overlain by the Tamiami Formation in parts of southern Florida and by undifferentiated post-Hawthorn sediments in the remainder of the area. The top of the Peace River Formation ranges from +175 feet (53 meters) MSL in Polk County to -150 feet (-46 meters) MSL in parts of Dade and Collier Counties. Thicknesses range to greater than 400 feet (122 meters) in central southern Florida.

The Peace River Formation often contains well preserved faunas, including foraminifera, diatoms and, in some areas, vertebrates. As a result, the range of ages this unit encompasses often can be documented. The oldest date assigned to the Peace River Formation, based on limited vertebrate faunas, is early Middle Miocene (early Serravalian). The youngest age applied to the unit is no younger than earliest Pliocene, based on planktonic foraminifera faunas.

The Peace River Formation correlates in part with the Coosawhatchie and Statenville Formations of north Florida and Georgia and the Pungo River Formation of North Carolina.

18) The Bone Valley Member of the Peace River Formation represents a reduction from formation to member status for the Bone Valley strata. This reduction is justified based on the limited areal distribution of the Bone Valley, its laterally and vertically gradational relationship with the undifferentiated Peace River Formation, and lithologic similarities with the Peace River Formation. The original type locality was in the phosphate mines west of Bartow in Polk County. No single section in the mines remains very long,

therefore, no neotype section has been erected. A reference core, W-8879 (NE¼, SW¼ Section 24, Township 29S, Range 24E, Polk County), is suggested here.

The Bone Valley Member is a clastic unit consisting of quartz sands, clays and variable, but usually high, percentages of phosphate. Characteristically, it consists of pebble- to gravel-sized and sand-sized phosphate in a quartz sand and clay matrix. The occurrence of the phosphate gravels is the most lithologically important factor in distinguishing the Bone Valley Member from the remainder of the Peace River Formation. Clay beds and quartz sand units are relatively common in the Bone Valley Member.

The Bone Valley Member unconformably overlies the carbonates of the Arcadia Formation throughout much of its areal extent. In the southern area of the Bone Valley, it interfingers with and overlies the undifferentiated Peace River Formation. The Bone Valley is overlain by undifferentiated post-Hawthorn sediments. This contact is unconformable although weathering often obscures it, creating a gradational appearance.

The top of the Bone Valley Member ranges from +175 feet (53 meters) MSL to less than +100 feet (30.5 meters) MSL. The maximum thickness reaches just over 50 feet (15 meters).

The age of the Bone Valley Member is derived entirely from vertebrate remains. The oldest ages suggested are late Early Miocene (mid-Barstovian; late Burdigalian). Most of the Bone Valley Member is late Middle to mid-Late Miocene (Clarendonian; late Serravallian to mid-Tortonian). The uppermost phosphate gravels of the original Bone Valley "Gravels" are very latest Miocene to Early Pliocene (Late Hemphillian; Messinian to Zanclian).

The Bone Valley Member correlates in part with the Coosawhatchie and Statenville Formations of northern Florida and Georgia. It also correlates in part with the Pungo River Formation of North Carolina.

19) The sediments of the eastern Florida panhandle Hawthorn Group occur in the area between the axis of the Ocala Platform and the Apalachicola River. These sediments show significant variation from the Hawthorn Group east of the platform in north Florida, facilitating the use of separate formational names. In the panhandle the sediments of the Hawthorn Group are placed entirely in the Torreya Formation.

20) The Torreya Formation of the Hawthorn Group was named by Banks and Hunter (1973) and revised by Huddlestun and Hunter (1982) and Huddlestun (in press). Their terminology is used in this paper. The type section for the Torreya Formation is located on the Apalachicola River at Rock Bluff (SW¼, Section 17, Township 2N, Range 7W, Liberty County). Reference sections designated here are in cores W-6611 (SE¼, NE¼, Section 23, Township 2N, Range 7W, Liberty County), W-7472 (SE¼, NW¼, Section 19, Township 2N, Range 3W, Gadsden County), and W-6998 (SE¼, NW¼, Section 8, Township 2N, Range 2E, Leon County). The Torreya contains two named members, the Dogtown and the Sopchoppy.

