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THE HAWTHORN FORMATION OF NORTHEASTERN FLORIDA

PART I - THE GEOLOGY OF THE HAWTHORN FORMATION OF NORTHEASTERN FLORIDA

By
Thomas M. Scott
Florida Bureau of Geology

1982

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REPORT OF INVESTIGATIONS NO. 94

THE HAWTHORN FORMATION OF NORTHEASTERN FLORIDA

PART I - THE GEOLOGY OF THE HAWTHORN FORMATION OF NORTHEASTERN FLORIDA

by

Thomas M. Scott
Florida Bureau of Geology

PART II - CHARACTERIZATION AND BENEFICIATION OF THE NORTHEASTERN THE PHOSPHATE-BEARING HAWTHORN FORMATION

by

B. E. Davis, G. V. Sullivan, and T. O. Llewellyn
U.S. Bureau of Mines, Tuscaloosa Research Center
Tuscaloosa, Alabama

1982

Part II is missing

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PART I

THE GEOLOGY OF THE HAWTHORN FORMATION OF NORTHEASTERN FLORIDA

by

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Tallahassee, Florida

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ABSTRACT

The Hawthorn Formation in northeastern Florida consists of widely varying mixtures of clay, quartz sand, carbonate and phosphate. Phosphate is virtually ubiquitous throughout the Hawthorn sediments and occurs primarily as allochemical grains. The carbonate component consists predominantly of dolomite. Limestone is generally less than 5 percent of the total Hawthorn carbonates. Clays are present in much of the Hawthorn. Palygorskite and montmorillonite are the most common clay minerals.

The Hawthorn Formation unconformably overlies the Upper Eocene Ocala Group limestones. It is unconformably overlain by sediments referred to as Post-Hawthorn Undifferentiated Sediments.

The stratigraphy of the Hawthorn is both complex and variable. However, a generalized three-part subdivision of the Hawthorn is recognized in northeastern Florida. In general, there is a basal dolomite unit overlain by a sand and clay member (containing some dolomite) which is, in turn, overlain by a dolomitic unit. A fourth unit is recognized in the western part of the study area. This unit is a clayey, sandy, phosphatic unit thought to be, at least in part, reworked.

The study area appears to have been affected by episodes of structural movement. Both minor warping and faulting are recognized.

ACKNOWLEDGMENTS

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The author appreciates the assistance of the United States Bureau of Mines in providing funding for core and data acquisition under contract Grant Number G0166038.

INTRODUCTION

The Florida Bureau of Geology in cooperation with the U.S. Bureau of Mines began to study the phosphate bearing sediments of the Hawthorn Formation in peninsular Florida in 1975. The first phase looked at the phosphatic sediments in southwestern central Florida (Scott and MacGill, 1981). The second phase, a continuation of the U.S. Bureau of Mines grant (Grant Number G0166038), studied the Hawthorn Formation in northeastern Florida. This report on the second phase presents the results of a detailed lithostratigraphic study of the Hawthorn Formation and of the overlying and underlying sediments.

PURPOSE AND SCOPE

The purpose of this study is to provide an understanding of the geologic framework of the phosphatic Miocene Hawthorn Formation in northeastern Florida and its relation to the overlying and underlying units.

The Florida Bureau of Geology drilled 33 core holes in the study area. These ranged from 140 to 500 feet (43 to 152 meters) in depth. Core data obtained during this study were supplemented by water well cuttings drilled prior to the investigation. All cores and cuttings are on permanent file at the Bureau of Geology in Tallahassee. This data provided the basis for construction of the geologic cross sections and structure and isopach maps of the various geologic horizons throughout the area. The study area includes 10 counties: Alachua, Baker, Bradford, Clay, Duval, Flagler, Marion, Putnam, St. Johns and Union (figure 1).

METHODS

Thirty-three core holes were drilled in the study area utilizing a Failing 1500 Drill Master drill rig recovering 3 inch and 1 3/4 inch (7.6 and 4.4 cm) cores. The core diameter varied with the type of tools required to sample a particular interval. Washed samples of the post-Hawthorn sediments were collected at 5 foot intervals. Continuous coring began at the top of the Hawthorn Formation and continued into the Eocene limestones. All cores from Bradford, Clay, Putnam and western St. Johns counties were split and half sent to the U.S. Bureau of Mines in Tuscaloosa, Alabama for chemical analysis. The remaining split is stored at the Florida Bureau of Geology in Tallahassee. All core holes had gamma-ray logs run to facilitate correlations.

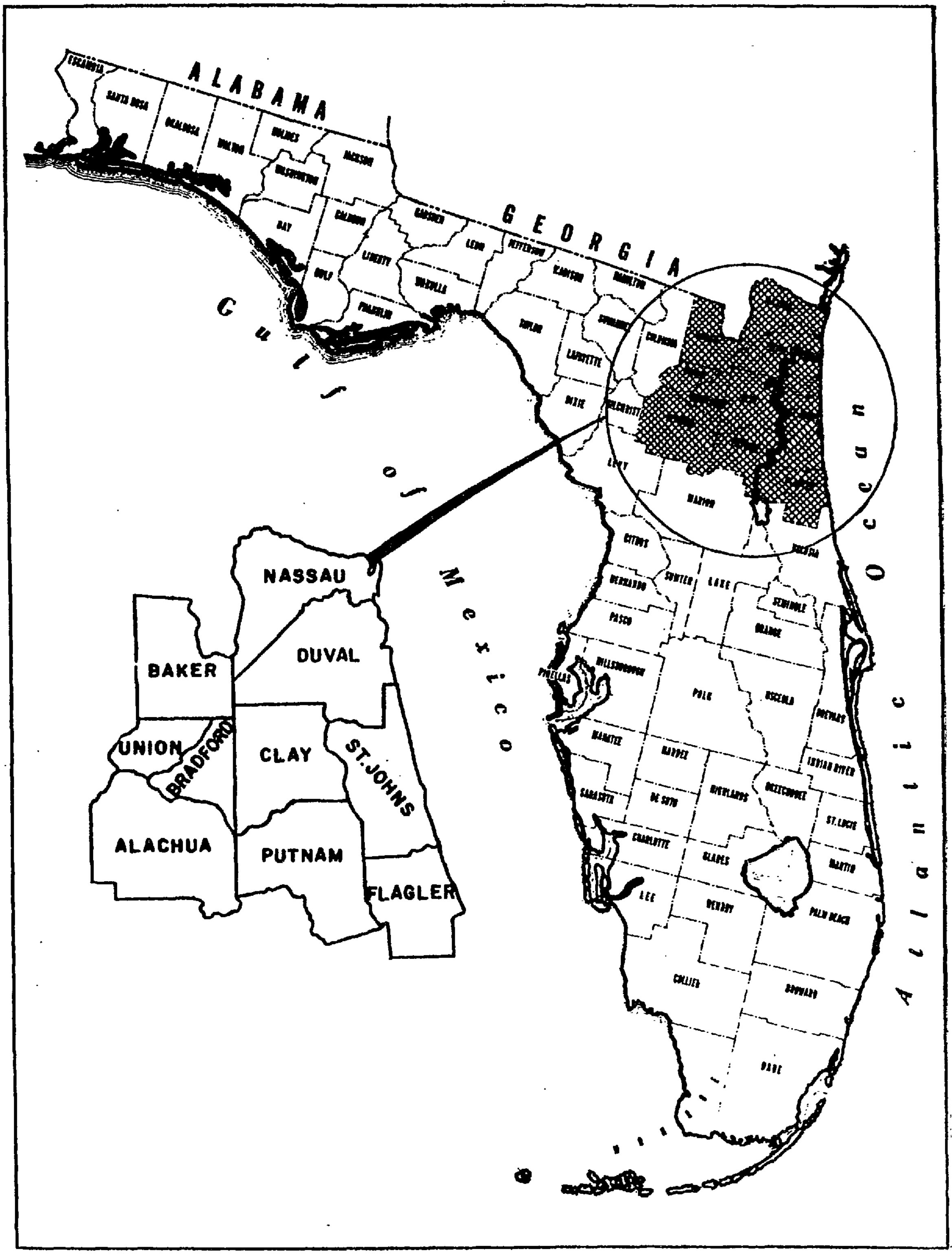

Figure 1. Study area location.

This information plus well locations and total depth are listed in the Appendix.

The cores were examined by a geologist, described and then entered into the Bureau's computer data files. The computer program is designed to aid the geologist in the interpretation of lithologic parameters. Color coded strip logs were constructed and correlated with the gamma ray logs. This aided in the visual correlation between cores. The strip logs and gamma ray logs were then used to construct geologic cross sections. Samples were taken from the cores at various depths for x-ray analysis to determine the dominant minerals present. The analysis was done for both bulk samples and oriented clay samples.

PREVIOUS WORK

Ocala Group

The limestones presently incorporated in the Ocala Group were originally placed in the Eocene by Conrad (1846). Smith (1881) correlated the exposed limestones of Florida with the Vicksburg Limestone of Mississippi and Alabama and applied that name to them. Dall and Harris (1892) referred to these sediments as the Vicksburg Group. The term Ocala Limestone was first used by Dall and Harris (1892) in reference to the rock being quarried and best exposed near Ocala in Marion County. Dall (1896) lumped the Eocene and the "Old Miocene" of Florida into the Oligocene. Dall (1903) proposed the term "Peninsular Limestone" for the lower division of the Vicksburg Group in the Florida peninsula. Cooke (1915) discovered that the Ocala Limestone and the Peninsular Limestone were identical and older than the Vicksburg Limestone. He placed the Ocala Limestone back into the Eocene (Jackson Age). Applin and Applin (1944) divided the Ocala Limestone into an upper and lower member. Vernon (1951) restricted the Ocala Limestone to the upper member of the Applins and referred to the "basal 80 feet of the Ocala Limestone of Cooke (1945)" as the Moodys Branch Formation. Vernon's Moodys Branch Formation was subdivided into the Williston Member and the Inglis Member. Puri (1957) raised the Ocala Limestone to group status and included three formations: the Crystal River, Williston, and Inglis. The Florida Bureau of Geology currently accepts and uses Puri's terminology (Table 1).

Hawthorn Formation

The Hawthorn Formation was originally described by L. C. Johnson (1888), who referred to the phosphatic beds in Alachua and Columbia counties as the Waldo Formation. Dall and Harris (1892) using much of Johnson's work, abandoned Johnson's Waldo Formation and described the phosphatic beds as the "Hawthorne

TABLE 1: Nomenclature of previous authors and this report.

	DALL & HARRIS (1892)	MATSON & CLAPP (1909)	COOKE (1945)	PURI & VERNON (1964)	THIS REPORT
PLEISTOCENE	Sands	Terrace and Coastal Deposits	Terrace and Coastal Deposits	Terrace deposits Caloosahatchee beds	Undifferentiated Post-Hawthorn Sediments
PLIOCENE	Caloosahatchee beds	Nashua and Caloosa-hatchee beds	Caloosahatchee and Citronelle Fms.		
MIOCENE	Newer Miocene Jacksonville Ls. Older Miocene Hawthorne	Choctawhatchee Marl and Jacksonville Fm. (Ls.)	Duplin Marl Hawthorn Fm.	Ft. Preston-Coarse Clastics	Hawthorn Fm.
EOCENE	Ocala Ls. (Nummulitic beds)	Oligocene: Hawthorne Fm. Ocala Ls. "Peninsular" Ls.	Ocala Ls.	Ocala Group	Ocala Group

beds." Even though Dall did not describe a type locality or use the term "formation," later workers have credited him for naming the Hawthorn Formation and describing the type locality around Hawthorne, Alachua County. The Devil's Millhopper, near Gainesville, as discussed by L.C. Johnson (1888) Dall and Harris (1892), and Cooke (1945), and Brook's Sink in Bradford County, as described by Cooke (1945), are accepted as cotype localities for the Hawthorn Formation (Pirkle, 1956). Scott (1982) discusses the cotype localities and equates them to cores taken nearby, designating the cores as cotype cores for the Hawthorn Formation.

In 1909, Matson and Clapp designated Dall's "Hawthorne beds" as a formation and considered it to be at least in part contemporaneous with the Tampa and Chattahoochee formations. They included the Hawthorn, Tampa, Chattahoochee and Alum Bluff formations in the Apalachicola Group. Matson and Clapp's description did include some limestone containing the echinoid Cassidulus sp. This limestone is now referred to as the Suwannee Limestone.

Vaughan and Cooke (1914) correlated the Hawthorn Formation with the Alum Bluff Formation in northwest Florida as defined by Matson and Clapp (1909, p. 91) and suggested the name Hawthorn be dropped. In later publications, Matson and other authors referred to the Hawthorn Formation as the Alum Bluff Formation.

In 1929, Cooke and Mossom reinstated and redefined the Hawthorn Formation to include Dall's (1892) "Hawthorne beds," the Sopchoppy Limestone and the Alum Bluff Formation of peninsular Florida as defined by Matson and Clapp (1909). This new definition excluded the Cassidulus-bearing limestone that had been described by Matson and Clapp (1909).

