

LITHOLOGIC AND HYDROGEOLOGIC FRAMEWORKS FOR A CARBONATE
AQUIFER: EVIDENCE FOR FACIES CONTROLLED HYDRAULIC
CONDUCTIVITY IN THE OCALA FORMATION, WEST-CENTRAL FLORIDA.

U.S.A.

by

Nicholas T. Loizeaux

B.A., Williams College. 1991

A thesis submitted to the Faculty of the Graduate
School of the University of Colorado in partial
fulfillment of the requirements for the degree of

Master of Science

Department of Geological Sciences

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has been approved for the

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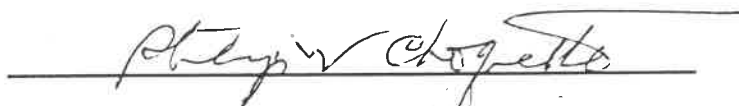
by

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David A. Budd

A handwritten signature in dark ink, appearing to read "Shemin Ge", written over a horizontal line.

Shemin Ge

A handwritten signature in dark ink, appearing to read "Philip W. Choquette", written over a horizontal line.

Philip W. Choquette

Date

9/5/95

Nicholas T. Loizeaux (M.S., Geological Sciences)

Lithologic and Hydrogeologic Frameworks for a Carbonate Aquifer: Evidence for Facies Controlled Hydraulic Conductivity in the Ocala Formation, West-Central Florida, U.S.A.

Thesis directed by Professor David A. Budd

Facies scale heterogeneity was found to be a dominant control on vertical hydraulic conductivity within the carbonate Late Eocene Ocala Formation of the Upper Floridan Aquifer in west-central Florida. Verification of this conclusion was achieved by establishing a sedimentary and stratigraphic framework for the Ocala Formation and establishing facies-vertical hydraulic conductivity (K_z) relationships. This two-fold procedure enabled the construction of a hydrogeologic framework for this unit in west-central Florida. The framework, as first proposed here, suggests that the Ocala Formation is a hydrogeologically heterogeneous carbonate body.

Logging of seventeen cores and review of more than 300 petrographic thin sections suggest that six wackestone facies, four packstone facies, and two grainstone facies make up the vast majority of Ocala lithologies. Three distinct and mappable subdivisions or sequences of the Ocala Formation are recognized in west-central Florida and these appear to be correlatable to other Jackson stage sequences recognized elsewhere in the Gulf of Mexico. The three sequences and their component facies architectures indicate subtidal deposition on a distally steepened carbonate ramp during the Late Eocene.

The results of falling head permeameter tests on 44 Ocala Formation core plugs show that vertical hydraulic conductivities range from 1.19×10^{-4} cm/sec (.337 ft/day) to 1.14×10^{-9} cm/sec (3.24×10^{-6} ft/day). Subdividing the permeameter data by sedimentary facies, three facies are shown to have geometric mean hydraulic

conductivities an order of magnitude higher than five others. The two grainstone facies in the Ocala have geometric means of 7.77×10^{-5} and 5.13×10^{-5} cm/sec and the mixed skeletal packstone facies 1.32×10^{-5} cm/sec. Five packstone and wackestone facies have geometric means on the order of 1.00×10^{-6} to 1.00×10^{-7} cm/sec. The division of these facies into K_z classes is shown to be statistically significant.

The distribution of the higher and lower K_z facies varies significantly within each of the three sedimentary sequences identified. As a whole, the Ocala Formation should not be considered a regional aquiclude/aquitard within the Upper Floridan Aquifer. Only the middle sequence displays a regionally continuous package of lower K_z facies and may therefore act as an relatively impermeable barrier between more hydraulically conductive lithologies. The basal sequence in the northern 1/2 of the study area and the uppermost sequence across the west-central portions of the study area should demonstrate good aquifer capabilities. Using a conservative estimate of the K_z to $K_{x,y}$ ratio of 1:10 there is great three-dimensional heterogeneity in the Ocala Formation.

ACKNOWLEDGMENTS

"....For afterwards a man finds pleasure in his pains, when he has suffered long and wandered long. So I will tell you what you ask and seek to know" - Homer

"I'm glad I did it, partly because it was worth it, but mostly because I shall never have to do it again." - Mark Twain

I would like to first thank those people and agencies that facilitated my research both strategically and financially: Dr. Jon Arthur of the Florida Geological Survey, David DeWitt and Douglas Rappuhn of the Southwest Florida Water Management District, EMARC, and the Department of Geological Sciences. I would also like to thank ENVIRON Corporation for providing me the opportunity to pursue a graduate education full-time.

Endless thank-you's go out to my thesis advisor, Dr. David Budd. He spent an enormous amount of time working with me and never failed to be accessible or patient during those times. For thoughtful criticisms of my work I would like to thank my other committee members Dr. Shemin Ge and Dr. Philip W. Choquette.

As I am usually inclined to save the best for last, I shall do so once again. Without the support of a number of people my thesis work would not have been as enjoyable, or even possible. I would like to thank the following folks for giving more dimensions to my life while I often felt it was becoming one-dimensional: Jimmy, Wilson, Miles, PT, Peter, K.B., Jules, Kevin, Chris, the boyz in Oakland, my fellow geo-grads, and Captain Trips (RIP 8/9/95). Lastly, I must once again thank my parents, Peter and Elisabeth, for their incessant support, advice, love and guidance.

"One of the best-paying professions is getting ahold of pieces of country in your mind, learning their smell and their moods, sorting out the pieces of a view, deciding what grows there and there and why, how many steps that hill will take, where this creek winds and where it meets the other one below, what elevation timberline is now, whether you can walk this reef at low tide or have to climb around, which contour lines on a map mean better cliffs or mountains. This is the best kind of ownership, and the most permanent. It feels good to say 'I know the Sierra' or 'I know Point Reyes.' But of course you don't-what you know better is yourself, and Point Reyes and the Sierra have helped."

- Terry and Renny Russell

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CHAPTER 1

INTRODUCTION AND STUDY AREA

I. Introduction

The importance of determining the controlling mechanisms on permeability in sedimentary bodies has been of paramount interest to the petroleum industry and more recently to the environmental industry. Early researchers were motivated by the need for more complete and efficient extraction of hydrocarbons and now by the need for similar extraction of potable or contaminated ground waters. Judging by advances in the petroleum industry over the last two decades, it is clear that a better understanding of the relationship between sedimentology and permeability is needed in analogous heterogeneous carbonate ground water reservoirs. Recent research has shown that depositional environments are the dominant control on permeability in all types of depositional systems (e.g. Ebanks 1987; Goggin et al. 1988; Anderson 1989; Blair et al. 1991; Johnson and Budd 1994; Davis et al. 1994; Rovey and Cherkauer 1994a; Eisenberg et al. 1994). However, much of the transmissivity observed in carbonate aquifers, including the one in this study, is attributed to fracture porosity produced by diagenesis, karstification or tectonics (White 1988; Rovey and Cherkauer 1994b).

This investigation is subdivided into two parts that jointly seek to prove the validity of a thesis that sedimentary facies are a dominant factor affecting ground water flow in the carbonate Ocala Formation in west-central Florida. The first part is the establishment of the sedimentary architecture of the Ocala Formation and the second part is the use of vertical hydraulic conductivity (K_z) data from various depositional facies of the Ocala Formation to create a hydrogeologic framework. The operating hypothesis is that sediments deposited in higher energy regimes (winnowing of fines) would have better primary intergranular pore connections and lower flow path tortuosities, and thus better hydraulic conductivity. Sediments deposited in lower

energy regimes would have fine grained mud in intergranular pore spaces, and therefore have smaller pore throats, higher tortuosities, and lower hydraulic conductivities. Other controls on ground water permeability (alternative hypotheses) that may or may not act in concert with sedimentary facies include geographic location, depth, diagenesis, porosity, karst solution channels, and fractures.

The aquifer unit used as a field area for this study is the Ocala Formation in west-central Florida. The paleo-depositional geometry of the Ocala has been seismically interpreted as a distally steepened carbonate ramp (Mullins et al. 1988b; Gardulski et al. 1991). Detailed sedimentary facies patterns across a Tertiary Gulf of Mexico carbonate ramp were undescribed previously until Hammes (1992) outlined the framework for the Oligocene Suwannee Formation in west-central Florida. Other studies of Cenozoic ramps include those from the Persian Gulf (Purser 1973), the Mediterranean (Frost 1981; Buxton and Pedley 1989), Southern Bavaria (Darga 1990), a cool-water ramp in Australia (James and Von Der Borch 1991), Morocco (Trappe 1992), and Libya (Mresah 1993). Studies on Tertiary ramps, however, still remain significantly outnumbered by those on Paleozoic and Mesozoic ramps (Hammes 1992). It should be noted that prior researchers have identified sedimentary facies within the Ocala Formation (e.g. Zachos 1978, Fenk 1979), but their investigations included observations from few cores (2 and 3, respectively), and therefore were unable to propose sedimentary frameworks for the entire formation across the ramp.

More rare than research on the sedimentologic frameworks of Tertiary carbonate ramps are studies addressing hydrologic heterogeneity in the Floridan Aquifer System. Numerous researchers have established regional formational scale frameworks for the aquifer (e.g. Ryder 1982, 1985; Miller 1986; Bush and Johnston 1988), but, to date, no comprehensive facies scale frameworks have been established. Some researchers have recognized the fine scale heterogeneity within the Floridan Aquifer (Ryder et al. 1980; Hickey 1982; Miller 1986; Green et al. 1995) but, for lack of one or both a

detailed sedimentary framework or fine scale hydrologic testing, were unable to establish correlations. A pilot study by this author and D.A. Budd in the Suwannee Formation identified facies controlled permeabilities, albeit with a weak statistical correlation (Loizeaux and Budd 1994).

Outside of the Floridan Aquifer System comparable hydrologic studies are equally as rare. Facies and permeability correlations have been suggested for dolomite ground water aquifers in Wisconsin (Rovey and Cherkauer 1994a, 1994b) and for phreatic ground water lenses on carbonate paleo-islands (Vacher 1988; Budd and Vacher 1991). The information and knowledge disparity between carbonate hydrocarbon reservoirs and ground water reservoirs, is confirmed and accentuated by the number of papers addressing stratigraphic facies control on permeability in hydrocarbon reservoirs (e.g. Halley and Loucks 1980; Harris 1983; 1984; Crevello and Harris 1985; Roehl and Choquette 1985; Ebanks 1987; Eisenberg et al. 1994; Saller et al. 1994).

To achieve the two-fold objective of establishing a sedimentologic and hydrologic framework, 17 cores containing Ocala Formation sediments were logged at the Florida Geological Survey Core Repository in Tallahassee, FL. From these cores, 322 petrographic thin sections were produced to identify and confirm sedimentary facies recognized in the field. Lastly, 44 falling head permeameter tests and corresponding bulk porosities were run from various sedimentary facies. These procedures enabled the construction of both sedimentary and hydrogeologic frameworks for the Ocala Formation in west-central Florida.

II. Study Area and Historical Background

A. Study Area

The investigation focuses on the west-central portion of the Florida peninsula in the southern two-thirds of the Southwest Florida Water Management District

(SWFWMD) (Figure 1). The boundaries of the study area are the boundaries of SWFWMD to the east and south, the Gulf of Mexico to the west, and to the north by incomplete subsurface recovery of the Late Eocene Ocala Formation. The primary reasons for choosing this region as a study area include the availability of archived cores, the ongoing related research by Dr. David Budd and students at the University of Colorado, and the key role the Ocala Formation plays as part of the Upper Floridan Aquifer System, a major ground water supply for the state of Florida.

B. Regional Structure

A number of significant regional structures affected carbonate deposition on the Floridan peninsula during the Paleogene. These features are shown in Figure 2. Features that were present at the onset of the Paleogene were the "positive" Peninsular Arch and the "negative" Apalachicola Embayment (also called the Southwest Georgia Embayment) and South Florida Basin (Salvador 1991). The Peninsular arch is a northwest trending feature that was continuously positive from the Jurassic until the Late Cretaceous and intermittently positive during the Cenozoic (Miller 1986). The two basins affected sedimentation on the west Florida peninsula throughout the Paleogene primarily as sediment sinks.

The Ocala "uplift" is a local feature in the study area and parallels the Peninsular Arch to the north of the modern day Tampa Bay (Figure 2). The origin and name of this feature have been contested for the past four decades. Vernon (1951) described it as a gentle southeast-trending surface anticline, but this was later refuted because the "anticline" exhibits no structural closure at its bottom (Winston 1976). Winston (1976) hypothesized a localized thickening of the Lake City Limestone (basal Avon Park Formation) and subsequent eastward tilting of the Peninsular Arch during the early Oligocene. This created what Winston (1976) called the Ocala "blister dome". The

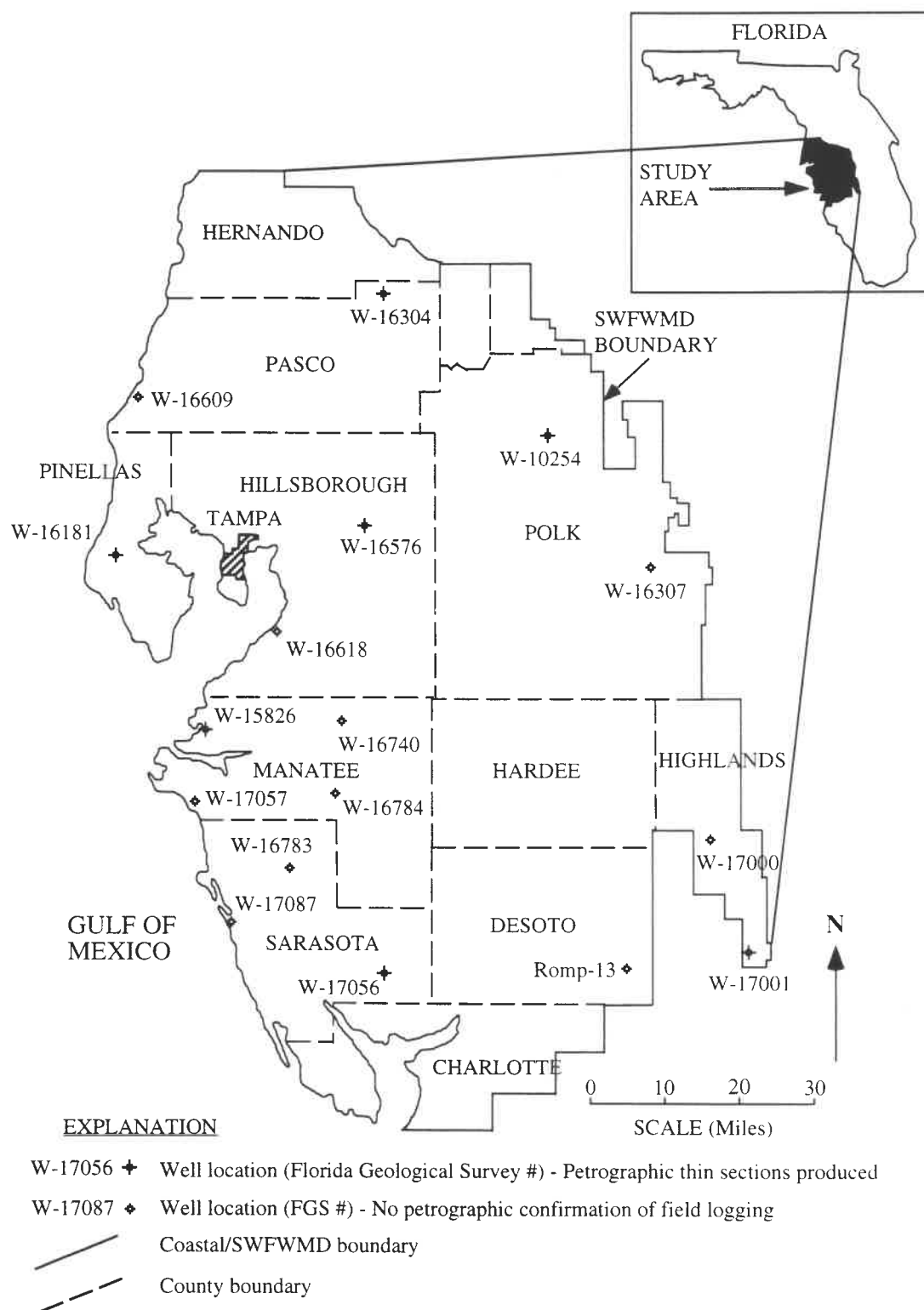


FIGURE 1: Map showing study area. Wells shown are those used in this investigation for sedimentologic and stratigraphic architecture of the Ocala. This area represents the southern 2/3 of the Southwest Florida Water Management District (SWFWMD).