The Torreya Formation is characteristically a siliciclastic unit with increasing amounts of carbonate in the Gulf Trough area. Lithologically, the siliciclastic section is clayey quartz sand to quartz sandy clays with variable percentages of accessory minerals including dolomite, limestone and phosphate. Fuller's earth clays are an important part of the Torreya Formation in the Gulf Trough area. Phosphate is often absent from the Torreya sediments. The carbonate portion of this unit is typically a quartz sandy limestone (occasionally dolomitic to dolostone).

The Torreya Formation overlies the Chattahoochee and/or St. Marks Formations. The contact appears gradational in part of the Gulf Trough but disconformable in other areas. It is overlain unconformably by the Citronelle and Miccosukee Formations throughout much of its extent. In limited areas it is overlain unconformably by the Jackson Bluff Formation. In some areas the Torreya is overlain by undifferentiated surficial sands.

The age of the Torreya Formation based on predominantly vertebrate faunas, is mid-Early Miocene (early to mid-Burdigalian). This unit correlates with the Marks Head Formation of north Florida and south Georgia and the upper part of the Arcadia Formation of southern Florida. In the southern portion of the Apalachicola Embayment the Torreya grades into the Bruce Creek Limestone. The Torreya equates with the lower part of the Pungo River Formation of North Carolina.

21) The Dogtown Member of the Torreya Formation is the clay-rich interval in the upper Torreya in parts of Liberty, Gadsden, and Leon Counties, Florida, and Decatur County, Georgia. The type locality is

the La Camelia Mine of Englehard Minerals and Chemical Corp. in Gadsden County (Section 15, Township 3N, Range 3W). A reference core for the Dogtown is W-7472 (SE¼, NW¼, Section 19, Township 2N, Range 3W, Gadsden County).

The Dogtown Member consists predominantly of clays with thin sand and carbonate beds. The commercial clay beds are quite pure, but the other clays of this unit are often quartz-sandy, silty and occasionally dolomitic. The clay minerals associated with this unit are mainly palygorskite and smectite.

This member ranges in thickness from 15 feet (4.7 meters) to 40.5 feet (12 meters) where it is recognized in cores. Its areal extent is not presently defined. The relationship of the Dogtown to overlying and underlying units has not been accurately defined. The age is considered to be mid-Early Miocene (early to mid-Burdigalian).

22) The Sopchoppy Member of the Torreya Formation is a sandy, fossiliferous limestone of limited areal extent. Its type locality is on Mill Creek in Wakulla County (center, Section 34, Townhip 4S, Range 3W).

The Sopchoppy varies from a sandy, phosphatic, fossiliferous limestone to a dolomitic, phosphatic, quartz sand. It has only been recognized near the type locality at the present time and its thickness and extent are not defined. This member is thought to be Early Miocene based on faunal similarities with the main portion of the Torreya Formation.

23) The Hawthorn Group, statewide, often contains an unusual mineral assemblage consisting of palygorskite and sepiolite (mixed with other clay minerals), phosphate minerals, and dolomite. Although dolomite is not an uncommon mineral, some of the types present in the Hawthorn are poorly understood.

24) Phosphate is present throughout the sediments of the Hawthorn Group, constituting one of the primary lithologic parameters for this unit. In peninsular Florida, the occurrence of nonphosphatic lithologies is not common but does occur. However, in the eastern panhandle non-phosphatic, very clayey sediments are quite common. Phosphate is usually present as sand-sized to pebble-sized grains in concentrations ranging from less than 1 percent to greater than 50 percent. The average content is generally between 2 and 10 percent.

Economically important phosphate deposits are recognized in limited areas of northern and central Florida. Hard rock phosphates are also found in west-central Florida.

25) Palygorskite and sepiolite are not generally considered common clay minerals. The occurrence of these clays in association with dolosilts and phosphate suggests unusual depositional environments for the Miocene sediments in the southeastern United States. These clays occur throughout the Hawthorn Group in association with variable amounts of smectite, illite and, in some cases, kaolinite.

26) Dolomite is the most common carbonate component of the Hawthorn Group throughout much of Florida. Replacement dolomite and dolosilts are the predominant types. Replacement dolomite is the result of dolomitization of an original limestone. Dolosilts, on the other hand, resulted not only from the replacement of pre-existing fine grained carbonate, but also may be precipitated under a variety of conditions.