Very early in the nomenclatural history of the Hawthorn Formation it was considered to be of "older Miocene" age by Dall and Harris (1892). They observed the Hawthorn Formation in Alachua County lying unconformably on rocks of supposed Vicksburg age and thought it contemporaneous with the Chipola Formation. A short while later, they altered their concept of the Oligocene-Miocene boundary and positioned the Tampa, Hawthorn, and Chipola formations, previously called "Older Miocene," in the Oligocene. Matson and Clapp (1909) continued this age assignment, equating the Tampa and Chattahoochee formations in the panhandle of Florida to the Hawthorn Formation.

Vaughan and Cooke (1914), in describing several sections near White Springs on the Suwannee River, thought the Hawthorn Formation was contemporaneous with the Alum Bluff Formation. Faunal and stratigraphic data formed the basis for their correlation.

Cooke (1945) correlated the Hawthorn Formation with the Chipola Formation and parts of the Shoal River Formation in the Florida panhandle. He tentatively transferred some beds of Late Miocene age that were previously included in the Hawthorn by Matson and Clapp (1909) to the Duplin Marl. Cooke considered their contact unconformable and postulated that the Hawthorn was deposited by an expanded Tampa sea and that the Tampa/Hawthorn contact was conformable.

Pirkle (1956) studied the types of sediments in the Hawthorn Formation. He stated that the dominant sediment types found in the Hawthorn in Alachua County include quartz sand, clay, carbonate and phosphate. He further stated, "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." Pirkle, et al. (1965) studied the Hawthorn sediments in more detail paying particular attention to the heavy mineral suites.

Reynolds (1962), in studying the relationship of the Tampa-Hawthorn sequence in peninsular Florida, identified lithosomes and used clay mineralogy to conclude that the two formations interfingered. He identified a western carbonate lithosome (Tampa), an eastern clastic lithosome (Hawthorn), and a central Florida shelf where these two lithosomes interfingered. The carbonate lithosome contained a palygorskite-montmorillonite-sepiolite suite, whereas the clastic lithosome contained a montmorillonite-illite suite.

Espenshade and Spencer (1963) included all the phosphate bearing sediments overlying older carbonate rocks in North Florida in the Hawthorn Formation. This included the reworked phosphorites. They divided the Hawthorn into an upper phosphorite unit and a lower phosphatic dolomite unit.

Brooks (1966) proposed raising the Hawthorn to group status based on the complex stratigraphy that has been discussed by many authors (Pirkle, 1956; Espenshade and Spencer, 1963; Brooks, et al., 1966). Brooks (1967) later reiterated this adding that the youngest formation to be included in his Hawthorn "Group" would be the Bone Valley Formation.

Sever, et. al., (1967) were able to divide the Hawthorn into four recognizable lithologic units in the South Georgia - North Florida area. They state, however, that all these units are not present over the entire area.

Puri and Vernon's (1964, p. 145) statement concerning the Hawthorn expresses the feelings of many geologists. They state that the Hawthorn Formation "...perhaps is the most misunderstood formational unit in the southeastern United States. It has been the dumping ground for alluvial, terrestrial, marine, deltaic and pro-deltaic beds of diverse lithologic units in Florida and Georgia that are stratigraphic equivalents of the Alum Bluff Stage."

The North Florida phosphate district (as delineated by Williams, 1971) includes the western part of the present study area. Williams (1971) studied the phosphate deposits and included part of them in the Hawthorn Formation.

Cooke (1945) divided the Miocene series into three different stages in peninsular Florida: Early, Middle and Late. He believed that the age of the Hawthorn Formation was Middle

Miocene. In the past, this type of definition has been general practice in defining both the age and boundaries of Florida formations. However, the lack of diagnostic data has made it difficult to determine the exact age and boundaries of the formations. As a result, the age assignment of the Hawthorn Formation has varied considerably since its inception. Recent data indicates that the deposition of the Hawthorn began in the earliest Miocene as shown by foraminifera in W-13815 in Nassau County (R. Hoenstine, Fla. Bur. Geol., personal communication). A core (W-13958) in Indian River County, Florida, suggests that Hawthorn deposition continued into the Early(?) Pliocene south of the study area (ibid).

The areal extent of the Hawthorn Formation was extended by Cooke (1945) from Dall and Harris' (1892) descriptions of sections in central Florida to include strata occurring east of the Apalachicola River, northward to Berkeley County, South Carolina, and southward to cover almost all of the peninsula of Florida except where it has been completely eroded. The Hawthorn Formation is present in the subsurface of the study area except where it is absent due to erosion or possibly nondeposition near the southeast, south and southwest edges of the study area.

The authors mentioned in this section were those who defined or redefined the Hawthorn Formation. Many others have published on the Hawthorn Formation but have followed the authors mentioned for their definition of the Hawthorn Formation. They are too numerous to discuss in this report.

Undifferentiated Post-Hawthorn Sediments

The undifferentiated post-Hawthorn sediments consist of a variety of lithologies. These include fine to coarse quartz sands, occasionally containing quartz gravel, sandy clay, clay, shell beds, marl and limestone. Formational assignments have been as varied as the lithologies. Formation names applied, from oldest to youngest, include: Fort Preston Formation, Jacksonville Limestone, Choctawhatchee Formation, Duplin Marl, Nashua Marl, Caloosahatchee Marl, unnamed coarse clastics and terrace deposits.

The Upper Miocene Jacksonville Limestone was named by Dall and Harris (1892) for a limestone exposed in an excavation near Jacksonville. It was described as a "...porous, slightly phosphatic, yellow rock...contains numerous molds of fossil shells belonging to the new Miocene." Dall and Harris noted occurrences of the Jacksonville Limestone on Black Creek in Clay County and Preston Sink in Alachua County.

Matson and Clapp (1909) called the Jacksonville Limestone the Jacksonville Formation and described it as a clayey, sandy limestone with zones of abundant fossils. They differentiated it from the Choctawhatchee Marl in that the Jacksonville Formation contained mica, more lime and less sand.

Cooke (1945) dropped the name Jacksonville Limestone or Formation and placed the rocks in the Duplin Marl which he described as a sandy, shell marl. Cooke differentiated the Duplin from the Choctawhatchee and restricted the Choctawhatchee to the Florida panhandle.

Bermes, et al. (1963) in their study of Flagler, Putnam and St. Johns counties simply called these lithologies "Upper Miocene or Pliocene deposits." Clark, et al. (1964) extended the Choctawhatchee Formation into Northeastern Florida and referred the "late Miocene beds" in Alachua, Bradford, Clay and Union counties to it.

The Miocene Fort Preston "formation" is an informal name applied by Puri and Vernon (1964) to the coarse clastic material of peninsular Florida. Puri and Vernon (1964) described these sediments as "...poorly sorted quartz grains, ranging in size from fine sand to small pebbles, in a clay matrix...usually red or orange in color...to white or light yellow gray." Cooke (1945) had placed these sediments in the Citronelle Formation. Clark, et al. (1964) stated that their unnamed coarse clastics, which Puri and Vernon (1964) identified as Fort Preston (Middle Miocene), overlie the Choctawhatchee Formation which is younger than the Fort Preston. Due to the nonfossiliferous nature of these clastics, they have been assigned to several different ages. This has given rise to the confusion which is evident from the variety of names applied to them.

The Nashua Marl was named by Matson and Clapp (1909) for "... Pliocene marls extensively developed in the valley of the St. Johns River...". It was named for the town of Nashua in Putnam County on the St. Johns River. Matson and Clapp state, "The Nashua Marl bears a strong lithologic resemblance to the Caloosahatchee Marl. There is the same alternation of sand beds with shell marl. The matrix of the Nashua Marl, white, usually calcareous, is always more or less sandy and sometimes consists of nearly pure sand. The shells are commonly well preserved though locally a marl consisting of broken and eroded fragments of shells is not uncommon." Mansfield (1918) studied the mollusks of the Nashua and decided they were very similar to the Caloosahatchee Marl. Cooke and Mossom (1929) equated the Nashua with the Caloosahatchee and discarded the term Nashua.

Dall and Harris (1892) described a unit of predominantly sand and shells in south Florida, giving it the name "Caloosahatchee beds." Matson and Clapp (1909) used the term marl rather than beds. Cooke and Mossom (1929) brought the term Caloosahatchee Marl into the present study area when they discarded the Nashua as discussed above.

The unnamed coarse clastics of Clark, et al. (1964) are described as a "...nonfossiliferous, deltaic deposit that is composed mostly of varicolored sand and clayey sand that contains quartz gravel locally." They placed it in the Pleistocene Epoch. These are the same sediments that Cooke (1945) called Citronelle

(Pliocene) and Puri and Vernon (1964) called Fort Preston (Miocene). This unit is mapped by Puri and Vernon (1964) as Fort Preston (Miocene). Puri and Vernon mapped the Fort Preston as occurring in the higher ridges of the study area.

The terrace deposits are often considered to be Pleistocene in age and are related to the fluctuations of sea level. These deposits include a wide variety of lithologies occurring at many different elevations. Clark, et al. (1964) included sands, clayey sands, clays, marls, and shell in this unit. Clark, et al. (1964), and Bermes, et al. (1963), believed that this unit blanketed the greater part of the present study area.

Pirkle (1956), in discussing the post-Hawthorn sediments, placed the units above the Choctawhatchee shell marl in an undifferentiated category. Pirkle believed these materials to be Pliocene or Pleistocene. He states, "...a Pleistocene age is considered far more likely."

In this report the term undifferentiated is used for the sediments overlying the Hawthorn in the study area due to the evident stratigraphic confusion that exists. These will be referred to as Undifferentiated Post-Hawthorn Sediments.

LITHOLOGIC CHARACTERISTICS OF THE HAWTHORN FORMATION

The Hawthorn Formation in the southeast is probably one of the most misunderstood units in the stratigraphic section. Such glorified terms as "a garbage can" and "F.U.B.A.R." (Fouled Up Beyond All Recognition) have been applied to it. The confusion as to what actually constitutes the Hawthorn Formation is readily understood since the variability of the sediments is the rule rather than the exception.

The sediments of the Hawthorn Formation consist of widely varying mixtures of clay, quartz sand, carbonate and phosphate. Beds of end-member composition (i.e., pure clay) are not common but do occur. The most common lithologies encountered in the Hawthorn are dolomitic, clayey sands and clayey and/or sandy dolomites.

Phosphate is virtually ubiquitous throughout the Hawthorn sediments. The occurrence of phosphate is the most important lithologic factor in the identification of the sediments grouped in the Hawthorn. It is, however, not the only factor involved since phosphatic material is commonly reworked into the overlying, post-Hawthorn units.

The phosphates occur primarily as allochemical grains. These can be divided into pelletal form and intraclasts. The pelletal grains are the dominant phosphate form in the Hawthorn of the study area. They are sand-sized and generally well rounded with a smooth to polished surface. These grains contain varying amounts of microscopic inclusions disseminated throughout (Riggs, 1979a). The inclusions are dolomite rhombs, microfossil debris and terrigenous clastic material. Riggs (1979a) suggests that the pelletal phosphate was formed by benthic organisms ingesting the phosphate mud along with the included contaminants and excreting these as fecal pellets. Miller (1982) feels that gentle bottom currents were strong enough to cause the pelletal phosphate to form from a phosphatic gel or mud. The pelletal phosphates are generally black to dark gray but range to tan and white in more weathered or reworked sections. The lighter colors are generally found higher in the section near the upper Hawthorn boundary.

Phosphatized skeletal debris and oolitic or pseudo-oolitic grains are also found in the Hawthorn Formation. Miller (USGS, 1981 personal communication) reports oolitic phosphate grains in the Hawthorn in the Osceola National Forest in the northwestern section of the study area.

Phosphatic intraclasts occur scattered throughout the section but are most common in the dolomites in the lower Hawthorn. Two types of intraclasts are recognized in the study cores. First are the phosphate intraclasts which Riggs (1979a) describes as fragments of penecontemporaneous phosphate sediments that have been torn up and redeposited. The intraclasts are abraded, rounded and somewhat irregular. In some of the intraclasts, remnants of original bedding may be seen. Smaller intraclastic grains may be difficult to separate from the pelletal forms.

The second type of intraclasts are phosphatized dolomite intraclasts. These intraclasts show a zoned replacement of dolomite by phosphate. The zonation trends from unreplaced dolomite in the interior to replacement phosphate at the outer edges. They are irregular and abraded with somewhat rounded to very rounded edges. This type of intraclast is most common in the lower Hawthorn dolomites.

Many "rubble" zones occur scattered through the Hawthorn Formation. These zones consist of phosphate and dolomitic intraclasts incorporated in a soft matrix of sand, clay, and dolomite. They appear to represent periods when the phosphate and carbonate muds were able to accumulate, become somewhat lithified to well lithified, then were ripped up and redeposited. The clasts commonly are bored by pelecypods and show varying degrees of abrasion.