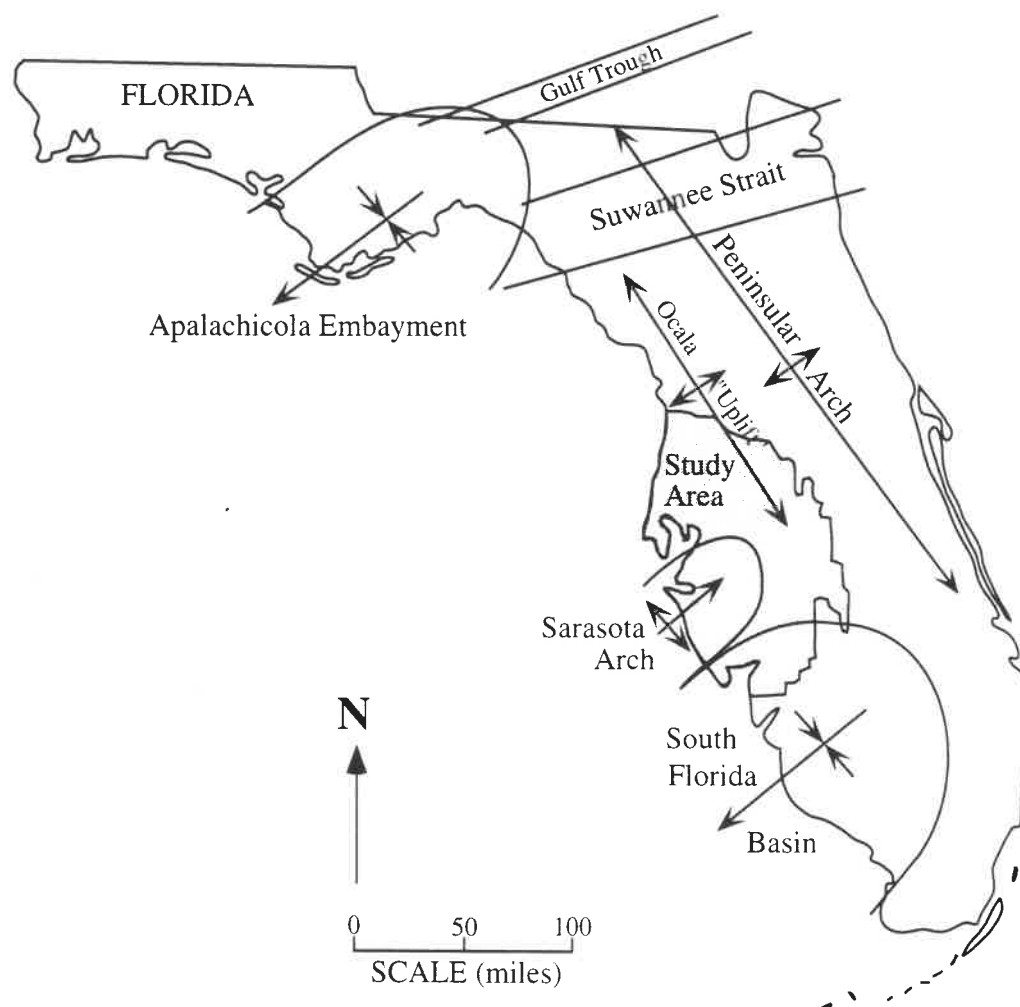


Figure 2: Antecedent structural features possibly affecting the deposition of the Ocala during the Late Eocene (modified from Miller, 1986)

localized high is now called the Ocala Platform and is attributed to a westward tilting of the thickened Eocene strata (Scott 1988).

Two features outside of the study area in this investigation that influenced the evolution of the Florida peninsula during the Late Eocene were the Suwannee Strait and the Gulf Trough (Figure 2). These two features, although different in origin, trended in the same direction and had similar effects on sedimentation to the south. They both separated the terrigenous sedimentation of the southern Appalachians from the carbonates on the Florida peninsula and both connected the Gulf of Mexico to the Atlantic Ocean. There are significant differences of opinion in the literature as to the locations, nomenclatures, and active time frames for these two features.

The Suwannee Strait was first described by Dall and Harris (1892) and renamed Suwannee Channel by Chen (1965). The difference in nomenclature reflects the authors' interpretations of the "channel's" origin. Dall and Harris (1892) termed it a strait, comparing it to a localized channel like the modern Straits of Florida. This nomenclature usage was furthered by later researchers (Jordan 1954; Hull 1962). Chen (1965) interpreted the feature to be a shallow depression across a shelf bounded by two differing sedimentary regimes, a model revised in later literature to a sediment-starved boundary (McKinney 1984). This feature was present from the Late Cretaceous to Early Eocene (Popenoe et al. 1987) or Late Eocene (McKinney 1984), and migrated northwest during its existence.

The Gulf Trough overlapped the Suwannee Channel in its western and central parts during the Eocene and Oligocene (Popenoe et al. 1987). The trough's formation has been attributed to a series of small normal faults resulting in an extensive graben (Miller 1986). Like the Suwannee Channel, the Gulf Trough connected the Gulf of Mexico to the Atlantic. The importance of these features to the Florida peninsula carbonate province was their effect as a barrier to southward terrigenous sediment influx. Sediments carried off the southern Appalachians were trapped in these localized

flows and transported eastward onto the Atlantic Blake Plateau (McKinney 1984; Pinet and Popenoe 1985; Popenoe et al. 1987). The closure of the Gulf Trough during the Late Paleogene, combined with renewed uplift in the Appalachians, marked a major shift in sedimentary regimes, evidenced by the flooding of terrigenous sediments across the northern Florida Platform (Salvador 1991). By the Neogene, carbonate production had largely been replaced by terrigenous sedimentation in this region (Scott 1988).

C. Chronostratigraphy of the Ocala Formation

The Late Eocene Ocala Formation was first identified by Dall and Harris (1892), but incorrectly correlated to Oligocene strata (Puri 1957). The correct stratigraphic position of the Ocala Formation was first described by Cooke (1915) (Figure 3). The rocks of Late Eocene time have historically been subdivided into two or three separate stratigraphic units. Applin and Applin (1944) recognized an upper and lower member, but this was later modified to reflect three subdivisions (Vernon 1951; Puri 1953). Puri (1953) assigned the three members formation status as the Crystal River, Williston, and Inglis in descending order and raised the Ocala Formation to Group status. The subdivision of the Ocala limestone has since been contested and is argued to be invalid as it is based on biostratigraphic zones and not lithologic zones (Randazzo 1976). In most aquifer studies the difficulty in distinguishing between the subdivisions has led researchers to make the parts of the Ocala Formation a single unit (Ryder 1985; Miller 1986). Recently the Florida Geological Survey (FGS) also abandoned the use of Ocala Formation subdivisions (Scott et al. 1991).

The Ocala Formation correlates to the Jackson stage in the western Gulf of Mexico and the Priabonian stage of Europe. Bounding ages for these stages vary slightly in recent literature. The COSUNA chart (1988) for the Gulf Coast region shows ages of 39.5 and 38 m.y. for the Ocala Formation and shows two internal sequences, but fails to recognize a third at the base of the Ocala (the Inglis Formation of

GLOBAL CHRONOSTRATIGRAPHY						
	SERIES	STAGES	FLORIDA LITHO-STRATIGRAPHY	AGE (m.y.)		
MIOCENE	LATE	MESSINIAN	Peace River Fm.	Hawthorn Group	5.3	
		TORTONIAN			10.5	
	MIDDLE	SERRAVALLIAN		Arcadia Fm.	Hawthorn Group	25
		LANGHIAN				
	EARLY	BURDIGALIAN	Tampa Member			
		AQUITANIAN				
OLIGOCENE	LATE	CHATTIAN (CHICKASAWHAYAN)	Hiatus		30 31 (Hammes, 1992)	
	EARLY	RUPELIAN (VICKSBURGIAN)	Suwannee Limestone		36 (Hammes, 1992) 38 (Murchum, pers comm., 1995)	
	LATE	PRIABONIAN (JACKSONIAN)	Ocala Group		40.5 (Murchum, pers comm., 1995) 41	
EOCENE	MIDDLE	BARTONIAN	Avon Park Limestone		50	
		LUTETIAN				
	EARLY	YPRESIAN	Oldsmar Limestone		55	
		THANITIAN				
PALEOCENE		DANIAN	Ceder Keys Formation		66.5	

Figure 3: General chronostratigraphy and lithostratigraphy of the Floridan Peninsula. Absolute ages are from COSUNA (1988) unless noted otherwise. Gulf of Mexico stages are given parenthetically below global stage names.

Puri (1953)). The Cenozoic cycle chart of Haq et al. (1988) shows dates of 39.5 and 36 m.y. for the Priabonian. The most recent chart available for the region (Alabama) shows 40 and 37 m.y. but has the Priabonian framed by condensed sections, rather than sequence boundaries (Baum et al. 1994). The ages of the associated sequence boundaries on this chart (immediately above and below the condensed sections) are 40.5 and 36 m.y. As will be discussed in Chapter 2 (Recognition of 3rd Order Sequences) all these cycle charts recognized internal 3rd order sequences within the Jackson/Priabonian.

D. Depositional Setting

Recent work by seismic stratigraphers in the eastern Gulf of Mexico suggests the depositional geometry of a distally steepened carbonate ramp during Ocala Formation deposition in the Late Eocene (Mullins et al. 1988; Gardulski et al. 1991; Jee 1993). This geometry would be analogous to the combined homoclinal and distally steepened ramps of Read (1985). The deposition occurred during a long-term (2nd order) eustatic highstand (Haq et al. 1987; Mullins et al. 1988). In the distal ramp environment, which underlies the modern outer continental shelf, the Late Eocene sediments are relatively thin (< 4 m) and are characterized by radiolarians, benthic foraminifera, and macro-fossil fragments, all indicative of bathyal water depths (Gardulski et al. 1991). On the modern Floridan Peninsula, which includes the area of this study, the Ocala Formation is characterized by thicker, shallower water deposits (Vernon 1951; Puri 1953; Miller 1986) of the proximal ramp setting.

The Late Eocene Ocala Formation is present everywhere on the Floridan peninsula except where locally eroded on the Ocala Platform. The formation ranges in thickness across the study area from 100 feet in the north (Pasco and Sumter Counties) to over 400 feet in Polk and Hardee Counties (Miller 1986). It grades to the north and west, off the peninsula, into clastics of the Moody's Branch and Cooper Formations.

Its lower boundary with the Avon Park Formation is considered to be an unconformity due to 1) truncation of Avon Park sediments near the Peninsular Arch, 2) a biostratigraphic hiatus, and 3) apparent compaction, diagenesis, and lithification of the Avon Park prior to deposition of the Ocala Formation (Chen 1965).

Miller (1986) describes the Ocala Formation as "a white, generally soft, somewhat friable, porous coquina composed of large Foraminifera, bryozoan fragments, and whole to broken echinoid remains, all loosely bound by a matrix of micritic limestone" and in its basal parts as "cream to white, generally fine grained, soft to semi-indurated, micritic limestone containing abundant miliolid remains and scattered large foraminifers." The boundaries between these two lithologies (or the 3 of Puri (1953)) are considered unrecognizable regionally and are more dependent on fauna (i.e. biozones; Randazzo 1976). Fauna typical of the Ocala Formation include the macro-foraminifera *Lepidocyclina ocalana* Cushman, *Lepidocyclina ocalana floridana* Cushman (Miller 1986), and *Nummulites vankerstoki* (Puri 1953).

While Ocala Formation lithologies and depositional environments are considered simple compared to its adjacent formations by most workers (e.g. Zachos 1978; Fenk 1979; Miller 1986), sedimentological anomalies compared to the underlying Avon Park and overlying Suwannee Formations suggest an "atypical" depositional regime on the Florida Peninsula during the Late Eocene (Bryan 1993). Most of the Ocala Formation sediments contain relatively few green algae or corals, while bryozoans may be very abundant. This may be indicative of sub-tropical or temperate paleo-oceanic conditions, although the expected "temperate" coralline red algae are rare in the Ocala Formation (Bryan 1993).

More recent work has speculated that the Ocala Formation is a deepening-upward sequence, as evidenced by progressively muddier substrates through Ocala time (Carter et al. 1989). This suggests that the West Florida ramp may have undergone drowning conditions during the Late Eocene sea level highstand, with the

drowning exacerbated by temperate fauna that could not "keep up" (Bryan 1993). It is not clear what influence the closure of the Suwannee Strait or Gulf Trough to the north of the Florida Peninsula during this time may have had, but it is speculated that reduced oceanic circulation in the Eastern Gulf Coast might have produced a similar increase in substrate mud.

CHAPTER 2

SEDIMENTARY COMPONENTS AND STRATIGRAPHIC ARCHITECTURE

I. Methods

A total of seventeen cores were logged during the summer of 1994. Access to the cores was provided by the Florida Geological Survey in Tallahassee, Florida. Cores were chosen for logging so as to insure broad geographic coverage of the study area and complete stratigraphic recovery of the Ocala Formation. Except for well W-10254, the cores were collected by the SWFWMD as part of their monitoring program in the Floridan Aquifer System. W-10254 was drilled by the USGS. Core recovery ranged from 48.6% to 100% and averaged 84.4%. The logging was facilitated by slabbing the 2" diameter cores and etching the flat surface with dilute HCl. Table 1 lists the wells logged for this study as well as other important information on the Ocala Formation's occurrence in each well.