27) The Alachua Formation and its relationship to the Hawthorn Group has long been debated. The present author believes the Alachua is a weathered and/or reworked residuum of the Hawthorn Group.

28) Carbonate deposition dominated the Florida Plateau prior to Miocene time. During the Miocene a flood of siliciclastic sediments intermixed with and spilled over the carbonate environments. The siliciclastics filled the Gulf Trough and entered the depositional environments of Florida. This great influx of siliciclastics was possibly due to renewed uplift in the southern Apalachians.

29) The geologic history of the Hawthorn Group is directly related to the fluctuations of sea level throughout the Miocene. The highest sea levels were reached in the Middle Miocene during the deposition of the Coosawhatchie. During low stands of sea level, terrestrial vertebrate faunas migrated and developed on the exposed land.

30) The Miocene sediments of Florida were deposited in a series of complex depositional environments, resulting in the complex lithostratigraphic nature of the Hawthorn Group. The sediments of the Hawthorn Group of northern Florida were deposited in shallow water to limited supratidal environments. This is based on the molluskan fauna (molds), the occurrence of intraclasts, crossbedding,

and mudcracks. As mentioned above, the deepest water environment (still shallow) occurred during Coosawhatchie Formation deposition when the sea level was at its maximum.

In southern Florida, a carbonate bank environment existed throughout the time of deposition of the Arcadia. Water depths and siliciclastic supply increased to the east. As sea level rose during the Middle Miocene the carbonate bank environment was overrun by siliciclastics during the deposition of the Peace River Formation. The Bone Valley Member of the Peace River Formation was deposited in shallow water environments ranging from high energy nearshore to quieter water lagoons.

Hawthorn deposition during the Miocene in the eastern panhandle was limited to the late Early Miocene Torreya Formation. The depositional environment suggested by Weaver and Beck (1977) is a tidally influenced lagoon.

31) Gamma-ray logs provide an important tool for the correlation and interpretation of the Hawthorn sediments throughout Florida. The Hawthorn Group, in general, has a unique, identifiable gamma-ray signature. It has significantly higher (more intense) peaks than the overlying and underlying units, with gamma-ray intensities that vary from less than 50 cps to greater than 500 cps. Within each region of the state, signatures are characteristic and correlate well with the formational breakdown of the group.

CONCLUSIONS

The Hawthorn Group of the southeastern Coastal Plain is an unusual and complex unit. The complex lithostratigraphy of the strata indicates that the Hawthorn should be described as a group, rather than retaining the former formation status. The Hawthorn is formally raised herein to group status in Florida and is subdivided regionally into its component formations.

Regionally, the Hawthorn Group shows significant variation. As a result, the formational subdivision of the group is different for the northern and southern peninsula and for the eastern panhandle areas of Florida. The formations of the group in northern Florida are, in ascending order: the Penney Farms; the Marks Head; the Coosawhatchie, including its Charlton Member; and the Statenville. In southern Florida the units are, in ascending order: the Arcadia Formation with its Tampa and Nocatee Members; and the Peace River Formation, with its Bone Valley Member. The group in the eastern panhandle is represented by the Torreya Formation, with its Dogtown and Sopchoppy Members.

The formational names are, with the exception of the Torreya, new names to Florida stratigraphy. The Marks Head, Coosawhatchie and Statenville are names extended into Florida from Georgia, while the Penney Farms, Arcadia and Peace River are new names proposed here. The use of the Charlton, Tampa and Bone Valley names as members represents a reduction from formational status for these units. This demotion is justified by their limited areal extent, lithologies and stratigraphic relationships with the formations of which they are members.

The lithostratigraphic units of the Hawthorn Group are related by the occurrence of unusual mineralogies (including phosphate, palygorskite and sepiolite clay minerals, dolomite and opaline cherts), color and stratigraphic position. The occurrence of the unusual mineral suite is suggestive of a unique set of environmental conditions present during the deposition of the Hawthorn Group.