Phosphate concentrations in the Hawthorn range from zero to greater than 40 percent. The higher concentrations are uncommon. Average phosphate concentrations in the Hawthorn range from 5 to 10 percent based on visual estimates. Reworked Hawthorn sediments form beds that often contain phosphate in concentrations of 30 to 40 percent (W-14255, Mizelle #1, Bradford County, for example). Units of this grade may one day be economically attractive.

The carbonate component of the Hawthorn Formation is composed predominantly of dolomite. However, limestone and micrite occur sporadically, both vertically and laterally throughout the area. In general, limestones account for less than 5 percent of the total Hawthorn carbonates. A notable exception to this occurs in the study area well W-14255, Mizelle #1. The carbonate sediments in the Hawthorn from Mizelle #1 core are predominantly calcareous with only a minor dolomite component.

Dolomite is common throughout the Hawthorn Formation. It occurs not only as a dolomite primary lithology but also as a matrix material in other lithologies. As a result, dolomite is found in virtually the entire Hawthorn section. Lithologies lacking dolomite are not common but do occur, particularly as clays.

Dolomitic sediments in the Hawthorn range from poorly consolidated to well indurated and contain widely variable amounts of quartz sand, silt, clay and phosphate. They can be subdivided into two basic categories, dolosilts and dolomites. Although they are both composed of the mineral dolomite and are gradational with one another, they form two identifiable lithologies and will be discussed separately.

Dolosilts are composed of silt-sized dolomite rhombs with varying percentages of accessory minerals. Induration is generally poor to moderate. The accessory minerals are quartz sand, silt, clay and phosphate. The phosphate occurrence is related to the occurrence of sand. If no sand is present, phosphate is generally not encountered. This is apparently due to the clastic nature of the phosphate grains. The phosphate is transported with the sand from areas of primary accumulation to the areas of dolosilt formation or accumulation.

Dolosilts are often confused with clays by geologists and others unfamiliar with the peculiarities of the Hawthorn Formation. Admittedly, the dolosilts bear a resemblance to clays particularly when first recovered and they often contain clay in abundance. However, the silty texture and reaction to dilute HCl indicate that clay is not the primary constituent. Examination under a binocular microscope and X-ray analysis confirm the identity of the dolosilts.

Dolosilts occur throughout the Hawthorn section. However, they commonly occur higher in the section. Color ranges from yellowish gray (5Y7/2 or 5Y8/1, GSA Rock Color Chart) to olive gray (5Y3/2 or 5Y4/1).

Dolomites in the Hawthorn Formation are composed of anhedral to subhedral, crystalline dolomites with varying percentages of accessory minerals. The dominant accessory minerals are the same as those in the dolosilts; sand, silt, clays and phosphate. The proportions of these minerals are highly variable. The dolomites generally range from moderately to well indurated. Color ranges from light gray (N7) to light olive gray (5Y5/2 or 5Y6/1). Dolomites often occur interbedded with dolosilts. The two lithologies also appear to grade into each other. The gradational nature and the more coarse, intergrown crystalline nature of the dolomites suggest that some of these dolomites are the result of aggrading neomorphism of the dolosilts.

Dolomites resulting from the replacement of limestone are common in the Hawthorn, particularly in the lower portion. These dolomites contain fossil molds and fossil "ghosts" that are indicative of an original limestone lithology.

The origin of the dolosilts is somewhat of an enigma. As previously mentioned, they are composed of a poorly consolidated dolomite in the form of discrete rhombs. They are often intimately mixed with varying amounts of clay, quartz, silt and sand. Riggs (1979a) suggests that the dolosilts are detrital, having been transported from source areas south and east of the present landmass. However, no definitive work has been done concerning the origin of this sediment type.

Figures 2, 3 and 4 show the relative percentages of dolomite, sand and clay units within the Hawthorn. These maps are constructed from core data only. Percentages of each rock type were determined by adding the thickness of each unit of a specific rock type and dividing by the total thickness of the Hawthorn Formation in the core. Additional information from well cuttings does not provide an accurate indication of the lithologies due to the loss of softer and finer grained materials during drilling, sample collection and sample preparation.

The total dolomite component of the Hawthorn sediments shows a trend of increasing abundance toward the south-central part of the study area (figure 2). The greatest amount of dolomite in the Hawthorn is in the southern Clay County - northern and western Putnam County area. Here cores contain from 50 to more than 70 percent dolomite. The lowest percentage of dolomite is found in westernmost Bradford County where less than 10 percent of the Hawthorn Formation is dolomite. In the study area, the percentage of dolomite is in the less than 10 to 70 percent range. Riggs (1979a) places the present study area in a section of the state in which the Hawthorn is dominantly terrigenous sediments with subordinate carbonates. This suggests that the abundance of dolomite in the Clay-Putnam county area is somewhat anomalous and represents a possible carbonate bank. Carbonate sediments increase in abundance south of the study area becoming the dominant sediment type in central and southern Florida.

Sand, both as a rock type and as an accessory mineral, is a major constituent of the Hawthorn Formation. It is the most abundant rock type encountered in the Hawthorn in the study area. Quartz sand also is the most common accessory mineral in the Hawthorn. Accessory minerals in the sand-size range include minor amounts of feldspar, heavy minerals and variable concentrations of phosphate. Pirkle, et al. (1965) studied the Hawthorn sediments from the Devil's Millhopper (northwest of Gainesville, Alachua County) and Brooks Sink (Bradford County). They analyzed the insoluble residues for percent quartz sand, clay, P_2O_5, type and abundance of heavy minerals and size distribution of the sands. In general, they showed the Hawthorn sands to be in the medium to fine size classification with the

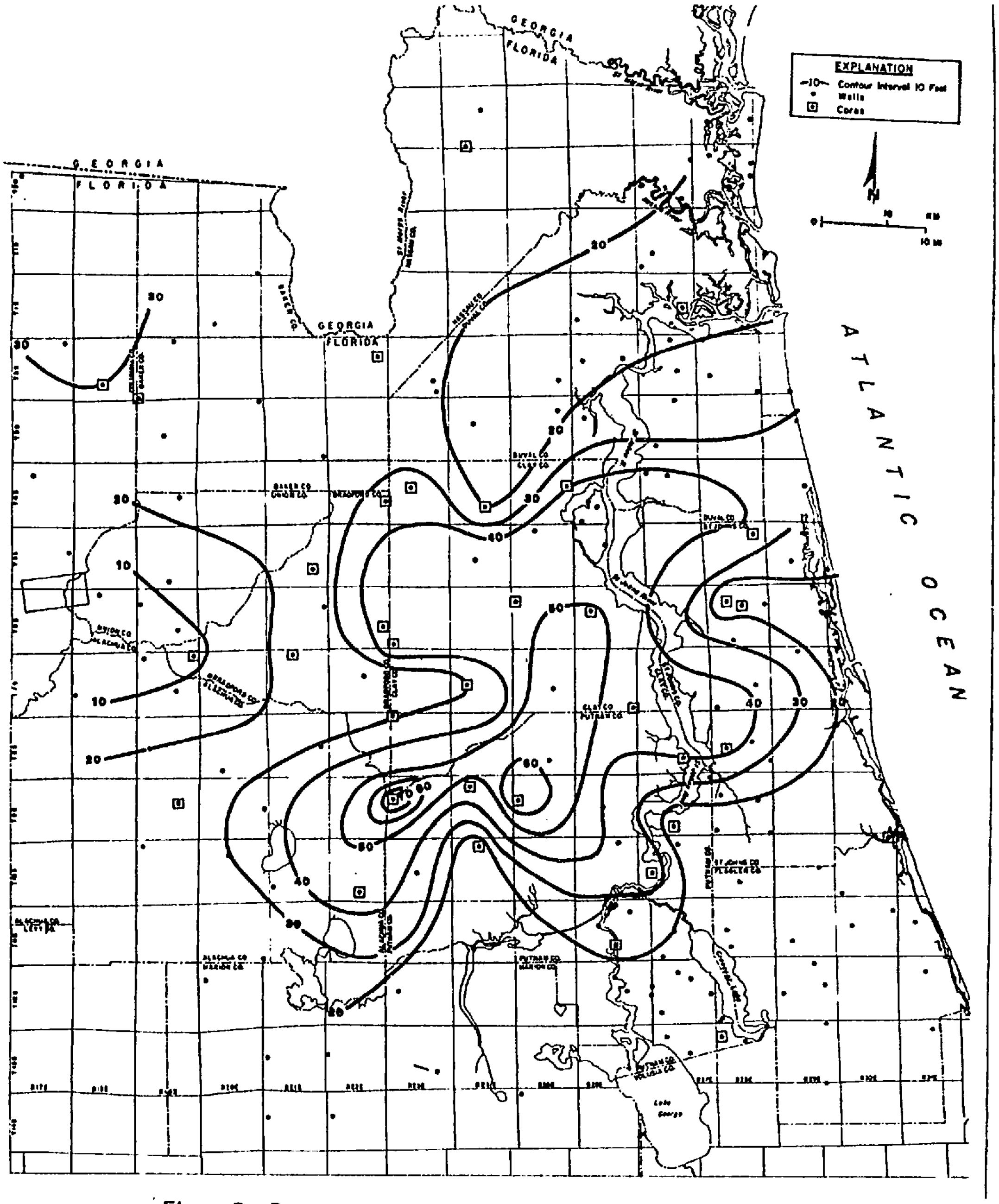

Figure 2. Percentage of dolomite units in the Hawthorn Formation.

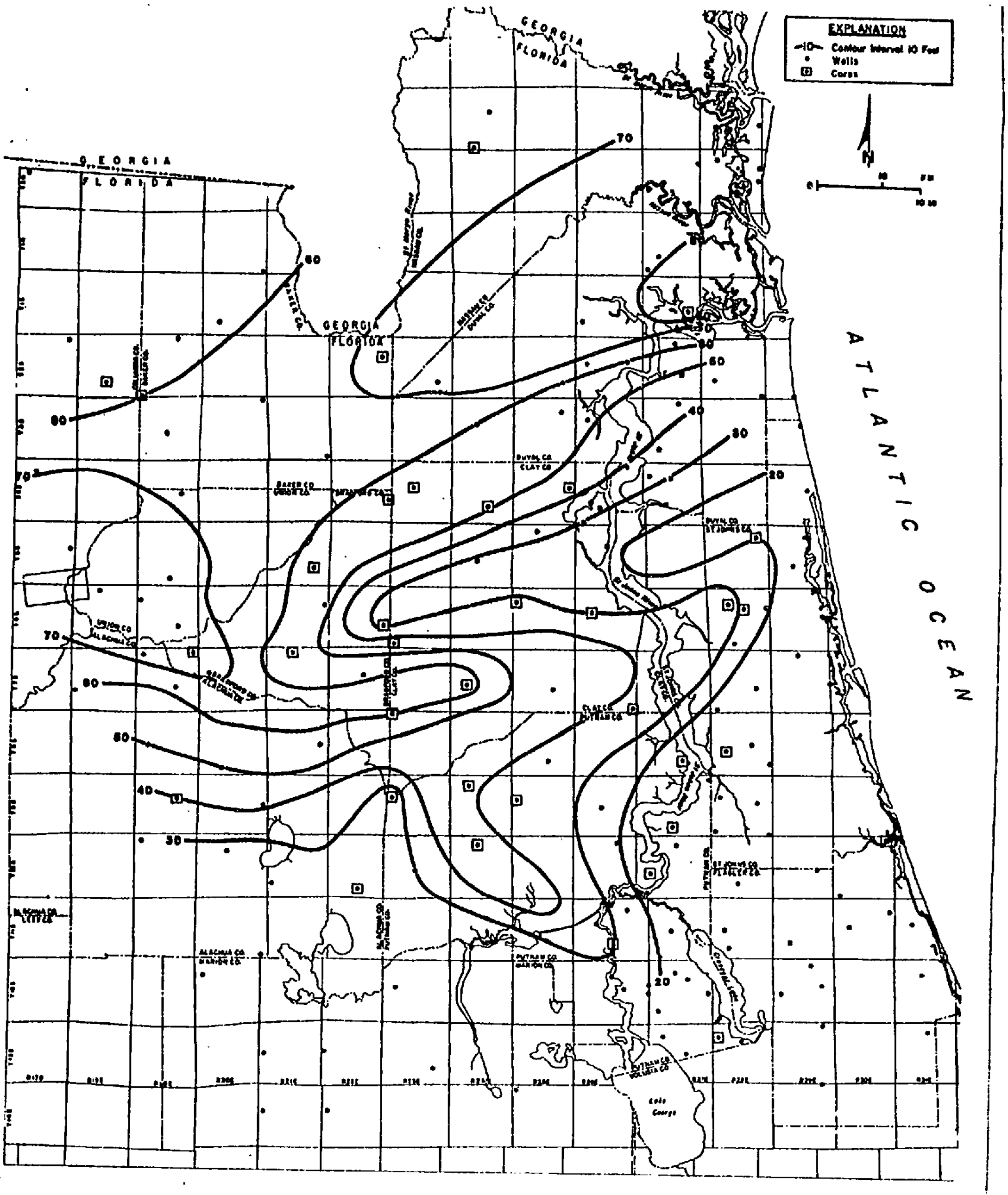

Figure 3. Percentage of sand units in the Hawthorn Formation.