Rock samples were collected from ten wells for petrographic thin sections. Of these ten wells, five were prioritized and 244 petrographic thin sections were cut at the University of Colorado by the author. Each rock sample was vacuum/pressure impregnated with blue epoxy. Only in a few samples was the rock matrix or cementation sufficiently tight to prevent epoxy infiltration. Seventy eight additional thin sections from two wells were available from the research of Hammes (1992). The thin sections were used to confirm field core logging and establish the spectrum of sedimentary facies that make up the Ocala Formation. Petrographic sample spacing ranged from 2" to 10' with an overall sample spacing goal of less than 5'. In addition to the 322 sections used for lithologies, a thin section was cut immediately adjacent to each of 44 falling head permeameter samples, bringing the total number of available thin sections to 366.

Table 1: Wells analyzed for this study. The "FGS #" is the number assigned by the Florida Geological Survey. The "well name" is the name given the well by SWFWMD.

FGS Well #	Well Name	County	Elev. (ft amsl) ^{††}	Ocala Fm. Interval (ft bgs) ^{††}	Ocala Fm. Interval (ft bmsl) ^{††}	Thickness of Ocala (ft)	% Core Recovery
W-10254*	Lakeland #1	Polk	130	148.5 - 323	18.5 - 193	174.5	est. @ 60%
W-15826*†	TR8-1	Manatee	24	642 - 906.5	618 - 882.5	264.5	98.3%
W-16181*†	TR13-1X	Pinellas	10	529 - 707	519 - 697	178	81.2%
W-16304*†	Romp-99	Pasco	60	52.5 - 219	(-7.5) - 159	166.5	79.1%
W-16307†	Romp-58	Polk	150	153 - 363	3 - 213	210	48.6%
W-16576*†	DV-1	Hillsborough	105	340.5 - 527	235.5 - 422	186.5	98.9%
W-16609	TR16-2A	Pasco	10	314.5 - 459.3	304.5 - 449.3	144.8	88.6%
W-16618†	TR9-2	Hillsborough	10	447 - 690	437 - 680	243	88.6%
W-16740†	Romp-39	Manatee	130	715.5 - 968.8	585.5 - 838.8	253.3	91.3%
W-16783†	Romp-22	Sarasota	40	639 - 942.6	599 - 902.6	303.6	82.3%

Table 1 (cont'd): Wells analyzed for this study.

FGS Well #	Well Name	County	Elev. (ft amsl) ^{††}	Ocala Fm. Interval (ft bgs) ^{††}	Ocala Fm. Interval (ft bmsl) ^{††}	Thickness of Ocala (ft)	% Core Recovery
W-16784 [†]	Romp-33	Manatee	75	725.2 - 1023	650.2 - 948	297.8	76.5%
W-17000 [†]	Romp-28	Highlands	85	580 - 863.5	495 - 778.5	283.5	78.1%
W-17001* [†]	Romp-14	Highlands	145	691 - 1018.5	546 - 873.5	327.5	78.0%
W-17056* [†]	Romp-9	Sarasota	25	864.5 - 1149	839.5 - 1124	284.5	100.0%
W-17057 [†]	TR7-2	Manatee	19	691 - 946	672 - 927	255	95.5%
W-17087 [†]	Romp-20	Sarasota	15	884 - 1148	869 - 1133	264	100.0%
W-30026 [†]	Romp-13	De Soto	60	777 - 1057.5	717 - 997.5	280.5	90.2%

* = wells with petrographic thin sections

† = wells with falling head permeameter data (and corresponding thin sections)

†† = ft amsl = feet above mean sea level

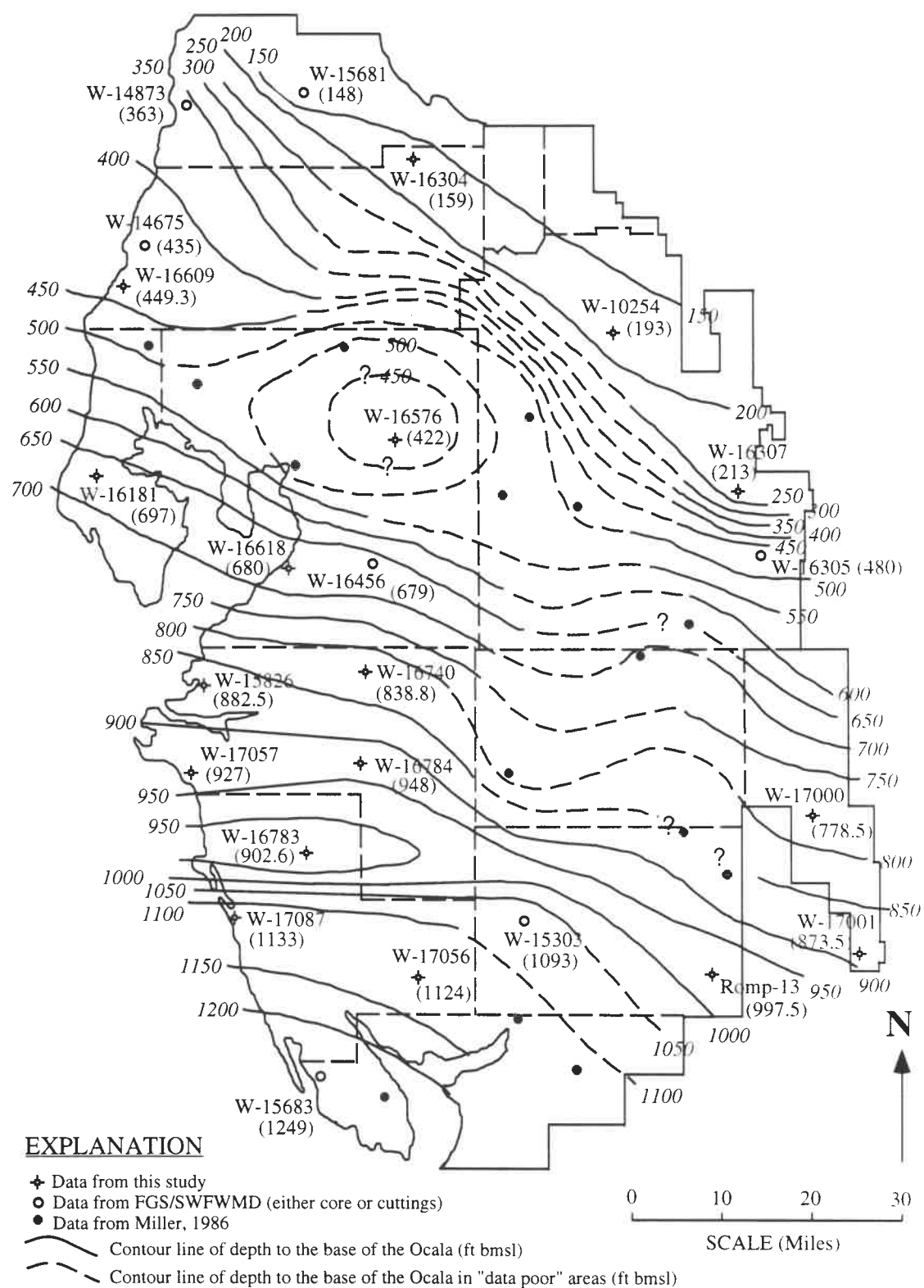
ft bgs = feet below ground surface

ft bmsl = feet below mean sea level

Sedimentary facies were identified in core and in petrographic thin section. The seven wells with regularly spaced thin section coverage were used to establish the spectrum of sedimentary facies. Sedimentary facies in an additional eight wells were recognized by using hand samples under a binocular microscope and tied to nearby wells with petrographic thin sections. Hand sample spacing ranged from approximately every five feet in five of the wells and every two feet in the other three wells. Finally, two wells contained neither thin sections nor hand samples, and facies were delineated based on original core logging of texture and biota and ties to nearby wells with petrographic data. The amount of available data per well can be seen on the corelogs in Appendix A.

II. The Ocala Formation in West-Central Florida

The Ocala Formation occurs in the subsurface across the study area in west-central Florida. Using the seventeen wells logged for this investigation, data from the FGS and SWFWMD, and data from Miller (1986), maps of the structural bottom, top, and total thickness of the Ocala Formation were produced (Figures 4-6). While similar maps have been produced in other reports (e.g. Chen 1965 and Miller 1986) significant formational boundary discrepancies have been found by this author and others (Dr. Jon Arthur, FGS, pers. comm., 1995) to warrant revised maps in west-central Florida. Formation boundary elevations in the seventeen wells logged in this study can be found in Table 1. The data from the FGS and SWFWMD was taken from lithologic logs on file at the FGS in Tallahassee. Of the nine wells involved, seven are from continuous cores and two (W-14873 and W-15303) are from cuttings. The data from Miller (1986) shows no numerical depths in the plates included in that study. Therefore, the data points borrowed represent control points for contours that are similarly borrowed from that study. Because these wells and the FGS/SWFWMD wells were not logged



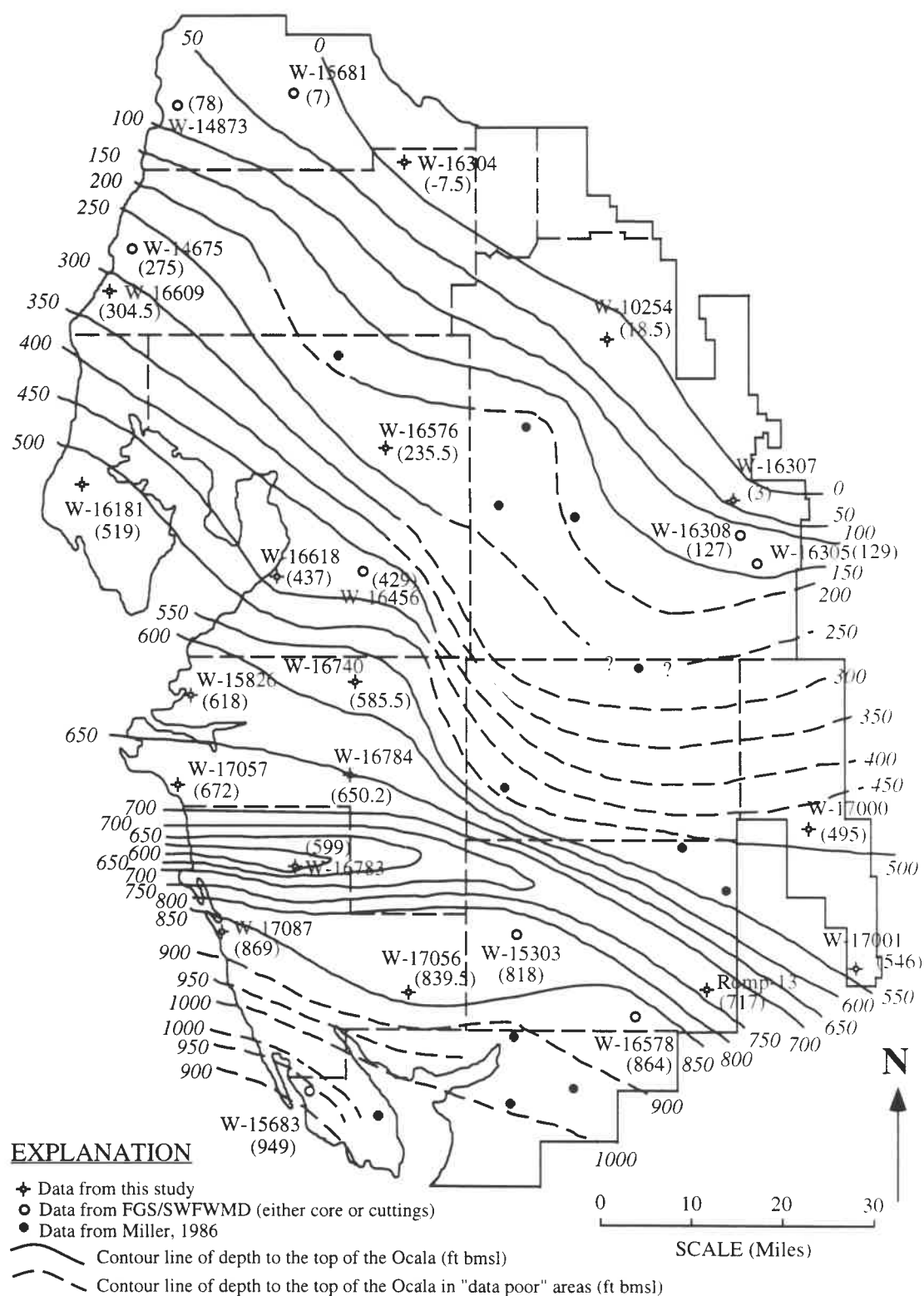


Figure 5. Structural surface of the top of the Ocala Formation (ft bmsl). Dashed contour lines indicate uncertainty in data poor areas.