Further refinement and definition of the concept of the Hawthorn Group and its component formations will occur as new data become available. A better understanding of the framework of the group will assist in determining the conditions and processes responsible for the deposition of the unusual mineral suite associated with the Hawthorn sediments.

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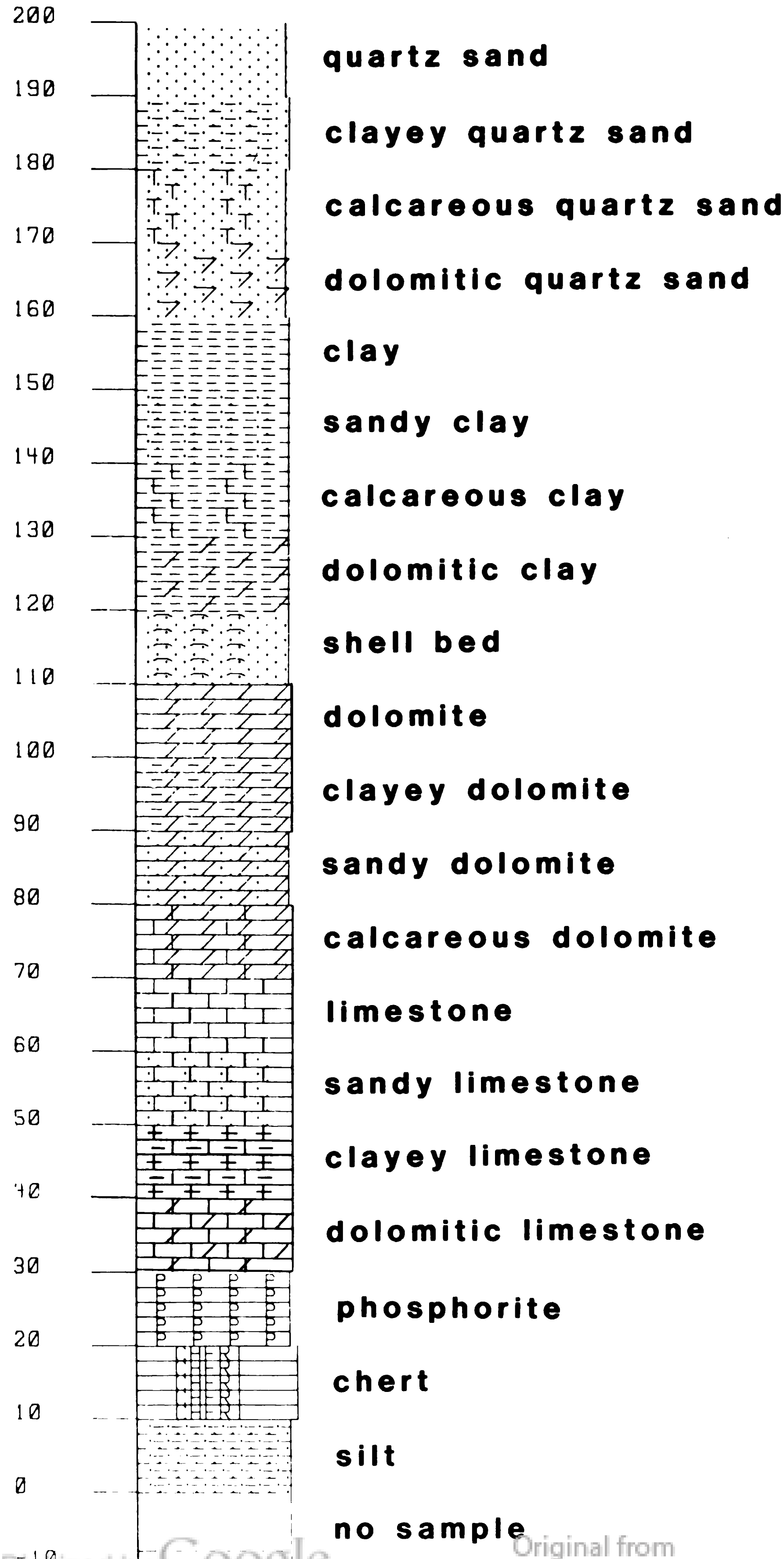
APPENDIX A

Lithologic legend for stratigraphic columns.



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