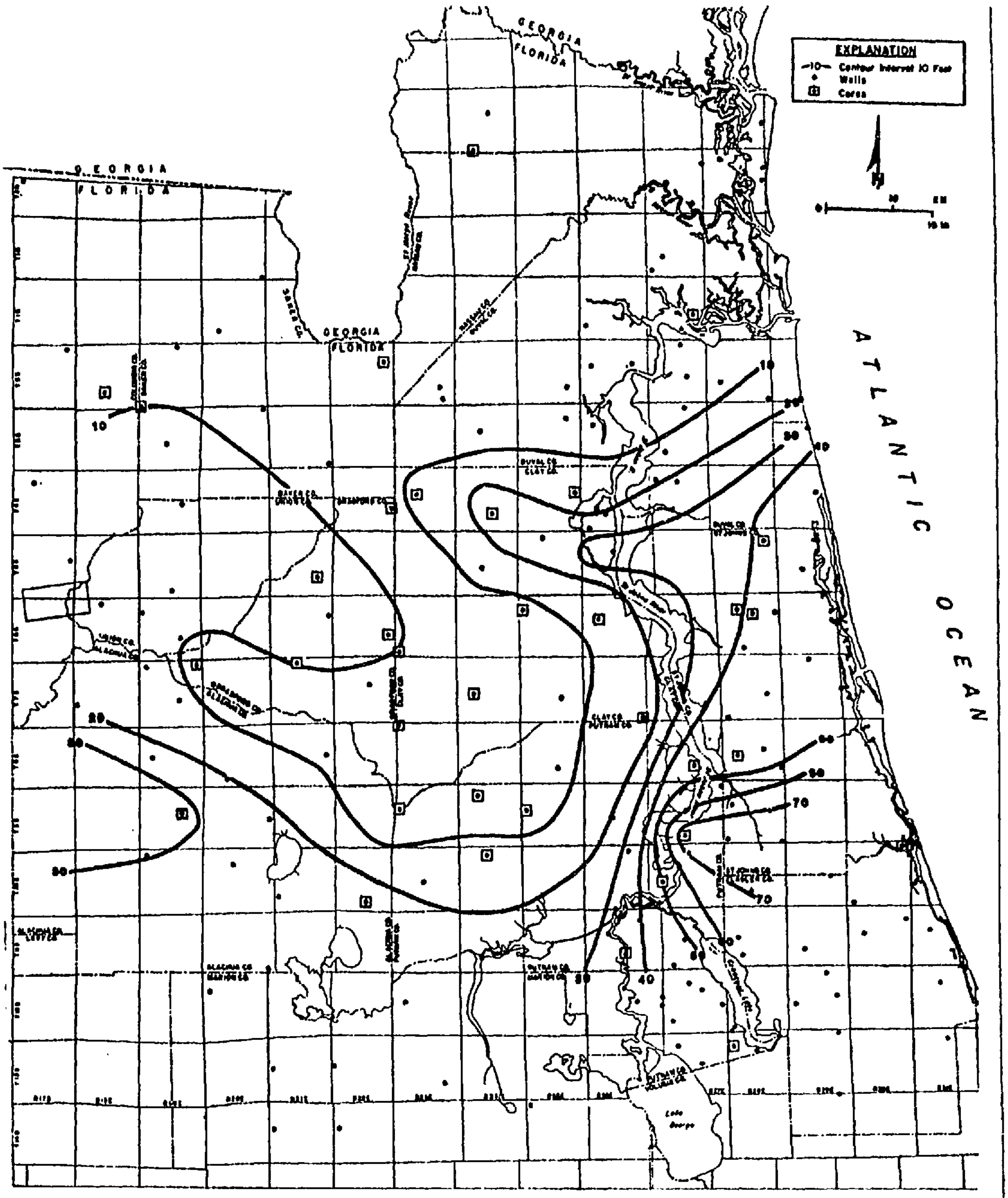

Figure 4.. Percentage of clay units in the Hawthorn Formation.

greatest amount of sand retained on the 60 mesh (2 Ø) and 120 mesh (3 Ø) sieves. The heavy minerals found to be most common were ilmenite, leucoxene, kyanite, sillimanite, staurolite, epidote and garnet.

Figure 3 is a percent sand (rock type) map. The greatest sand concentrations occur in north and northwestern portions of the study area suggesting a source to the north and northwest. Sand content generally decreases to the south and southeast. A general decrease in average sand grain size followed the same trend as abundance. The map shows a northwest-to-southeast trend of a decreasing percentage of sand units within the Hawthorn in the central portion of the study area.

Clays are present throughout much of the Hawthorn Formation. Most often the clays are accessory mineral in another dominant lithology, i.e., clayey, dolomitic sand or clayey, sandy dolomite. However, clay beds are not uncommon. Figure 4 shows the areal distribution of clays as a percentage of the total Hawthorn section. The maximum percentage of clay beds present is greater than 70 percent in W-14354 in east-central Putnam County. Clay percentages of 30 to 40 percent are found along the eastern and southeastern edge of the map. Lower percentages are dominant over most of the remaining map area. Note the increase in clay content in Alachua County.

The clay minerals present in the Hawthorn are palygorskite, montmorillonite, sepiolite, illite, kaolinite and chlorite (Reik, 1982). Palygorskite and montmorillonite are the dominant clays in the Hawthorn of the study area. Sepiolite, illite and chlorite are uncommon. Kaolinite is found only in the more weathered or leached sections of the Hawthorn.

STRATIGRAPHY

The Hawthorn Formation within northeastern Florida unconformably overlies the Eocene limestones of the Ocala Group. The unconformity cuts increasingly older rocks toward the southeast. Throughout most of the study area the first Eocene limestone encountered is the Crystal River Formation, the youngest unit of the Ocala Group. In eastern and southeastern Putnam County and into Flagler County, the Williston Formation underlies the unconformity in the southeastern most corner of the study area (Bermes, et al, 1963; Reik, 1980; Leroy, 1981). The entire Ocala Group is missing in central Volusia County, southeast of the study area (Wyrick, 1960). The first Eocene carbonate encountered in central Volusia County is the Avon Park Limestone.

The Hawthorn Formation is unconformably overlain by several different units. The location within the study area dictates which of the units lies on the Hawthorn. These units are often lumped into one of two categories 1) Upper Miocene to Pliocene Deposits; 2) Post-Hawthorn to Recent Deposits (Bermes, et al, 1963). Clark, et al (1964) referred to the Post-Hawthorn units as 1) Choctawhatchee Formation, 2) Older Pleistocene Terrace Deposits, 3) unnamed Coarse Clastics. For the purposes of this study formational names were not applied to these units. They are shown on the cross sections as specific lithologies (figures 5-9).

Sandy, often clayey, shell beds overlie the Hawthorn east of central Clay and Putnam counties (figure 9, DD'). Cross sections AA' and BB' (figures 6 and 7) clearly show how the shell unit onlaps the Hawthorn. Also, the clayey sand overlying the shell bed shows a similar relationship. Further west (inland), the sediments overlying the Hawthorn are predominantly sands, clays and clayey sands (figure 6 and 7). Scattered lenses or erosional remnants of shell beds and limestone occur on top of the Hawthorn (W-8400 BB'; W-14283 AA', CC'). The limestone cropping out in Brooks Sink (Bradford County, T7S, R20E, S12, SW1/4, of SW1/4) is an example of the scattered remnants or lenses of carbonate. The limestone is absent from the cores east and west of the sink (W-14255 and W-14280). Pirkle (1956) referred to this limestone as lower Choctawhatchee (Upper Miocene) in age based on ostracods identified by H.S. Puri of the Florida Bureau of Geology.

The stratigraphy of the Hawthorn Formation is complex and variable. However, lithologic patterns can be seen when lithologies are grouped into four categories. These categories, based on the dominant component, are dolomite, limestone, sand and clay. As previously stated, the occurrence of end-member lithologies (i.e., pure sand, etc.) is uncommon. However, they do occur, most often as clays and dolomites.

A generalized three part subdivision of the Hawthorn Formation is obvious from the cross sections (figures 6-9). The cross sections show an upper dolomite unit overlying a sand and clay member which overlies a basal dolomite unit. These units are gradational with each other. Each unit also contains thin beds lithologically similar to the other units. A fourth unit is recognized in wells in the western portion of the study area (figure 6, AA', W-14255, W-14280). It occurs at the top of the Hawthorn and is a unit of reworked clayey, sandy, phosphatic material. Scott (1982) discussed this briefly.

The upper dolomitic unit consists of sandy to very sandy, sometimes clayey, phosphatic dolomites. Induration is generally poor to moderate, however, well indurated units do occur. Thin sand beds are common and thicker sand units occur sporadically. Clay layers also occur in this member. The upper dolomitic unit is absent in the southeastern corner of the study area presumably due to erosion (figure 9, DD'). It is also absent over at least part of the St. Johns Platform (see structure section and figure 12) again presumably due to post-Hawthorn erosion. Westward across the study area, this unit appears to interfinger with and grade into a more clastic unit similar to the middle

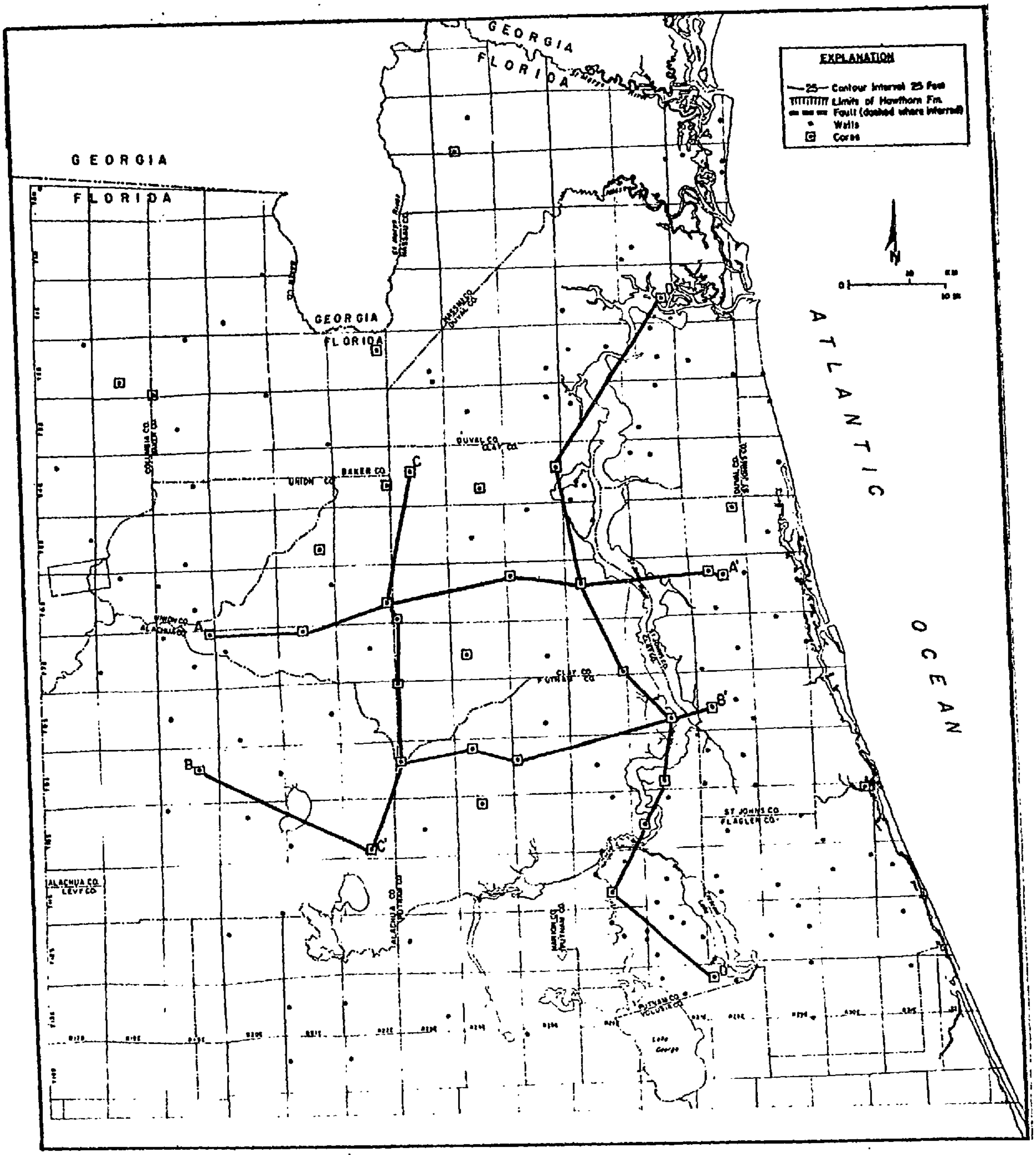

Figure 5. Location of cross-sections.