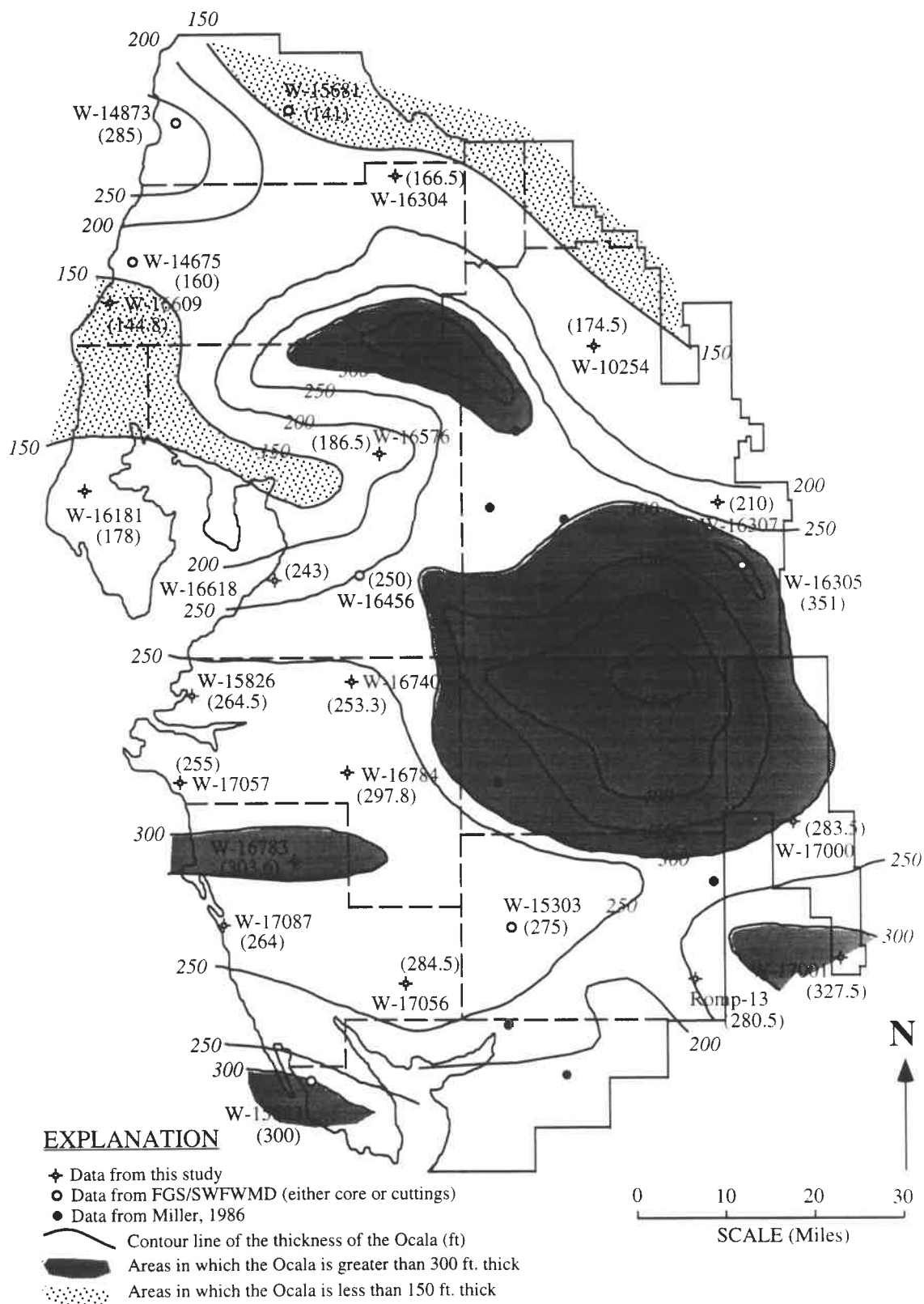


Figure 6: Isopach map of the Ocala Formation. Where well data was sparse thicknesses were generated by subtracting contours of the top and bottom of the Ocala (figures 4 and 5).

by this author, the uncertainty of others' data is indicated by dashed contours on the structure maps included here.

The bottom of the Ocala Formation (Figure 4) shows a dipping (approximately 13 ft/mile or $.14^\circ$ slope) contact along a northeast-southwest transect. Some of this dip trend may be attributed partially to the paleotopography at the end of the Middle Eocene (Avon Park Formation) but superimposed on this are the tectonic effects of a east-west movement. This movement was either the tilting eastward (Winston 1976) or westward (Scott 1988) of the Peninsular Arch following the deposition of the Ocala Formation. It seems more plausible that a westward tilting of the arch would produce the structural patterns we observe today. On the structural contour map there are also two anomalous regions, one in northeast Hillsborough County and one in northwest Sarasota County. They both reflect localized highs in topography and most likely reflect the pre-existing paleotopography of the Avon Park Formation.

The top of the Ocala Formation (Figure 5) shows a similarly dipping contact (approximately 11 ft/mile or $.12^\circ$ slope) with the overlying Oligocene Suwannee Formation. As with the Ocala Formation's lower boundary this most likely is the result of the combined effects of tectonics and general ramp geometry during the late Eocene. The slight decrease in grade (11 ft/mile vs. 13 ft/mile) reflects the overall thickening of the Ocala Formation as one moves downdip.

The final map shows total thickness of the Ocala Formation (Figure 6). This map was produced from known interval thicknesses in SWFWMD wells and subtracting contours from Figures 4 and 5 in data poor regions. Areas of localized thickening and thinning have been highlighted, but in the two large localized thicks, there are no core sections for verification. The other three thicks are based on observed core sections (W-16783 and W-17001) and cuttings (W-15683). The two regions of Ocala Formation thinning are based on observed core data and reflect a genuine depositional thin between Pinellas and Pasco Counties and post-Eocene erosion of the

Ocala Formation along the northern boundaries of the study area. Both of these regions will be discussed in greater detail later in this chapter in the section dealing with stratigraphy.

III. Facies Identification and Interpretation

A total of 12 sedimentary facies are recognized in the Ocala Formation. Six are wackestones, four packstones, and two grainstones following the carbonate classification scheme of Dunham (1962). Table 2 summarizes characteristics of each facies, and Appendix B provides a more detailed description of each and also includes a discussion on the paleoecology of the larger foraminifera. Facies characterizations are based on both the rock texture and the allochemic constituents of the sand/silt sized fraction. As an example, four general packstone facies were identified in core and thin section. All the packstones facies are typified by a grain supported matrix (grains $>31\ \mu\text{m}$) with intergranular voids partially or completely filled with mud (constituents $<31\ \mu\text{m}$). The make-up of the grain constituents is the distinguishing criterion between the four facies. The Nummulites/Lepidocyclina packstone contains those two macro foraminifera as its dominant allochems, while the mixed-skeletal packstone is typified by a broad array of various allochems and trace or no macro-foraminifera. Photographs of each facies in hand specimen and thin section are presented in Figure 7.

IV. Ocala Formation Stratigraphy and Cyclicity

A. Recognition of 3rd-Order Sequences

Hand-drafted corelogs (Appendix A) were transposed to computer drafted core logs showing only facies stacking patterns. These were then used in the construction of cross-sections that facilitated delineation of regional facies and stratigraphic trends. The cross-section locations and the cross-section key are presented in Figures 8 and 9. Cross-sections are shown in Figures 10 through 14.

Table 2: Summary of Ocala Formation Sedimentary Facies. See Appendix B for more detailed descriptions of each facies.

Facies	Dominant Allochems	Other Allochems	Structures	Porosity	Diagenesis	Paleo-Environmental Interpretation	Principal Occurrence
Miliolid Grainstone	Miliolids	Peloids, echinoids, bryozoans, bivalves, gastropods, solitary corals, intraclasts, rotalid and biserial forams, red and green algae, nummulites, lepidocyclina	Occasional walled burrows with geo-petal infill, cross-bedding, and burrowing	Interparticle, minor moldic and intraparticle	Limited to calcite cementation; may be heavy at cycle tops	Shoals and/or sheets on upper ramp	Basal Ocala in northern 1/3 of study area
Mixed Skeletal Grainstone	Peloids, echinoderms bryozoans, miliolids, bivalves, gastropods, intraclasts	Rotalid and biserial forams, red and green algae, nummulites, lepidocyclina, solitary corals	Occasional walled burrows with geo-petal infill, cross-bedding, and burrowing	Interparticle, minor moldic and intraparticle	Limited to calcite cementation; may be heavy at cycle tops	Shoals and/or sheets on upper ramp	Basal Ocala in northern 1/3 and top of Ocala in middle 1/3 of study area
Mixed Skeletal Packstone	Peloids, echinoderms bryozoans, miliolids, bivalves, gastropods	Rotalid and biserial forams, nummulites, lepidocyclina	Occasional walled burrows and bioturbation by burrowers	Interparticle and micro-interparticle, minor moldic and intraparticle	Limited to calcite cementation (not extensive)	Most likely sheets on upper ramp	Area around Tampa embayment and top sequence of Ocala
Nummulites/Lepidocyclina Packstone	Nummulites and Lepidocyclina	echinoderms, bryozoans, rotalid and biserial forams	Bioturbation by burrowers and occasional walled burrows	Interparticle, micro-interparticle, intraparticle in dense coquinas, moldic in dolomite	Extensive dolomitization in southwest portion of study area	Wide ranging down ramp profile, most prolific in middle and deeper ramp	Dominant in middle sequence of Ocala; occurs in all three sequences
Nummulites Packstone	Nummulites	Lepidocyclina, echinoderms, bivalves, bryozoans, rotalid and biserial forams	Bioturbation by burrowers and occasional walled burrows	Interparticle, micro-interparticle, intraparticle in dense coquinas, moldic in dolomite	Extensive dolomitization in southwest portion of study area	Wide ranging down ramp profile, most prolific in middle and deeper ramp	Dominant in middle sequence of Ocala; occurs in all three sequences
Lepidocyclina Packstone	Lepidocyclina	Nummulites, echinoderms, bivalves, bryozoans, rotalid and biserial forams	Bioturbation by burrowers and occasional walled burrows	Interparticle, micro-interparticle, intraparticle in dense coquinas, moldic in dolomite	Extensive dolomitization in southwest portion of study area	Wide ranging down ramp profile, most prolific in middle and deeper ramp	Dominant in middle sequence of Ocala; occurs in all three sequences

Table 2 (cont'd): Summary of Ocala Formation Sedimentary Facies

Facies	Dominant Allochems	Other Allochems	Structures	Porosity	Diagenesis	Paleo-Environmental Interpretation	Principal Occurrence
Nummulites/ Lepidocyclina Wackestone	Nummulites and Lepidocyclina	echinoderms, bivalves, bryozoans, pellets, rotalids	Bioturbation by burrowers-extensive at base of Ocala	Micro-interparticle, intercrystalline and moldic in dolomite	Extensive dolomitization in southwest portion of study area	Deeper ramp	Basal Ocala in southern 2/3 of study area
Nummulites Wackestone	Nummulites	Lepidocyclina, echinoderms, bivalves, rotalids, pellets	Bioturbation by burrowers-extensive at base of Ocala	Micro-interparticle, intercrystalline and moldic in dolomite	Extensive dolomitization in southwest portion of study area	Deeper ramp	Basal Ocala in southern 2/3 of study area
Lepidocyclina Wackestone	Lepidocyclina	Nummulites, echinoderms, bivalves, rotalids, pellets	Bioturbation by burrowers-extensive at base of Ocala	Micro-interparticle, intercrystalline and moldic in dolomite	Extensive dolomitization in southwest portion of study area	Deeper ramp	Basal Ocala in southern 2/3 of study area
Mixed Skeletal Wackestone	echinoderms, bivalves	bryozoans, nummulites, lepidocyclina, rotalids, pellets	Bioturbation by burrowers-extensive at base of Ocala	Micro-interparticle, intercrystalline and moldic in dolomite	Extensive dolomitization in southwest portion of study area	Deeper ramp	Limited, but occurs in all three sequences
Bioturbated Pelagic Wackestone	Pelagics	trace echinoderms and bivalves	Heavily bioturbated	Micro-interparticle,	Extensive dolomitization in southwest portion of study area	Deepest ramp environment within study area	Basal Ocala in extreme south of study area
Laminated Pelagic Wackestone	Pelagics	None	Finely laminated trace bioturbation	Micro-interparticle	Extensive dolomitization in southwest portion of study area	Deepest ramp environment within study area	Immediately on top of Avon Pk. Fm. in extreme south of study area

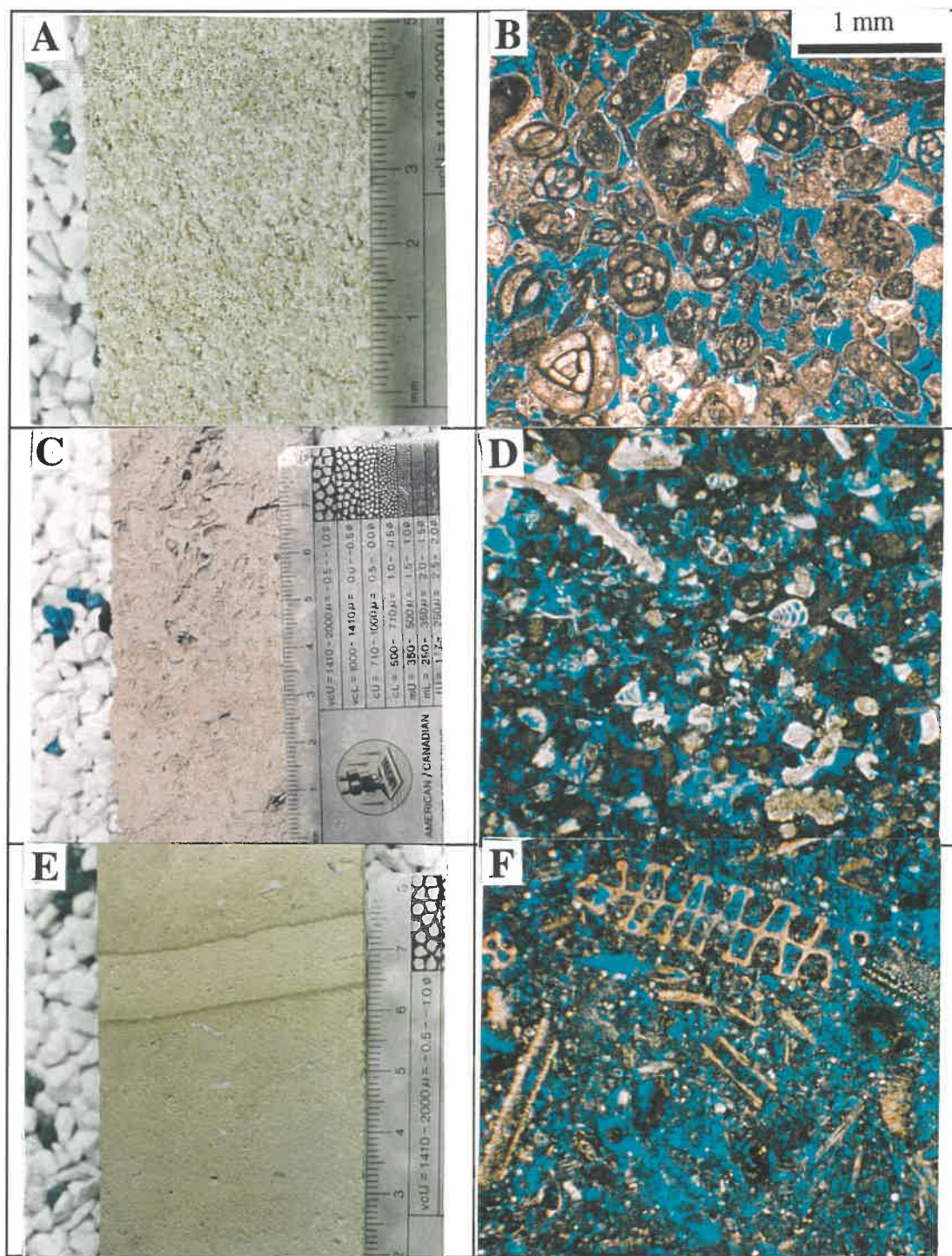


Figure 7: Photographs of the twelve facies identified in hand sample (left) and thin section (right). Scale in hand samples is centimeters with millimeter divisions and in thin section all photos are at 20X magnification with the millimeter bar in the upper right corner applying to all three photographs. **A&B:** Miliolid Grainstone from W-16304 @ 206' (left) and W-16181 @ 687.0' (right). **C&D:** Mixed Skeletal Grainstone from W-17056 @ 868.0' and W-16618 @ 624.3'. **E&F:** Mixed Skeletal Packstone from W-17056 @ 710.0' and W-16307 @ 179.5'. Note horizontal burrow bisecting core section.