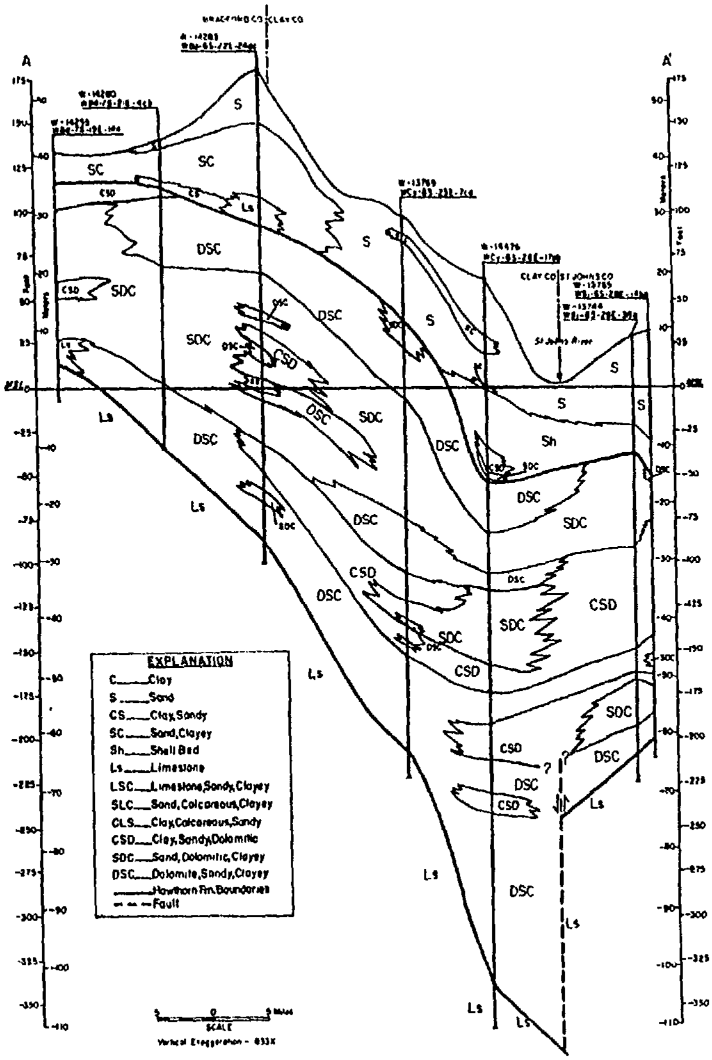

Figure 6. Cross-section A-A'.

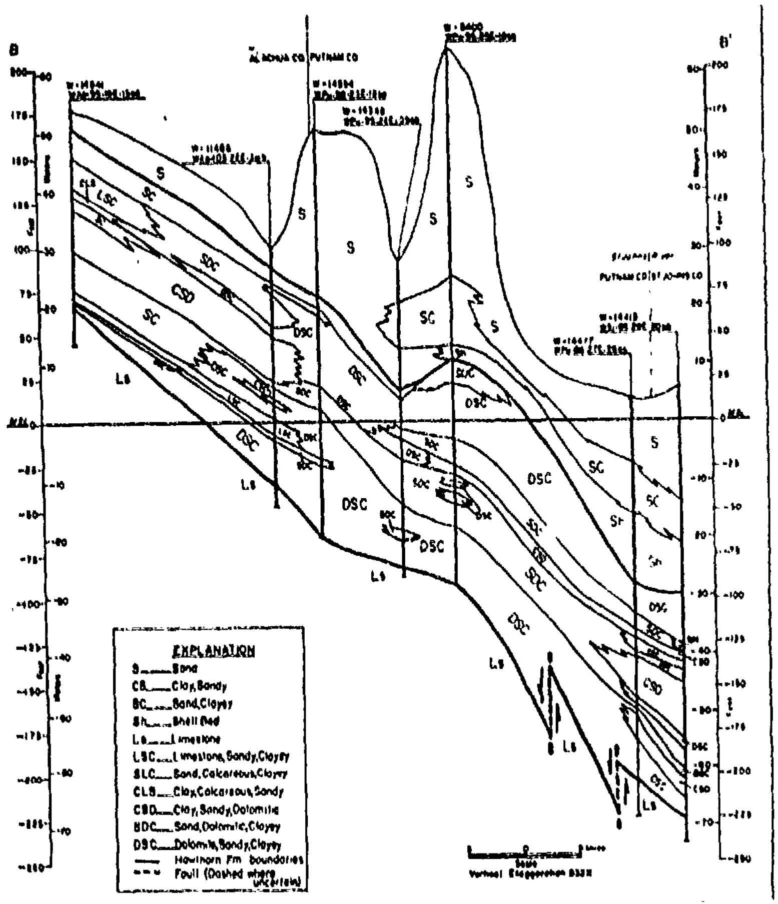

Figure 7. Cross-section B-B'.

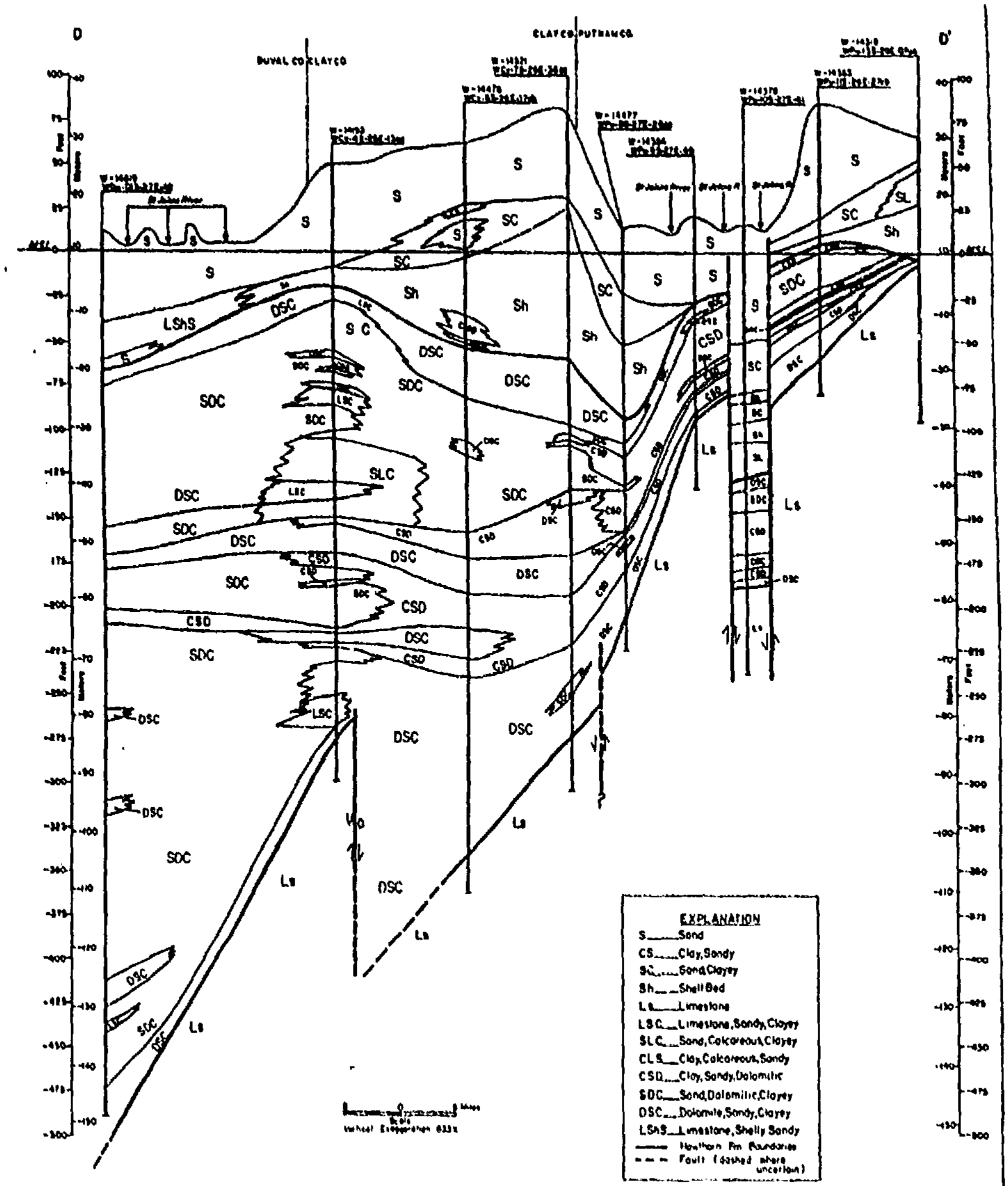

Figure 9. Cross-section D-D'.

member of this study (figures 6 and 7, AA' and BB').

The middle clastic unit of the Hawthorn Formation in northeast Florida consists of clayey, dolomitic, phosphatic sands. These are generally poorly to moderately indurated. Clays containing widely varying amounts of sand, dolomite and phosphate are common, occasionally comprising the bulk of this member. Thin dolomite beds are also often present. This unit is present throughout the study area but appears to become less distinct, merging with the upper and lower members, toward the north (figure 9, DD').

The basal dolomitic member is present throughout northeast Florida. It consists of sandy, sometimes clayey, phosphatic dolomites that are poorly to well indurated. Sand and clay beds also occur in this unit. This unit thins to the west in the study area and thickens toward the Jacksonville Basin (figures 6-9).

Miller (1978) investigated the Hawthorn in the Osceola National Forest in Baker and Columbia counties. He identified five lithologic units within the Hawthorn. The units, designated A through E, compare well with the three units identified in this report. Miller's basal member, E, is a carbonate unit comparable to the lower dolomitic unit of this report. Unit D is a complexly interbedded carbonate-clastic member representing a transitional sequence between units E and C. Unit C is a clastic unit comparable to the middle clastic unit of the present study. Unit B is a clastic (clay) to carbonate member which appears to correlate with part of the middle clastic unit. Unit A is a carbonate member and correlates to the upper carbonate rich unit of this study.

The upper dolomite unit seen on the cross sections crops out in Brooks Sink, Bradford County. This outcrop reveals the thin bedded and lithologically variable nature of the upper Hawthorn dolomites (Scott, 1982).

The lower boundary of the Hawthorn Formation is easily picked based on a drastic lithologic change. The basal Hawthorn is generally a brownish to greenish, sandy, phosphatic dolomite and lies directly on a gray to white often recrystalized limestone.

As stated previously, the upper surface of the Hawthorn Formation is an unconformity. Large deposits of dolomitic and phosphatic rubble often occur here. Variable amounts of phosphate gravel and sand are often found in the sediments immediately overlying the Hawthorn contact. These rapidly decrease in abundance upward away from the contact until the post-Hawthorn sediments contain only trace amounts of reworked phosphate.

The upper boundary of the Hawthorn, however, has long been a source of controversy and misunderstanding. The top of the unit cannot be picked strictly on the occurrence of phosphate. As previously mentioned, phosphate is commonly reworked into the younger sediments. In northeastern Florida, the most consistent method of recognizing the top of the Hawthorn is based on the occurrence of a mixture of sand, clay, phosphate and dolomite (or locally limestone). The sediment is most commonly a clayey, sandy, phosphatic dolomite or a clayey, dolomitic phosphatic sand. It lacks shell material and is normally an olive green to gray-green color.

GEOPHYSICAL INTERPRETATION

Gamma ray logs are quite helpful in recognizing the approximate boundaries of the Hawthorn Formation. The Hawthorn, in general, is marked by gamma ray activities that are significantly higher than the overlying and underlying sediments (figure 10). The Hawthorn-Ocala contact is always marked by a large decrease in activity in the Ocala. The basal Hawthorn often has strong gamma ray peaks (greater than 200 counts per second (cps) while the underlying limestones have very low activities (less than 20 cps). Cavities in the limestones just below the Hawthorn - Ocala boundary are occasionally filled with Hawthorn sediments. This produces a gamma ray peak which occurs below the contact and may cause a misinterpretation of the boundary. However, when this occurs the resulting peak is usually more subdued than the basal Hawthorn peaks.

The gamma ray signature of the top of the Hawthorn Formation shows strong peaks (often greater than 150 cps). The overlying sediments produce gamma ray peaks that are much less intense than those of the Hawthorn but greater than the Ocala Group limestones. Immediately above the uppermost Hawthorn, the gamma ray peaks may be quite variable due to the reworking of Hawthorn sediments as previously mentioned and the occurrence of clays. This can create confusion. However, these peaks are generally less intense than the typical uppermost Hawthorn peaks.