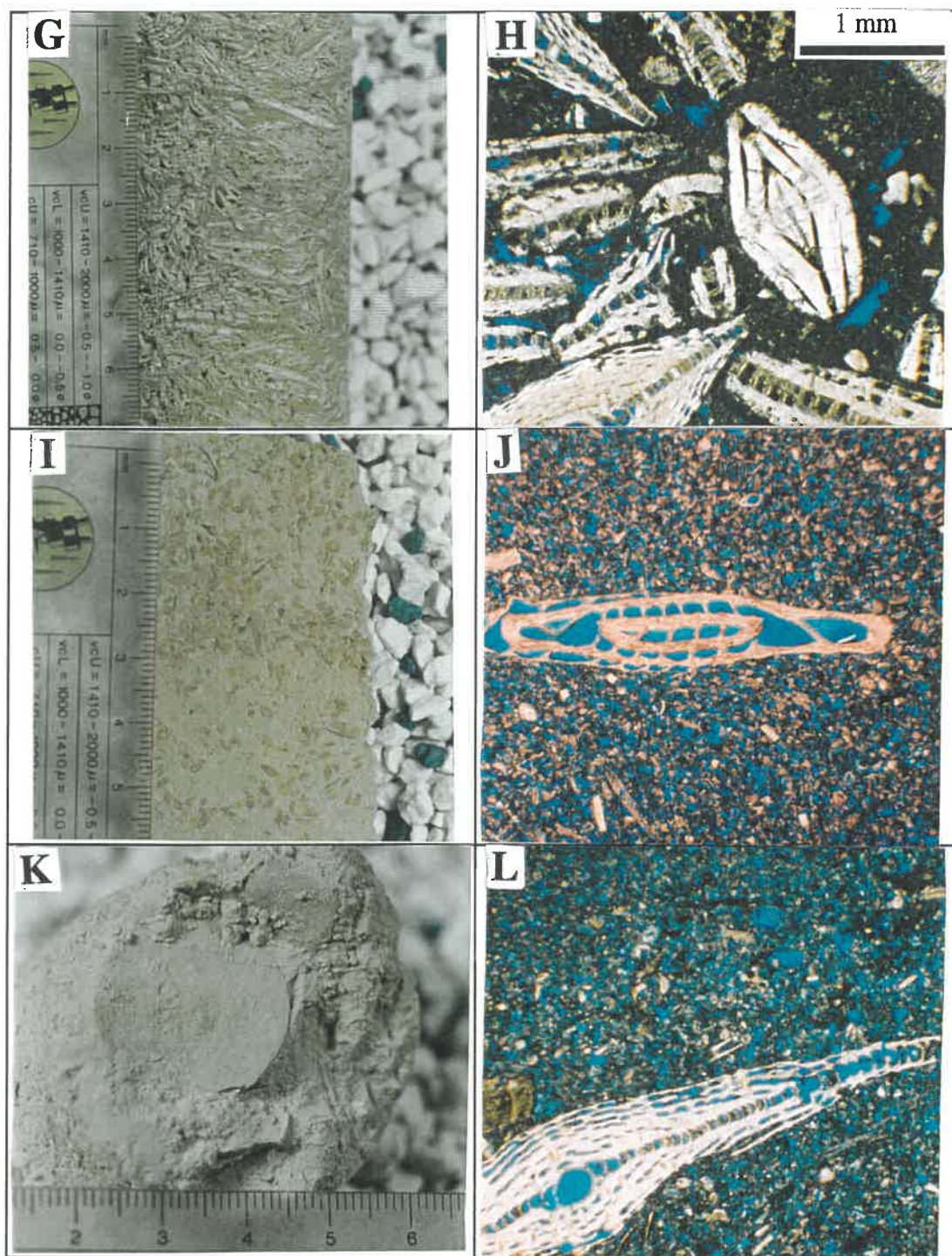


Figure 7 (cont'd): **G&H:** Nummulites/lepidocyclina Packstone from W-30026 @ 973.0' (left) and W-16307 @ 314.8' (right). Abundance and density of mud in thin section is unusually high for Ocala Formation packstones. **I&J:** Nummulites Packstone from W-16609 @ 361.5' and W-16181 @ 601.5'. **K&L:** Lepidocyclina Packstone from W-30026 @ 928.0' and W-16784 @ 805.0'. Hand sample photograph is end view of a broken section of core.

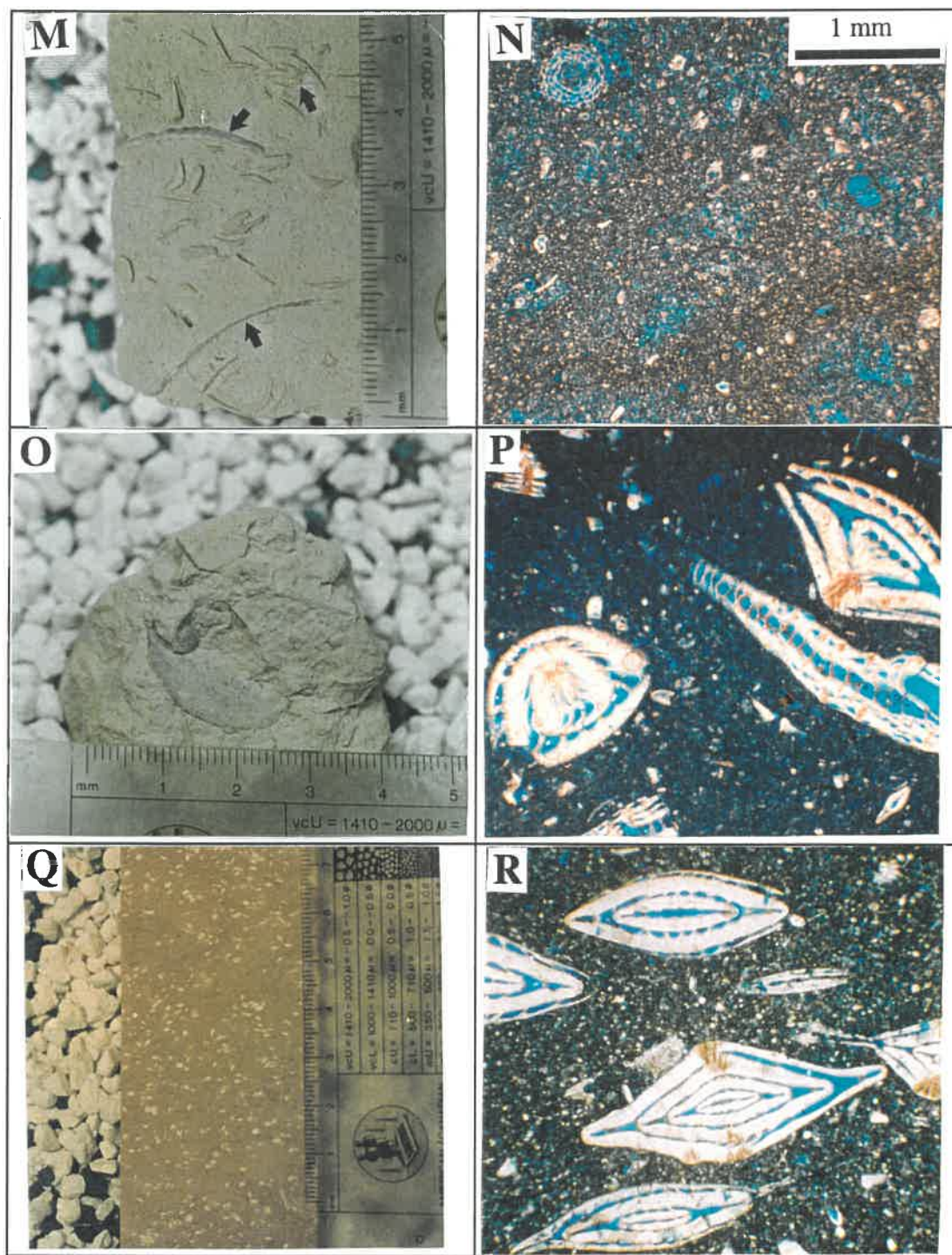


Figure 7 (cont'd): **M&N:** Mixed Skeletal Wackestone from W-16307 @ 240.0' (left) and W-17056 @ 964.9' (right). Note abundance of pelecypods (arrows) in core section. **O&P:** Nummulites/lepidocyclina Wackestone from W-17000 @ 807.0' and W-17001 @ 906.3'. Hand sample photograph is end view of a broken section of core. **Q&R:** Nummulites Wackestone from W-16783 @ 914.0' and W-16740 @ 912.0'. The fine matrix of the hand sample is partially dolomitized resulting in high contrast with the white nummulites tests.

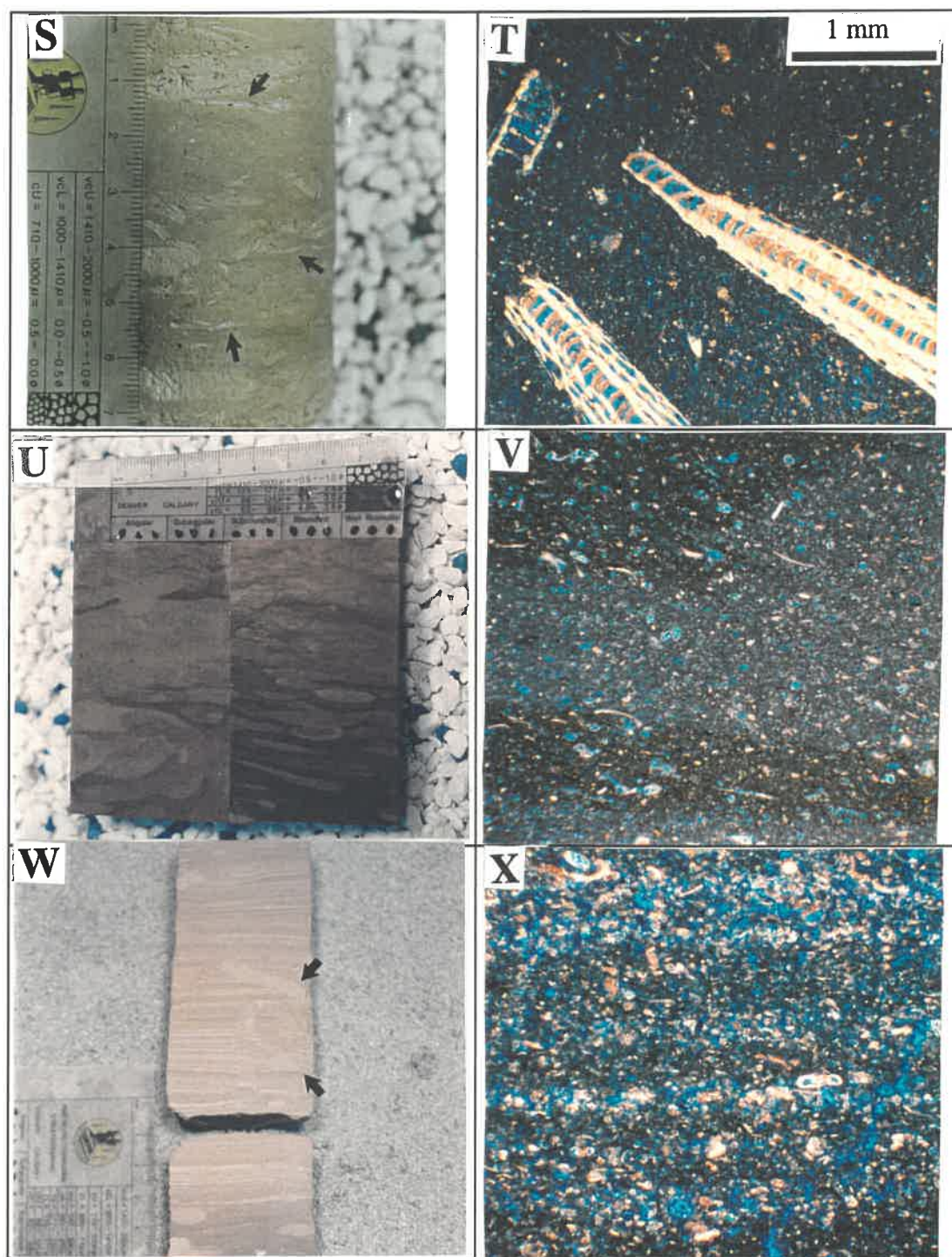


Figure 7 (cont'd): **S&T**: *Lepidocyclina* Wackestone from W-30026 @ 968.0' (left) and W-17001 @ 950.2' (right). Arrows show the location of lepidocyclina tests. **U&V**: Bioturbated Pelagic Wackestone from W-17056 @ approximately 1137' and W-17001 @ 1014.7'. **W&X**: Laminated Pelagic Wackestone from W-17001 @ 1016.5' and W-17001 @ 1016.1'. Note that hand sample contains a few burrows that cross-cut laminations.

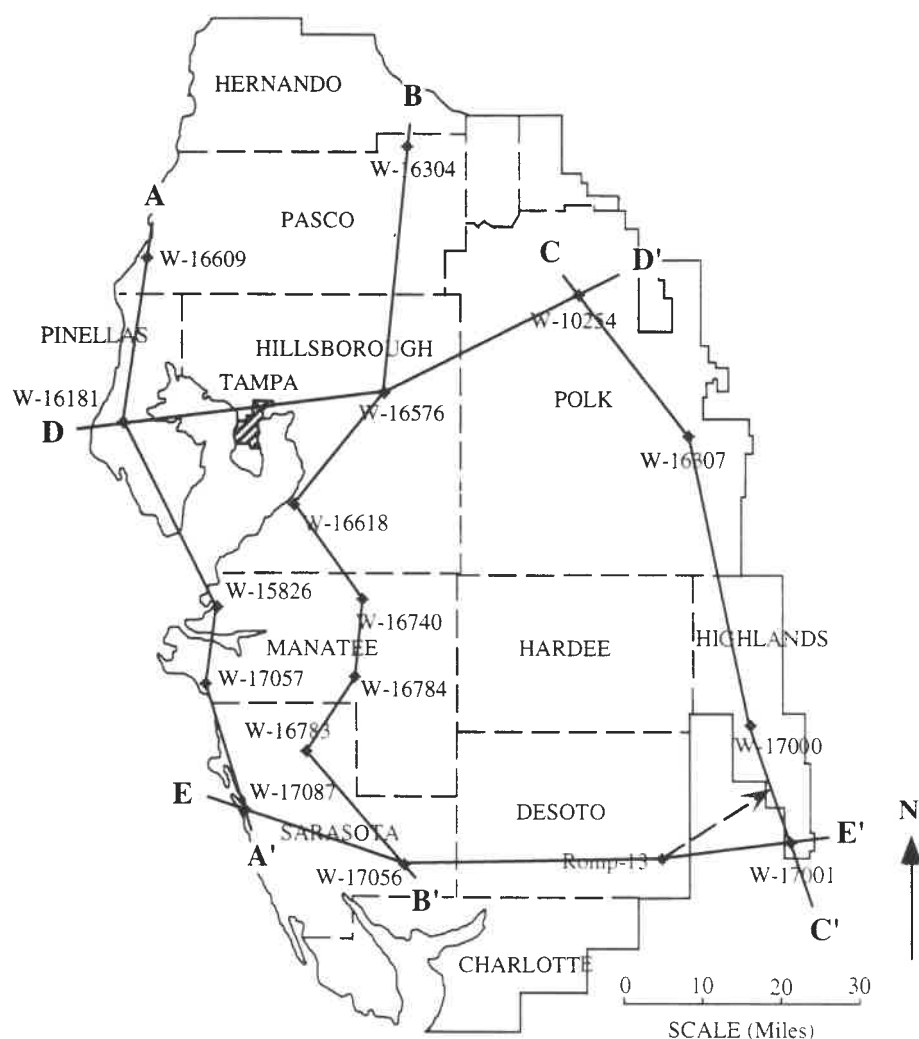


Figure 8: Cross section locations. The cross sections are shown in figures 10 through 14. Romp-13 appears on section E-E' and it is projected on section C-C' as well.