While the upper and lower Hawthorn sediments tend to exhibit strong gamma ray peaks, the sediments in between produce much less intense peaks. Although peaks in these sediments may reach 200 cps they average much less (around 40 to 50 cps). This contrast produces a general three part breakdown of the Hawthorn based on gamma ray logs (figure 10) which can be traced throughout much of the study area. However, this division based on gamma ray activity does not always correlate closely with the lithologic breakdown described earlier.

STRUCTURE

The Hawthorn Formation unconformably overlies the Ocala Group limestones and is in turn overlain unconformably by sediments ranging from Upper Miocene to Recent. The unconformity on top of the Ocala Group represents an interval of erosion or non-deposition that includes the uppermost Eocene, the entire

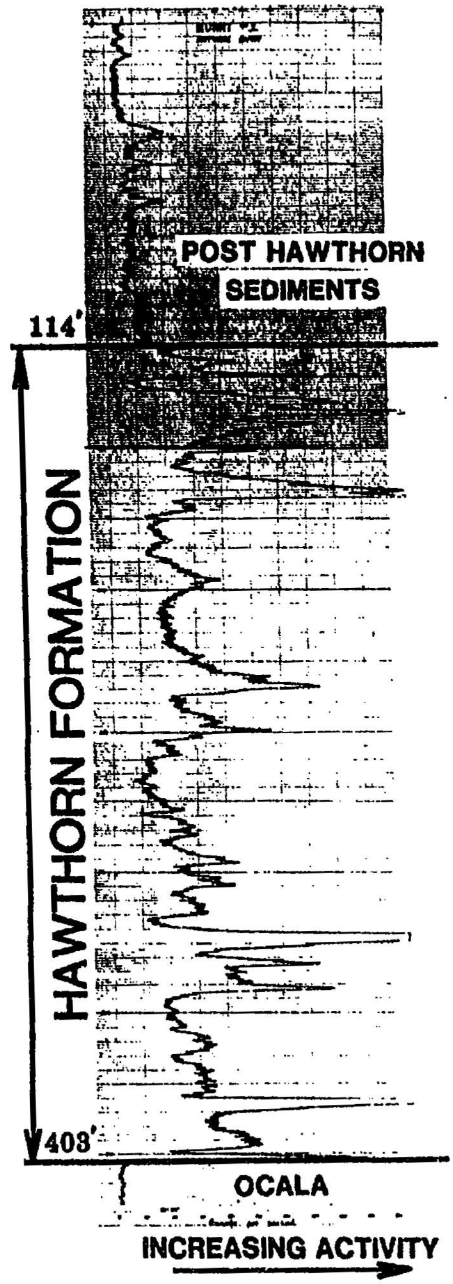

Figure 10. Typical geophysical log.

Oligocene and, in some areas, the basal Miocene. Figure 11 shows this unconformity and its relation to the structural features of the study area. The unconformity encounters older rocks towards the southeast. In the southeastern corner of the map area, the Crystal River Formation (youngest formation of the Ocala Group) is absent and the underlying Williston-Inglis Formation is thinned (Leroy, 1981; Leroy and Scott, 1981). In general, the top of the Ocala Group dips to the northeast toward the Jacksonville Basin (figures 11 and 12). The direction of dip becomes more northerly along the eastern edge of the map.

Structural features identified on the Ocala surface are indicated on figure 12. These are the Nassau Nose, Jacksonville Basin, St. Johns Platform, Baker-Bradford Slope, Marion Plain and the Ocala High. The dominant structural elements are the Ocala High, the St. Johns Platform and the Jacksonville Basin. The remaining features represent transitional areas between these major elements.

The Ocala High, often termed the Ocala Uplift (Vernon 1951), is the dominant feature of west-central and northwestern peninsular Florida and is an area where the Ocala Group limestones are well above sea level. The "crest" of the high is located southwest of the study area where it is breached by erosion exposing the Middle Eocene Avon Park Limestone. It trends northwest-southeast, plunging gently in both directions. The eastern flank of the Ocala High can be seen on the west side of figures 11 and 12.

The St. Johns Platform, named by Riggs (1979a), is a northward dipping extension of the Sanford High. The Sanford High is located south of the study area in Volusia and Seminole counties. In a regional sense, the St. Johns Platform parallels the Ocala High (figure 12).

The Jacksonville Basin (Riggs, 1979a) is the subsurface extension of the Southeast Georgia Embayment in northeastern Florida. It is separated from the onshore portion of the Southeast Georgia Embayment in Georgia by the Nassau Nose. The Nassau Nose is an eastward plunging apparently anticlinal feature. The Southeast Georgia Embayment was named by Toulmin (1955). Herrick and Vorhis (1963) state "...the embayment appears to have orignated in Middle Eocene time and continued as a de-positional basin intermittently through Miocene time." The Jacksonville Basin contains the thickest sequence of Miocene sediments found in the northern two-thirds of the peninsula. Maximum Hawthorn thickness is close to 500 feet (150 meters) in the center of the basin.

The Baker-Bradford Slope lies west of the Jacksonville Basin and the St. Johns Platform. It trends northwest-southeast, terminating against the St. Johns Platform (figure 12). Miller (1982) in discussing the phosphate in the Hawthorn under the Osceola National Forest (Baker and Columbia counties), refers to a "hinge line" which strongly affected the deposition of the

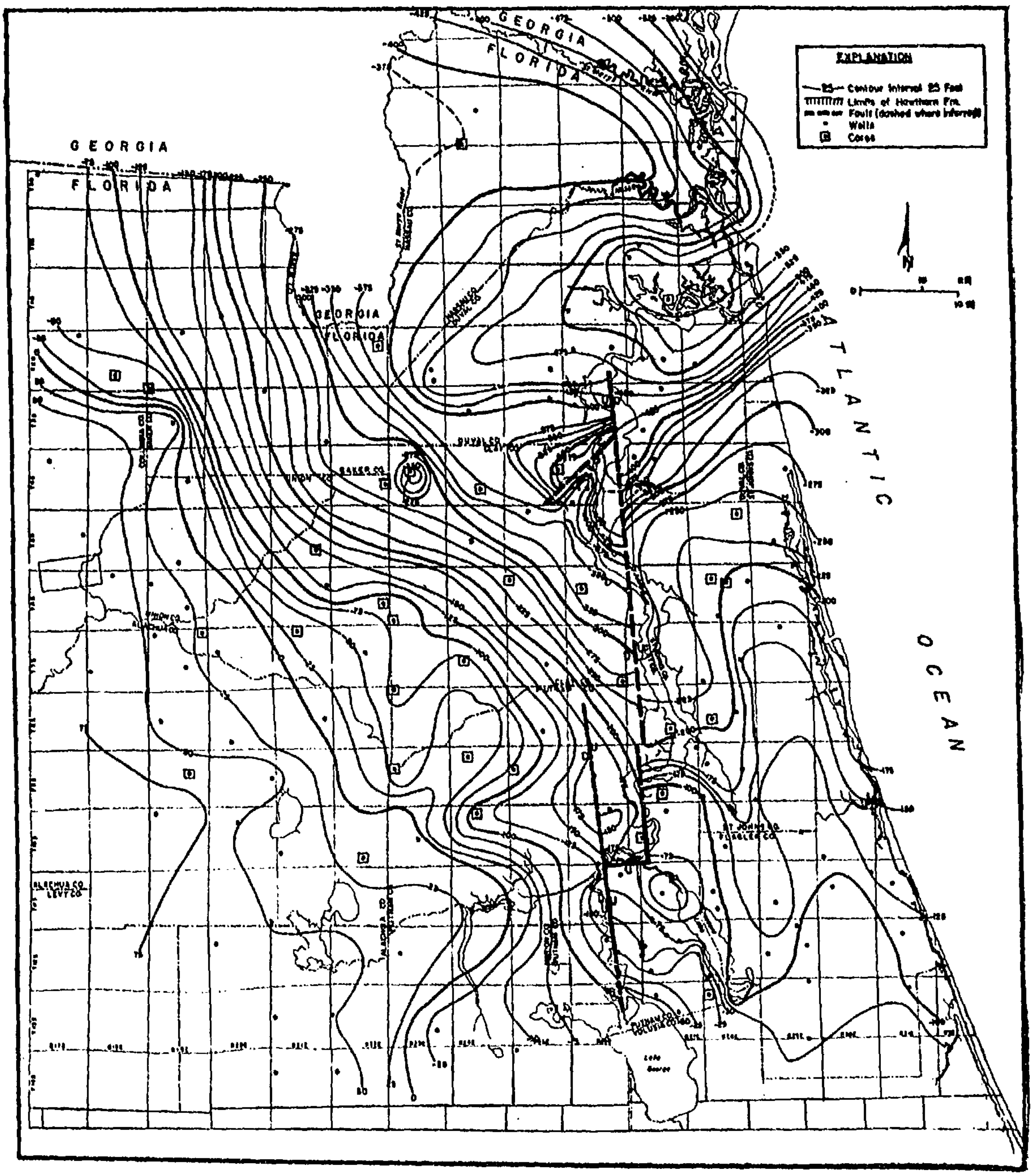

Figure 11. Structure map of Ocala Group.

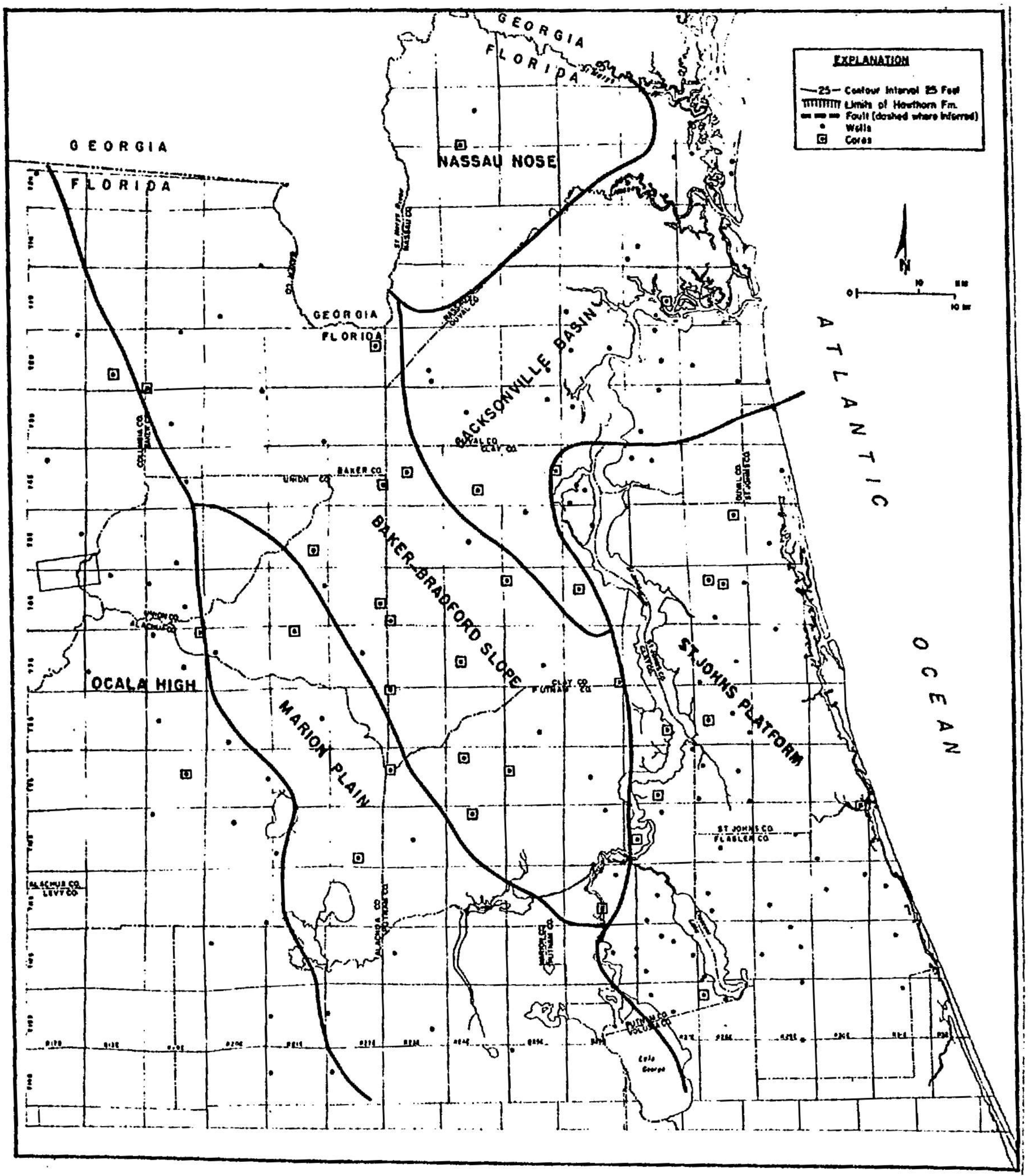

Figure 12. Features expressed on Ocala Group surface.

phosphorites. This "hinge line" coincides with a portion of the Baker-Bradford Slope. The Baker-Bradford Slope extends from the Florida-Georgia border southeastward to northeastern Putnam County. The extent of the slope in Georgia was not investigated in this study.