EXPLANATION TO CROSS SECTION FACIES:

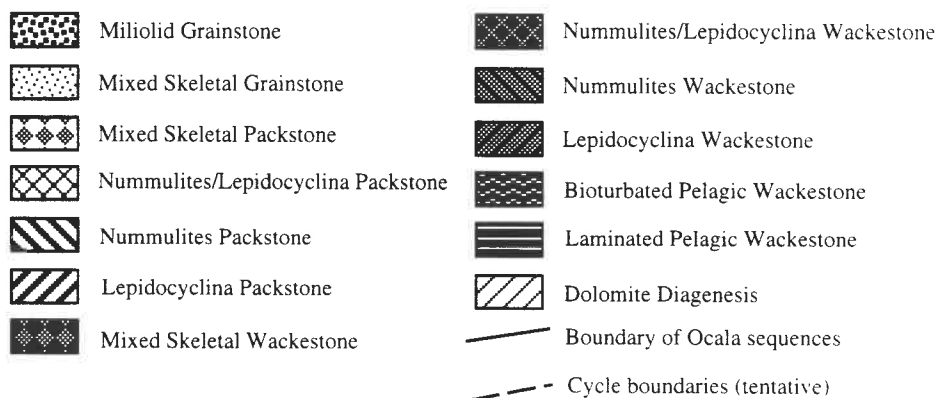


Figure 9: Key to sedimentary facies appearing on Figures 10 through 14 and Figures 39 through 43.

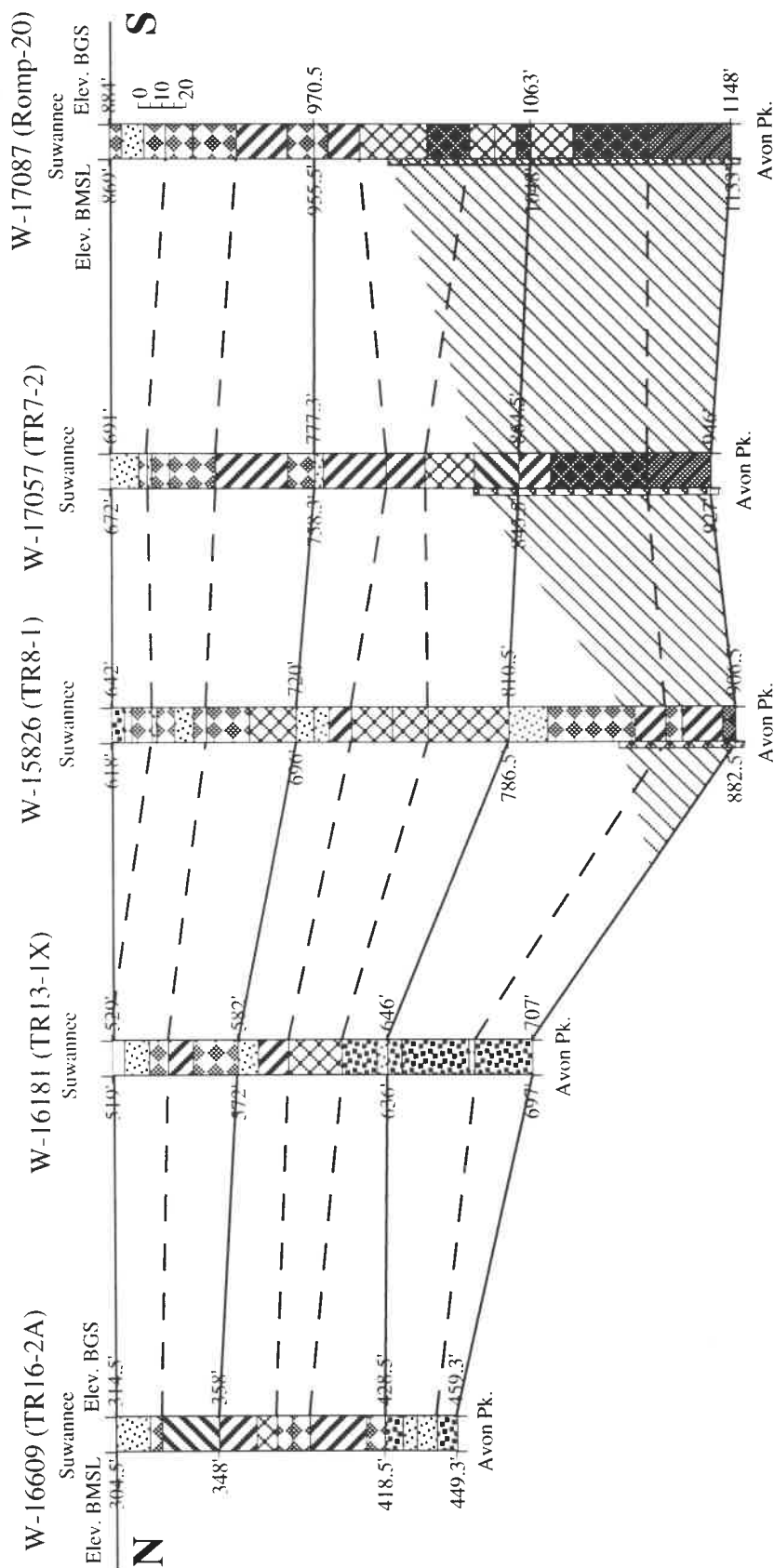


Figure 10: Cross section A-A' along the coast or western portion of the study area. Cycle boundaries within the sequences are tentative because they are subaqueous with rare subaerial exposure evidence. Cycle tops are primarily based on coarsening upward grain sizes. Sedimentary facies within dolomite sections are often distinguished by the moldic shapes of allochems. Note: corelogs are "hung" on a flat datum, the top of the Ocala Formation, but the Ocala dips gently to the south in this cross section.

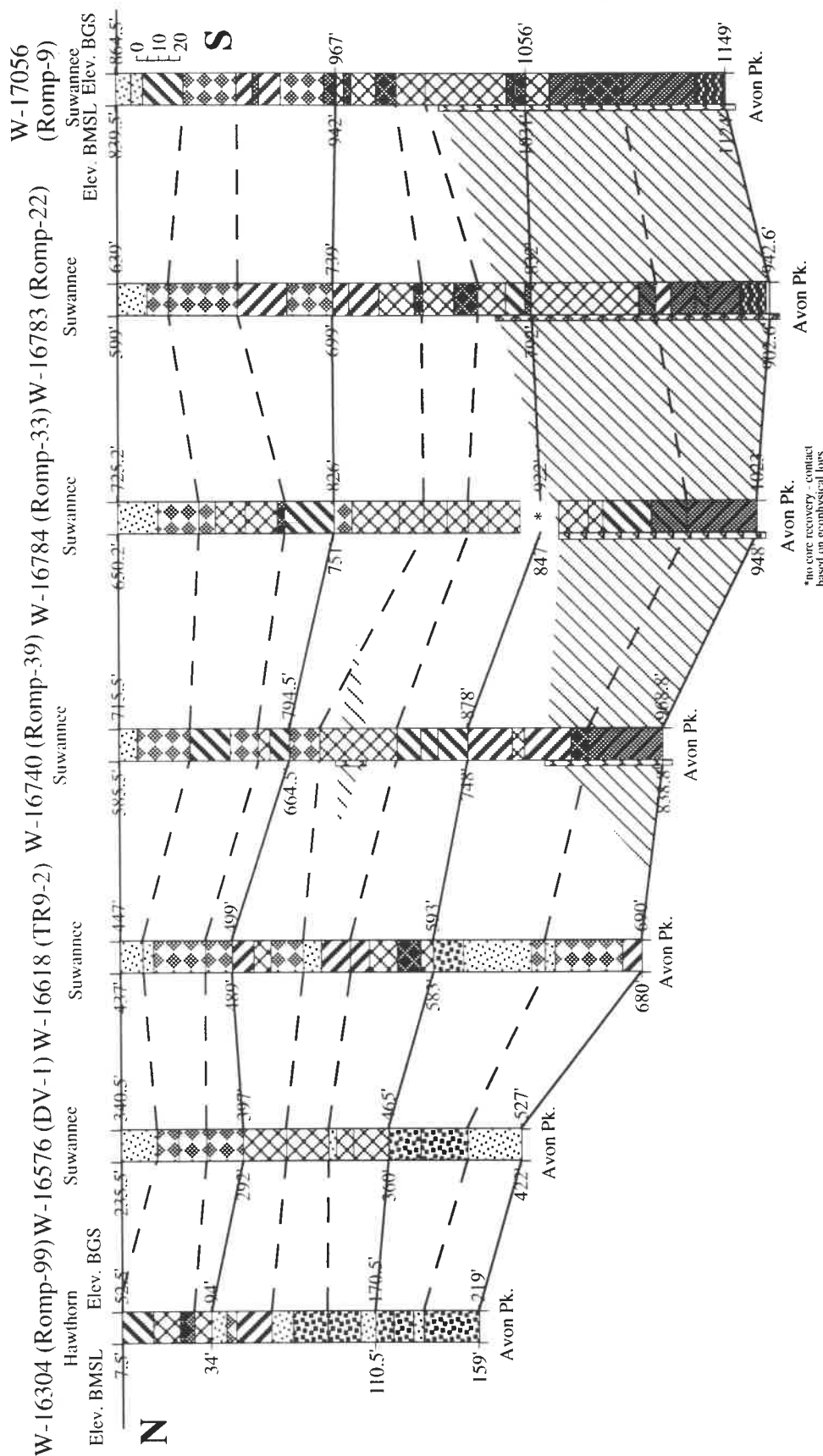


Figure 11: Cross section B-B' along the west-central portion of the study area. Cycle boundaries within the sequences are tentative because they are subaqueous with rare subaerial exposure evidence. Cycle tops are primarily based on coarsening upward grain sizes. Sedimentary facies within dolomite sections are often distinguished by the moldic shapes of allochems. Note: corelogs are "hung" on a flat datum, but the Ocala actually dips gently to the south and west.

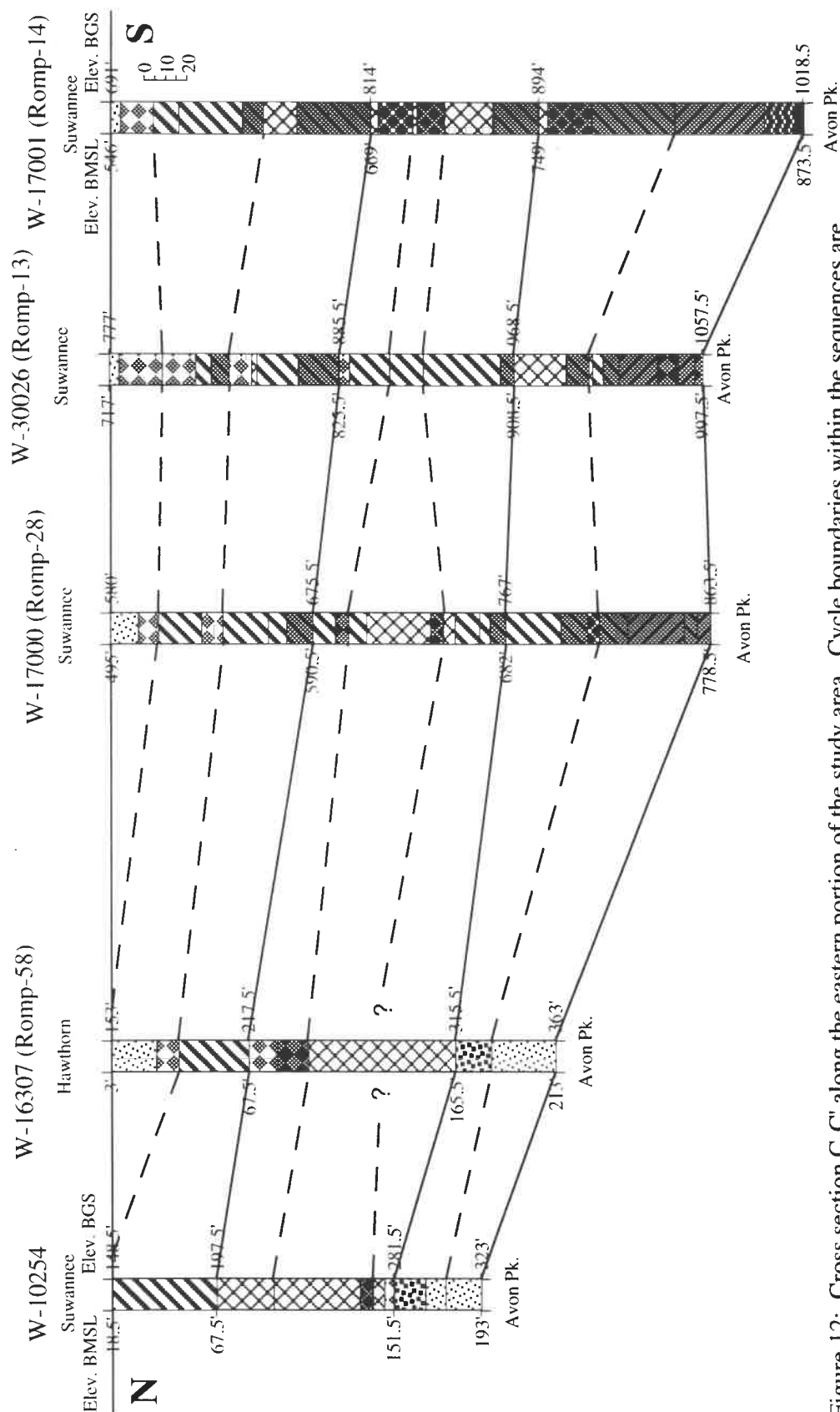


Figure 12: Cross section C-C' along the eastern portion of the study area. Cycle boundaries within the sequences are tentative because they are subaqueous with rare subaerial exposure evidence. Cycle tops are primarily based on coarsening upward grain sizes. Note: corelogs are "hung" on a flat datum, the top of the Ocala Formation, but the Ocala actually dips gently in a southward direction.