South and west of the Baker-Bradford Slope and between the Ocala High and the St. Johns Platform is the Marion Plain, named by Riggs (1979a). The Marion Plain is a fairly broad, relatively flat area underlying eastern Marion County extending northward into Union County. The erosional surface of the Ocala Group dips very gently towards the northeast where it terminates against the St. Johns Platform to the south and merges with the Baker-Bradford Slope to the north (figures 11 and 12).

The structure map of the Hawthorn Formation (figure 13) indicates that by the end of Hawthorn deposition many of the features noted on the Ocala Group structure map (figures 11 and 12) are no longer as pronounced. As is the case with the Ocala Group, the top of the Hawthorn Formation is an unconformity. This in turn, has modified the existing structures. The Hawthorn dips gently to the east and northeast.

One notable structure shown on the Hawthorn structure map is the low area over the Jacksonville Basin. This lies slightly south of the thickest accumulations of Hawthorn sediments and may represent a paleo-drainage pattern into the embayment. If this feature is an ancient drainage system, it is interesting to note that it nearly coincides with the present course of the St. Johns River.

The isopach map of the Hawthorn Formation (figure 14) shows the thickest accumulations to be in the northeast, coinciding with the deepest portion of the Jacksonville Basin. The Hawthorn ranges in thickness from zero in the southwest, west and southeast parts of the study area to greater than five hundred feet in the northeast. The Hawthorn thickens in a general manner from the southwest to northeast throughout the study area.

The paleoextent of the Hawthorn Formation beyond its present erosional limits has been postulated by (1981). Based on the assumption that much of the chert found in the limestones at or near the surface on the Ocala High is the result of silica released from the Hawthorn clays during weathering and erosion of the sediments, the approximate extent of the Hawthorn can be postulated. This line of investigation suggests that the Hawthorn Formation was probably deposited over almost all of the Florida peninsula. This approach appears to work well for the areas west and southwest of the study area. However, it does not appear to work well for the southeastern portion of the area due to the apparent lack of chert in the subsurface. The author believes that the paucity of chert in this area is directly related to the facies present in the Hawthorn. Figures 2 and 4 show relative dolomite and clay contents of these sediments.

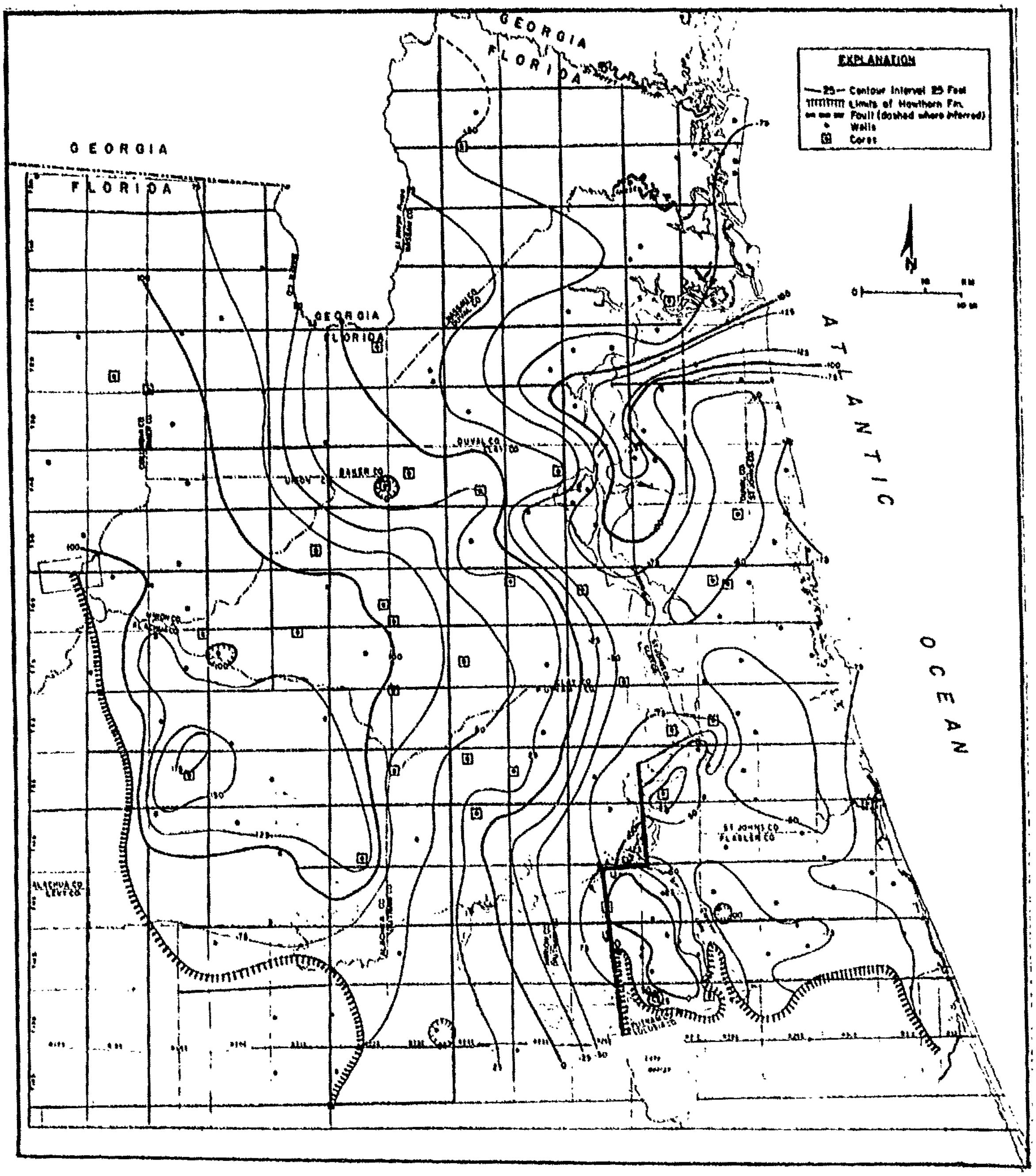

Figure 13. Structure map of Hawthorn Formation.

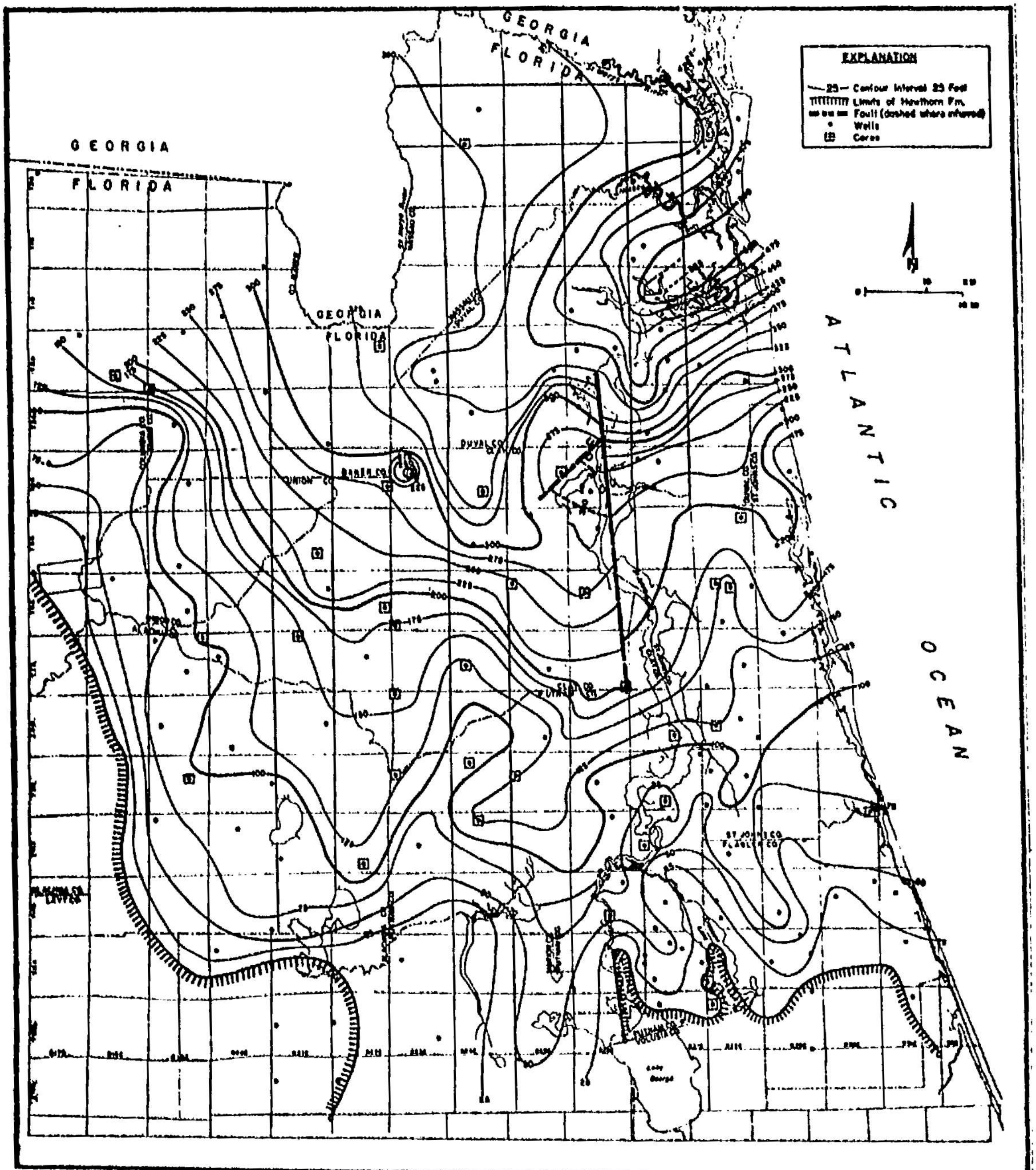

Figure 14. Isopach map of Hawthorn Formation.

These figures suggest an increased dolomite content and decreased clay component when comparing southwest and west with the southeast. With less clay present to be weathered, less chert (or none) resulted on the Sanford High.

GEOLOGIC HISTORY

The study area has been affected by episodes of erosion, nondeposition, faulting and warping. The result is an interesting geologic history. Determination of the geologic history is based almost entirely on subsurface data since there are few outcrops within this area.

Although this study did not investigate the deeper subsurface units (Lake City Limestone, Avon Park Limestone, etc.), other authors have done so. These include: Bermes, et al. (1963); Clark, et al. (1964); Leve (1966); Fairchild (1977); Reik (1980); Leroy (1981). The reader should consult these studies for information on the deeper units.

The carbonates of the Upper Eocene Ocala Group were deposited unconformably on the Avon Park Limestone. The Ocala Group attains a thickness greater than 300 feet (90 meters) under Duval County in the Jacksonville Basin. It is probable that the Jacksonville Basin existed at this time as a shallow basin. This is indicated by a slight thickening of the Ocala in the basin (Leve, 1966). However, the preservation of this thickness of Ocala Group limestones was due less to the existence of the basin at the time of deposition than it was to the subsequent downwarping of the basin in late Ocala and post-Ocala time, as indicated by the depth to the Ocala top and the increased thickness of the entire group in the basin.

The Oligocene Suwannee Limestone was not deposited within the study area. It was, however, deposited east of the present shoreline and is found in the JOIDES 1 drill hole approximately 25 miles (40 km) east of Fernandina Beach, Nassau County. The nondeposition of the Suwannee or equivalent units within the study area is evident from the lack of erosional remnants in even the deepest parts of the Jacksonville Basin while a quite thick section of Ocala Group is present.

The surface of the Ocala Group was exposed to erosion and dissolution prior to the deposition of the Hawthorn Formation. In the Miocene, the Hawthorn seas began to encroach on the exposed Florida Platform, transgressing across it. Accompanying the transgression was an influx of clastics from the north which filled the Suwannee Straits and began to enter the carbonate environments of the platform. Within the study area, the flood of clastics decreased from this time and carbonate-rich sediments became more important. This is shown by the general three part breakdown of the Hawthorn that was discussed earlier in this report and is seen in the cross sections (figures 6-9).

The Hawthorn Formation was deposited over most of the

Florida platform as is indicated by erosional remnants isolated from the main outcrop area and from subsurface data. Also, as previously discussed, the occurrence of chert in the Eocene and Oligocene limestones suggests that the Hawthorn covered a much larger area in the past (Scott, 1981). Post-Hawthorn erosion removed the Hawthorn from the Sanford High and the Ocala High and thinned the unit over much of the remaining area.