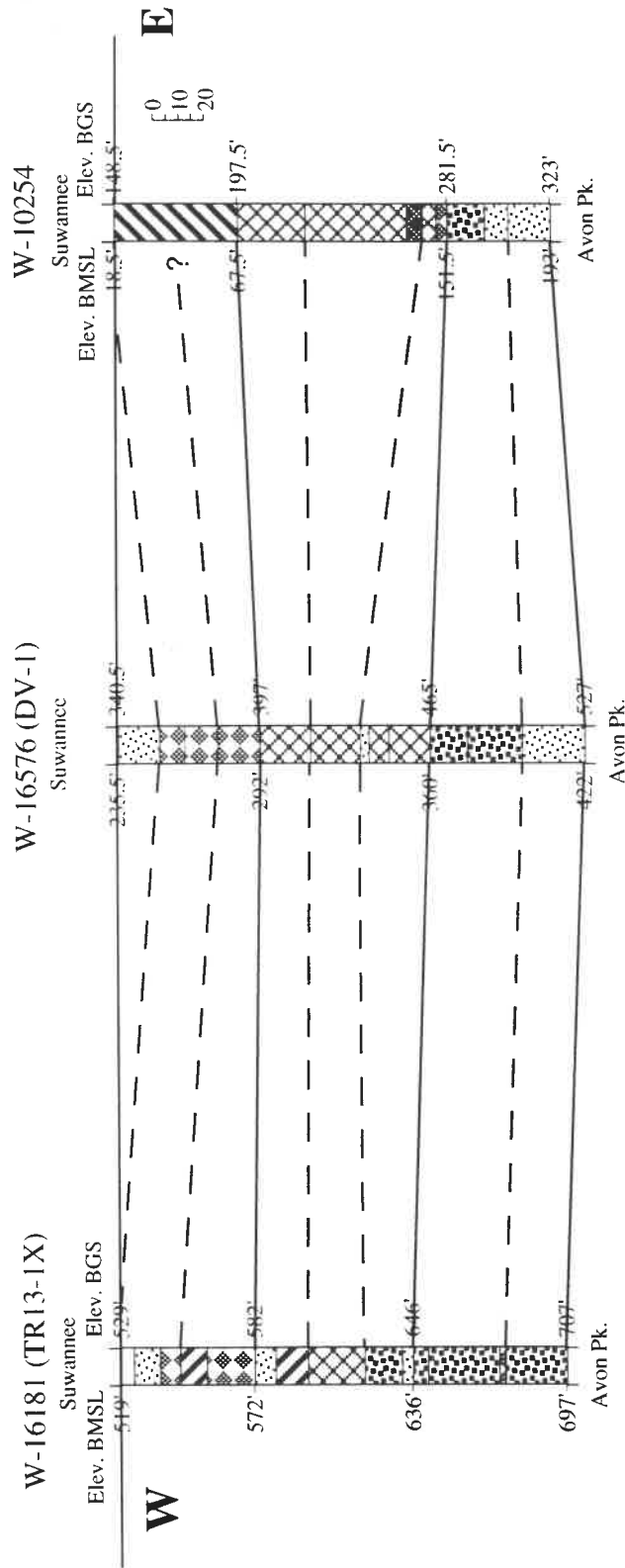


Figure 13: Cross section D-D' along the northern portion of the study area. Cycle boundaries within the sequences are tentative because they are subaqueous with rare subaerial exposure evidence. Cycle tops are primarily based on coarsening upward grain sizes. Note: corelogs are "hung" on a flat datum.

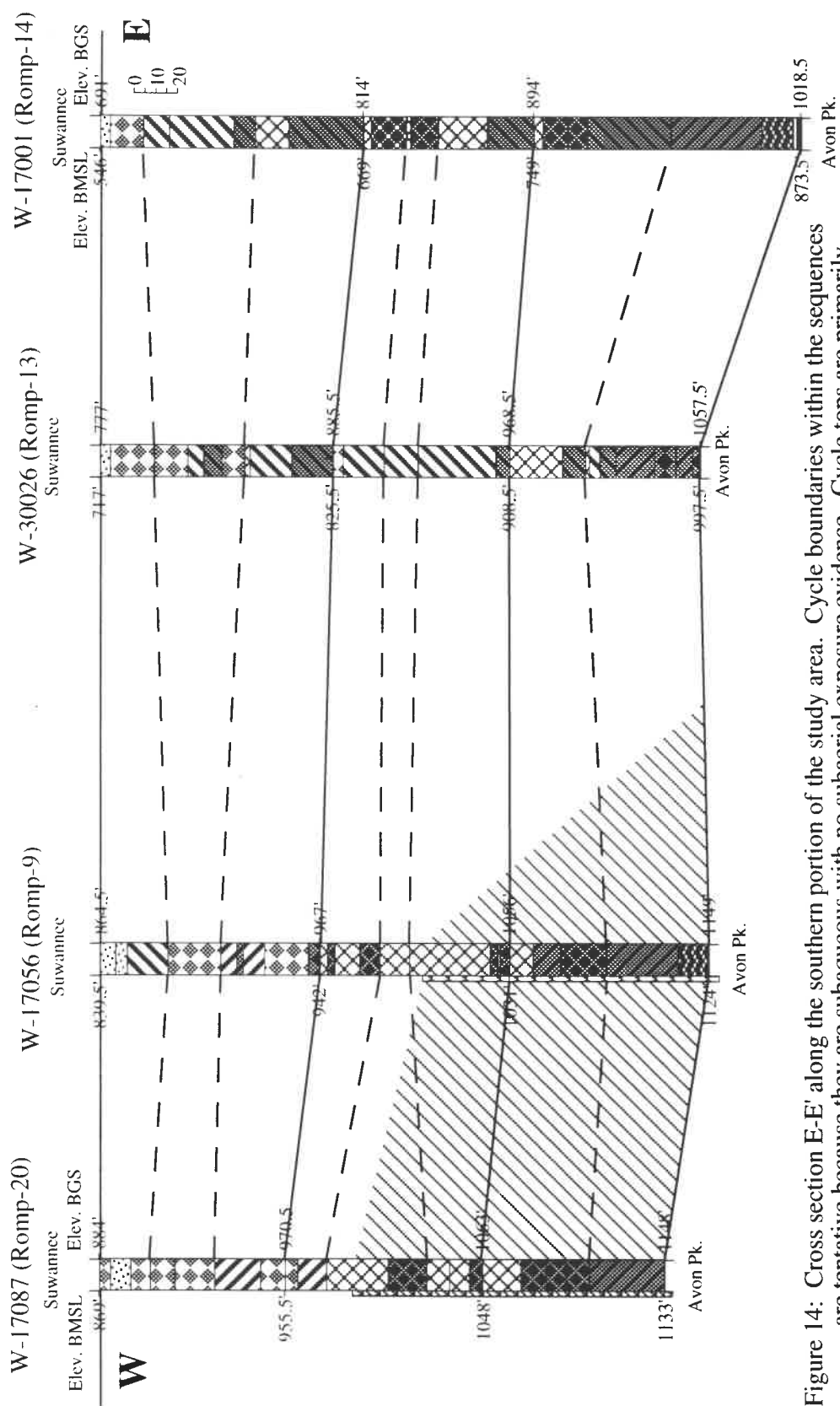


Figure 14: Cross section E-E' along the southern portion of the study area. Cycle boundaries within the sequences are tentative because they are subaqueous with no subaerial exposure evidence. Cycle tops are primarily based on coarsening upward grain sizes. Sedimentary facies within dolomite sections are often distinguished by the moldic shapes of allochems. Note: corelogs are "hung" on a flat datum, but the Ocala Formation actually dips gently to the west.

1. Upper and Lower Boundaries of the Ocala Formation

The upper and lower boundaries of the Ocala Formation are regional unconformities. Avon Park rocks, immediately below the Ocala Formation, are in most locations, heavily indurated suggesting a depositional hiatus and meteoric cementation. In wells W-16618, W-16784, W-17000, W-17057, and W-17087 there is evidence at the top of the Avon Park of shallow cave fill of Ocala sediments, open borings filled with Ocala sediments, and "rubble zone" contacts (Figure 15). The uppermost Avon Park is also typified by grainstones and packstones rich in the echinoid *Neolaginum dalli*. This may be interpreted as a time transgressive high-energy blanket sand deposit marking relative sea level regression across the West Florida ramp at the end of the Middle Eocene. Combined with an observed biostratigraphic hiatus on the Floridan Peninsula (Chen 1965), the evidence points towards a Type 1 sequence boundary on the West Florida ramp.

Other researchers in the Gulf of Mexico and around the world have recognized a similar boundary. On the most recent comprehensive global cycle chart, constructed primarily from sequence stratigraphic analysis, a Type 1 sequence boundary is shown between the Middle and Late Eocene (Haq et al. 1988). Isotopic data from Alabama ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$; Baum et al. 1994) and Atlantic margin benthic foraminifera ($\delta^{18}\text{O}$; Miller et al. 1987) show significant isotopic changes across this boundary, which represent major chronostratigraphic breaks, correlatable to a Type 1 sequence boundary (Miller et al. 1987). Finally, a combination of magnetostratigraphy and Sr-isotope data from the New Jersey coastal plain suggests a Middle/Late Eocene hiatus associated with a major drop in relative sea level (Miller et al. 1990).

Observed core sections of the upper contact with the Oligocene Suwannee Formation also suggest a significant sequence boundary. The strongest evidence for this rests in the post-Eocene erosion of the upper Ocala Formation in the northern regions of the study area (W-10254 and W-16304). In these wells the top of the Ocala

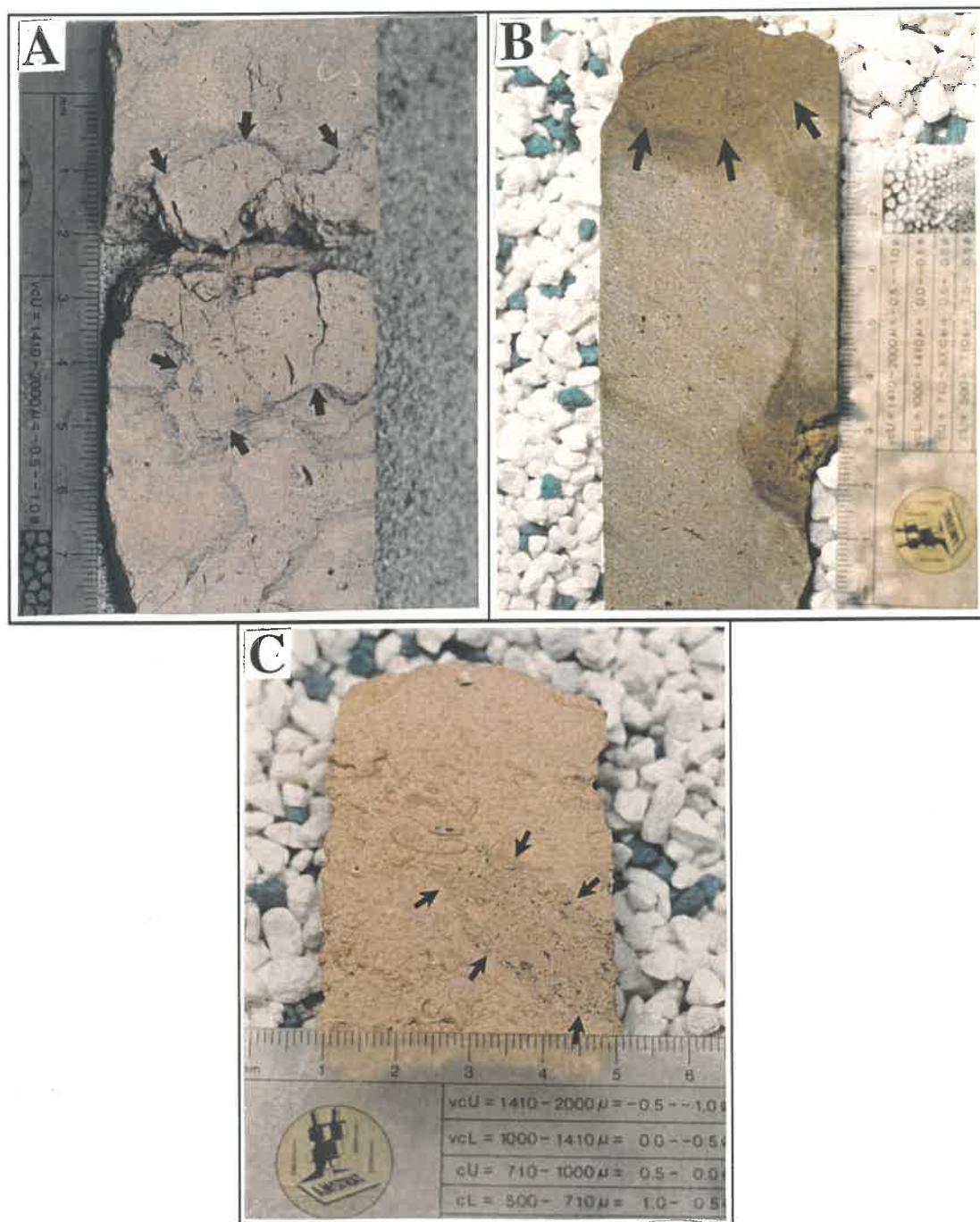


Figure 15: Photographs of the contact between the Avon Park Formation and the Ocala Formation. **A:** W-16618 @ 693.8' interpreted as a dissolution cavity in the Avon Park Formation with Ocala sediments infilling. Arrows denote boundary of the cavity. **B:** W-17057 @ 946.0'. Both formations are dolomitized, but the heavily altered Avon Park Formation has low K and water sprayed on it evaporates leaving a dry (light) core face. In contrast, the less heavily altered Ocala sediments are more permeable, absorb water, and maintain a damp (dark) core face. There also appears to be an infilled cavity in the Avon Park Formation, below the contact, which is denoted by arrows. **C:** W-17000 @ 866.5'. The weakly indurated Avon Park Formation contains a burrow (arrows mark boundary) infilled with Ocala Formation sediments and biota (actual contact @ 863.5').

section is comprised of macro-foraminiferal packstones that are considered typical of deeper water ramp environments, and they are directly overlain by sediments younger than Eocene. Further to the south, to the south and east of the present Tampa embayment, five wells (W-15826, W-16576, W-16618, W-16740 and W-16784) display erosive contacts with large lithoclasts of Ocala rock in the overlying Suwannee facies (Figure 16). While suggesting depositional hiatuses and erosion, they do not contain any obvious evidence of subaerial exposure. Even further south, the top of the Ocala section is characterized by mixed skeletal packstones or grainstones, most likely representing either a capping cycle or forced regression (see Hunt and Tucker 1992), but with no significant depositional hiatus or erosive evidence. The tops of these sections are most often indurated and may record small depositional hiatuses as marine hardgrounds (Figure 16). The regional variations in the Suwannee/Ocala contact taken jointly appear to be a north to south record of relative sea level fall down (but not off!) the West Florida ramp at the end of the Eocene. This would be a Type 2 sequence boundary in sequence stratigraphy nomenclature (Van Wagoner et al. 1988).