Post-Hawthorn shell beds and limestones appear to have been deposited during two separate depositional episodes. The limestones and shell referred to as Choctawhatchee Age (Upper Miocene) by Pirkle (1956) were possibly deposited prior to the major regression that occurred in the Late Miocene (Messinian). These were subsequently highly eroded during the regression leaving only scattered remnants. These remnants have been discussed by Pirkle (1956), Reik (1980) and Scott (1982). The second episode of shell bed deposition occurred when the sea transgressed onto the platform in the Pliocene. The shell units deposited during this time are found in the eastern half of the study area.

The post-Hawthorn shell beds and limestones lie on the eroded surface of the Hawthorn. These units contain variable percentages of reworked Hawthorn sediments. The most easily recognized component of the reworked sediments is phosphate which is common in the shell units and is generally most abundant in the shell beds just above the Hawthorn contact.

In the areas where the shell beds are missing, the sediments deposited on the Hawthorn are clayey sands and sandy clays. No age assignment has been possible for the clayey sands and sandy clays. These in turn are overlain by unconsolidated sands of presumed Pleistocene age. The Pleistocene age for the sands is based on the assumption that the Pleistocene sea levels fluctuated widely and deposited sands as terrace deposits over the entire state (MacNeil, 1950; Healy, 1975). It is most likely, however, that the higher level terrace sands are older than Pleistocene.

An episode of structural warping occurred during the period from the end of the Eocene to the Early Miocene. The Ocala Uplift (Ocala High of this paper) is postulated to have formed during this event (Vernon, 1951). The warping that formed the Ocala Uplift also may have formed the Sanford High, the St. Johns Ridge and associated features. Also, as mentioned above, the renewed downwarping of the Jacksonville Basin occurred during this time. The results of this warping are seen in the erosional thinning of the Ocala Group southward from the Jacksonville Basin onto the Sanford High south of the study area. The Ocala Group thins progressively onto the high and is absent over the crest of the feature. Where the Ocala is absent, the Avon Park Limestone is the first carbonate encountered below the undifferentiated sands of Plio-Pleistocene (?) Age.

Many authors believe that faulting occurred during this episode of deformation. Faults in Duval (Leve, 1966), Clay (Clark, et al, 1964; Fairchild, 1977; Reik, 1980), and Putnam (Bermes, et al, 1963; Leroy, 1981) counties have been proposed. These have been postulated in the Ocala Group, Avon Park Limestone and Lake City Limestone. None of these faults have previously been identified displacing the Hawthorn Formation and younger units. This suggests that the deformation ceased prior to Hawthorn time. The author, however, sees evidence for displacement of the Hawthorn and younger materials within the study area. This will be discussed later. Faults proposed by previous authors and by this author are shown on figures 6, 7, 9, 11, 13. Postulated displacements of the faults are variable.

Core data from the study area suggest the existence of faults which occurred during post-Hawthorn time. Figure 9 (cross section DD') indicates where the faults are believed to exist. The faults displace at least the Ocala group, Hawthorn Formation and the Pliocene shell beds. It is also possible that the undifferentiated sands overlying the shell beds were displaced but there is no evidence at this point to support such a conclusion. Displacement along these faults reaches a maximum of approximately 100 feet (30 meters) and decreases northward on the north-south faults (Leroy, 1981). This can be seen on figure 11. It is interesting to note that the St. Johns River follows this faulted course fairly well (figure 11). This seems to further substantiate the ideas of Pirkle (1971) concerning the offset course of the St. Johns River being affected by faulting.

SUMMARY AND CONCLUSIONS

The Hawthorn Formation in the Southeastern United States is probably one of the most misunderstood units in the stratigraphic section. The confusion as to what actually constitutes the Hawthorn Formation is understandable since the variability of the sediments is the rule rather than the exception.

The sediments of the Hawthorn Formation consist of widely varying mixtures of clay, quartz sand, carbonate, and phosphate. Beds of a single sedimentary component (i.e., pure clay) are not common but do occur. The most common lithologies encountered in the Hawthorn are dolomitic, clayey sands and clayey and/or sandy dolomites.

Phosphate is virtually ubiquitous throughout the Hawthorn sediments. The occurrence of the phosphate is the most important lithologic factor in the identification of the sediments grouped in the Hawthorn. It is, however, not the only factor involved since phosphatic material is commonly reworked into the overlying post-Hawthorn units.

The phosphates are generally sand-sized grains that are well rounded and "polished." They normally contain varying amounts of inclusions including dolomite rhombs, microfossil debris and clastic grains (quartz). Phosphate also occurs as intraclasts composed of phosphatic sedments or phosphatized dolomites. Phosphate concentrations in the Hawthorn range from zero to greater than 40 percent.

Dolomite is the predominant carbonate present in the Hawthorn Formation. It occurs both as a matrix material and as a primary lithology. The dolomitic sediments range from poorly consolidated to well indurated and contain widely varying percentages of quartz sand, silt, clay and phosphate. Dolosilt, a sediment composed of silt-sized dolomite rhombs, is a common constituent of the Hawthorn. The dolosilts often contain variable amounts of clay and are commonly mistaken for clays. Replacement dolomites are also common. Dolomites and dolosilts comprise an average of 25 to 40 percent of the Hawthorn within the study area.

Sand is a major constitutent of the Hawthorn Formation. It is the most abundant lithologic type encountered in the Hawthorn in the study area. Quartz sand is the most common accessory mineral in the Hawthorn. Accessory minerals in the sand-size range include minor amounts of feldspar, heavy minerals and variable concentrations of phosphate.

Clays are present throughout much of the Hawthorn Formation. Most often the clays are accessory minerals in another dominant lithology, i.e. clayey, dolomitic sand or clayey, sandy dolomite. However, clay beds are not uncommon. The clay minerals present in the Hawthorn are palygorskite, montmorillonite, sepiolite, illite, kaolinite, and chlorite (Reik, 1982). Palygorskite and montmorillonite are the dominant clays in the Hawthorn of the study area. Sepiolite, illite and chlorite are uncommon. Kaolinite is found only in the more weathered or leached sections of the Hawthorn.

Lithologic trends in the Hawthorn show that, within the study area, dolomite content increases eastward. Sand content is inversely proportional to the dolomite content in that it decreases eastward. Clay content is greatest in northern St. Johns County near the southern edge of the Jacksonville Basin. Clay content is also high in central Alachua County.

The complex mixture of clastics and carbonates that comprise the Hawthorn Formation unconformably overlie the Eocene Ocala Group limestones. The Hawthorn is in turn unconformably overlain by differing units depending on the location within the study area. In the eastern half of the study area, the Hawthorn is overlain by Pliocene shell beds. Sands and clayey sands overlie the Hawthorn in the western half with occasional remnants of Upper Miocene limestone and shell units.

The Hawthorn Formation in northeastern Florida can be divided into three members. In general, the upper unit is predominantly poorly consolidated dolomites and dolosilts with varying amounts of sand, silt, clay and phosphate. The middle member is largely clastic. It is a poorly consolidated dolomitic sand with varying percentages of dolomite, clay, silt and phosphate. The basal member is, once again, predominantly dolomite. Induration varies from poor to good and percentages of sand, silt, clay and phosphate vary widely. The three members are gradational with each other and each member contains beds of lithologies similar to that found in the other members. Occasionally, a fourth member is present at the top. The fourth member consists of reworked Hawthorn sediments. It is most commonly found in the western half of the study area.

The dominant structural features affecting the Hawthorn Formation are the Jacksonville Basin, Ocala High, Sanford High and the St. Johns Platform. These features are manifested on the Ocala Group and influenced the deposition of the Hawthorn Formation. These structures are more subtle on top of the Hawthorn.

The study area has been affected by episodes of warping and faulting. The first episode of warping that is identified occurred during the period from latest Eocene through Early Miocene. This episode formed the Ocala High (Uplift), St. Johns Platform, Sanford High and associated features. The Jacksonville Basin is thought to have existed as a more shallow basin prior to this time and was deepened considerably during the period of deformation. Faulting occurred during this period displacing the Ocala Group. An episode of faulting is postulated in eastern Putnam County which occurred after the deposition of the Pliocene shell beds. Faulting in the study area has a maximum displacement of at least 100 feet. It is interesting to note that the St. Johns River follows proposed fault zones fairly closely.

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APPENDIX

CORES USED IN THIS STUDY*
(Sea Level Datum)

ALACHUA COUNTY

WELL NUMBER	NAME	LOCATION	ELEV	TD	TOP OF HAWTHORN	TOP OF OCALA	GEOPHYSICAL** LOGS
11486	Hawthorne #1	10S 22E 3 SW NE	100	- 45	- 89	- 34.5	---
14641	Devils Millhopper #1	9S 19E 15 NW SE	178	+ 46	+167.5	+ 69	G

BAKER COUNTY

WELL NUMBER	NAME	LOCATION	ELEV	TD	TOP OF HAWTHORN	TOP OF OCALA	GEOPHYSICAL** LOGS
10473	Trail Ridge #3	2S 22E 15 SE SE	167	-121	- 13	---	---
13805	ONF-5	2S 19E 2 NW NW	132	-162	+ 98	-140	G
13812	ONF-7	2S 19E 30 NW SW	141	- 67	+121	- 41.5	G

BRADFORD COUNTY

WELL NUMBER	NAME	LOCATION	ELEV	TD	TOP OF HAWTHORN	TOP OF OCALA	GEOPHYSICAL** LOGS
13813	Raiford #1	5S 21E 26 NE NW	128	-144	+ 88	-143.5	G
14255	Mizelle #1	7S 19E 1 SE NW	133	- 7	+115	+ 22	G
14280	Varnes #1	7S 21E 4 SW NE	140	- 35	+113	-0-	G
14283	Wainwright	6S 22E 24 SE SW	181	-101	+ 93	+ 15	G

CLAY COUNTY

WELL NUMBER	NAME	LOCATION	ELEV	TD	TOP OF HAWTHORN	TOP OF OCALA	GEOPHYSICAL** LOGS
10488	Dupont #1	6S 23E 31 NE SE	239	- 93	+ 98.5	- 96	G
13769	Harris #1	6S 25E 7 SW SE	97	-222	+ 37	-205.5	C,E,G
14179	Long Branch #1	4S 23E 16 NW SE	86	-234	+ 18	-206	G
14193	Fox Meadows #1	4S 25E 13 NW SW	50	-307	- 20	-275	C,E,G
14219	Jennings #1	4S 24E 27 SE SE	90	-402	+ 30	-340	C,E,G
14301	Valldejul #1	7S 24E 20 NE SW	165	- 87	+ 60	- 62	G
14476	Kuhrt #1	6S 26E 17 NW NE	62	-363	- 52	-341	G
14521	Miss J #1	7S 26E 36 SW SW	80	-305	- 60	-273	G

DUVAL COUNTY

WELL NUMBER	NAME	LOCATION	ELEV	TD	TOP OF HAWTHORN	TOP OF OCALA	GEOPHYSICAL** LOGS
14619	Carter #1	1S 27E 42	12	-488	- 68	---	G

NASSAU COUNTY

WELL NUMBER	NAME	LOCATION	ELEV	TD	TOP OF HAWTHORN	TOP OF OCALA	GEOPHYSICAL** LOGS
13815	Cassidy #1	3N 24E 32 NW NW	80	-410	- 52	-402	G

PUTNAM COUNTY

WELL NUMBER	NAME	LOCATION	ELEV	TD	TOP OF HAWTHORN	TOP OF OCALA	GEOPHYSICAL** LOGS
8400	Baywood #1	9S 25E 18 SW NW	210	- 92	+ 36	- 87	G
14318	Nichols #1	13S 28E 7 SW NW	64	- 94	- 4.4	- 5.5	G
14346	Moody #1	9S 24E 9 NE NE	90	- 92	+ 20	- 77	G
14353	Merritt #1	11S 26E 27 SW NE	85	- 80	+ 5	- 57	G
14354	East Palatka #1	9S 27E 49	18	-134	- 27	- 90.7	G
14376	Devils Elbow #1	10S 27E 41	14	-238	-127	-187	G
14477	Bostwick #1	8S 27E 26 SW SW	12	-225	- 94	-204	G
14566	Atchenison #1	10S 24E 3 NE NE	80	-146	+ 5	-120.5	G
14594	Hall-Putnam #1	9S 23E 18 NE NE	166	- 64	+ 66.5	- 64	G

ST. JOHNS COUNTY

WELL NUMBER	NAME	LOCATION	ELEV	TD	TOP OF HAWTHORN	TOP OF OCALA	GEOPHYSICAL** LOGS
13744	Scott #1	6S 28E 38 NW	28	-224	- 37	-209	G
13751	Scott #2	5S 28E 11 SW NE	61	-281	- 43	-239	G
13765	Scott #3	6S 28E 14 NE NW	31	-211	- 68	-201	G
13844	Zonker #1	10S 30E 37	10	-168	- 89	-127	G
14413	Parker Farms #1	8S 28E 20 NE NE	19	-239	- 97	-223	G

* Data in feet. To convert multiply feet x 0.3048 to get meters.
** G = Gamma ray, C = Caliper, E = Electric