The nature of the Eocene/Oligocene boundary in the Gulf of Mexico and worldwide is contested in the literature. A global cycle chart (Haq et al. 1988) shows a Type 1 boundary, indicating rapid sea level regression off shelf margins. Within the Gulf of Mexico other researchers have also identified Type 1 boundaries (Dockery 1992; Combes 1993). The well documented presence of extensive lowstand deposits and a basinward shift in facies in the basal Vicksburg Formation of Texas indicates a Type 1 boundary (Combes 1993) coincident with the extensive Oligocene appearance of polar ice sheets (Miller et al. 1987). Other Gulf of Mexico researchers place the Eocene/Oligocene boundary in a condensed section in the middle of global cycle TA4.3 (considered Upper Eocene) (Mancini and Tew 1991; Baum et al. 1994). Both boundaries of the TA4.3 cycle (nomenclature from Haq 1988) are interpreted as Type 2 by these authors, so for Alabama, if one is to presume the Eocene/Oligocene boundary

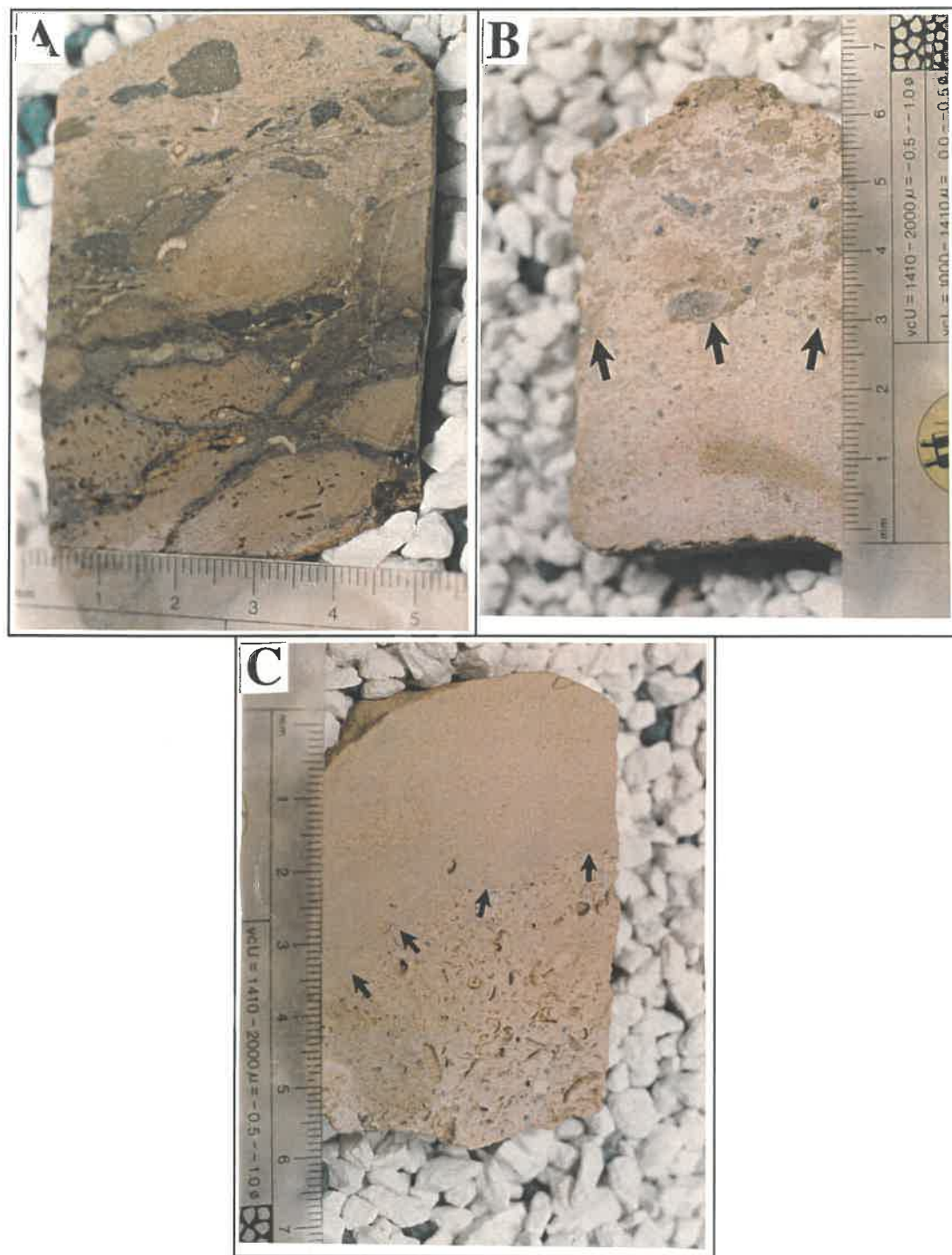


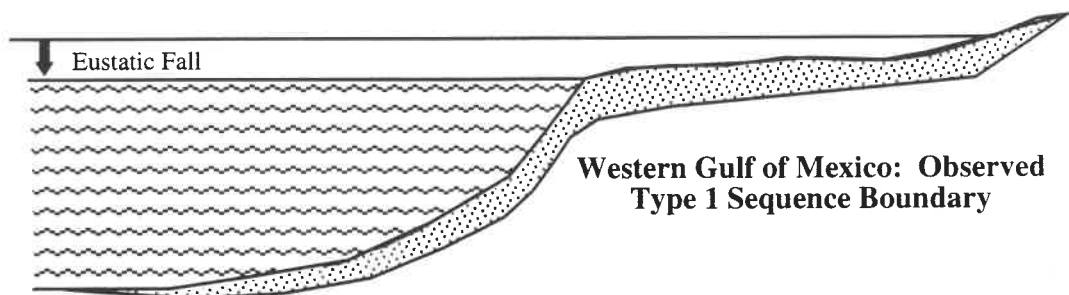
Figure 16: Photographs of the contact between the Suwannee Formation and the Ocala Formation. **A:** Large lithoclasts of well indurated Ocala Formation rock found in the overlying Suwannee Formation in W-16740 @ 715.3'. The actual contact is just below this core piece at 715.5'. **B:** Smaller lithoclasts of Ocala Fm. rock found in the overlying Suwannee Formation in W-16784 @ 725.2'. Formation contact is denoted by arrows. **C:** The same contact in W-17000 @ 580'. This "cleaner" contact (arrows) of indurated Ocala sediments underlying the non-indurated Suwannee sediments is more typical of the downdip wells.

to be a sequence boundary (and not a condensed section) it would have to be a Type 2 boundary. Finally, on the Florida Peninsula the boundary is equally as ambiguous being reported as a subaerial unconformity in local areas (Randazzo 1982) and as a continuous record of deposition in others (Bryan 1993).

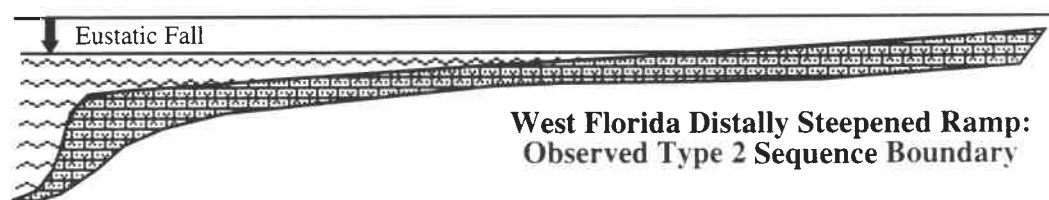
Further complicating the situation in west Florida is the fact that the depositional geometry of the area during the Eocene/Early Oligocene was a distally steepened homoclinal ramp (Gardulski et al. 1991), therefore, by definition, lacking a proximal shelf edge against which to gauge relative sea level movement (Combes 1995, pers. comm.). It is unlikely that a moderate sea level fall at the end of the Eocene that produced a Type 1 sequence boundary in the western Gulf of Mexico would leave an equally significant imprint on the west Florida Ramp. Locally, within the study area, the onlapping and lapping-out nature of the Suwannee Formation onto the Ocala Formation (Hammes 1992) suggests that the Ocala Uplift was a late Eocene structural event that may have been a significant contributor to sequence boundary formation. The westward tilting of the Eocene sedimentary package produced the extensive topographic erosion observed in updip wells and preserved the subaqueous nature of the package downdip (Figure 17). Despite a sharp sea level fall, subsidence of the sediments immediately to the west of the Ocala Uplift would "outpace" the eustatic fall and leave an apparent Type 2 sequence boundary.

In summary, while Type 1 sequence boundaries have been documented worldwide and in the western Gulf of Mexico (Haq et al. 1988; Combes 1993) for the Eocene/Oligocene boundary, the combined geometry of a homoclinal ramp and structural tilting left the signature of a Type 2 sequence boundary atop the Ocala ramp in west-central Florida Peninsula.

A



B



C

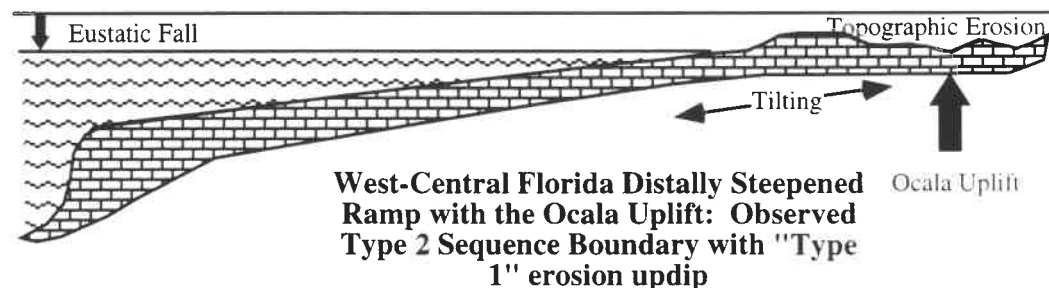


Figure 17: Schematic portraying different observed sequence boundary types in the Gulf of Mexico at the Eocene/Oligocene boundary. **A:** A standard type 1 boundary observed in Texas where a proximal shelf edge is present (Combes, 1993). **B:** The same eustatic event on a distally steepened homoclinal ramp (Gardulski, 1991). This would approximate the observations of Mancini and Tew, 1991 and Baum et al., 1994 in Alabama. **C:** The proposed scenario for west-central Florida. There is a structural overprint that produces "Type 1" erosion updip, but the relative eustatic fall is outpaced by ramp tilting, resulting in a Type 2 sequence boundary down dip.

2. Internal Sequences within the Ocala Formation

Three large subdivisions were identified within the Ocala Formation (Figures 10-14). The subdivisions of the Ocala Formation were recognizable in the cores and were confirmed by abrupt facies transitions in petrographic thin section. These three sequences have been recognized by prior researchers working on the Floridan Peninsula (Vernon 1951; Puri 1953) and have been named in ascending order the Inglis, Williston, and Crystal River Formations. Croft (1980) found Ocala Formation echinoids to be stratigraphically divided into three distinct communities with varying substrate preferences. Other researchers (Applin and Applin 1944; Miller 1986) recognized only two subdivisions, and Miller (1986) considers them unrecognizable lithologically and undifferentiable in the subsurface. It was found here, within the study area, that the subdivisions of the Ocala Formation can not only be recognized, but mapped and correlated to other sequences in the Gulf of Mexico. These findings may warrant a renewed debate on the Ocala's Formation/Group status.

The recognized internal subdivisions of the Ocala Formation are marked by transgressive surfaces with no subaerial exposures. The boundaries become less distinct as one moves down dip, or down the ramp, but are still discernible. Each boundary is marked by an abrupt decrease in mean grain size and changes in facies and limestone textures. Each boundary is interpreted as representing a major marine-flooding surface with younger, deeper water sediments (finer) overlying older shallower water sediments (coarser). Additional evidence pointing toward major marine flooding surfaces and depositional hiatuses includes minor induration down to 24 inches below a boundary indicating possible submarine hardgrounds (e.g. W-17056, W-30026, W-16307, and W-15826; Figure 18), blackened nummulites tests indicating prolonged exposure on the sea floor (e.g. W-16740 and -17000), and intraclasts of the lower sequence found in the upper sequence (e.g. W-16784, W-17057, W-16618, and W-17087).



Figure 18: Photograph of an internal sequence boundary and associated lithologies within the Ocala Formation. The boundary here is between sequences #1 and #2 in W-16307 @ 315.5'. The boundary is placed at the blackened surface (which may be 1 of 2 examples of subaerial exposure found in the Ocala sections logged). More typical of these boundaries are narrow bands of induration in the lower sequence (large arrows) and nearby black stained foraminifera (small arrows). Also common (but not shown here) are numerous gastropods or gastropod molds at the tops of the lower sequences. Gastropods are not common in the Ocala Formation, so their frequent occurrence at sequence boundaries may be indicative of a favorable grazing substrate, marked by firmness and produced by low-sedimentation rates.

The three sequences are delineated in cross sections (Figures 10-14) and their thickness distributions are portrayed on isopach maps of each sequence in Figure 19. The general thickening trend towards the south is typical of upper ramp slope deposits (Read 1985). As the study area is restricted to west-central Florida there is no observed evidence of decreasing sequence thickness due to reduced sedimentation rates as one moves into the deeper ramp setting. However, in the extreme distal portions of the ramp the entire Eocene section is represented in 3-4 meters of sediments (Gardulski et al. 1991).

As the entire late Eocene spans from 3 million years (Figure 3) to 4.5 million years (Figure 20), the presence of three internal sequences would suggest that their deposition took on the order of 1 to 1.5 million years per sequence, or 3rd order in magnitude (Vail et al. 1991). Three 3rd order sequences have been recognized elsewhere during the Late Eocene (Haq et al. 1988) and it is likely that the three sequences of the Ocala Formation can be correlated to them. To the west, three distinct sedimentary packages bound by sequence boundaries have been found in Alabama (Baum et al. 1994) and three dated sequences have been recognized in Texas (Mitchum 1995, pers. comm.). Dates for the Texas sequence boundaries starting with the Middle/Late Eocene boundary are 40.5, 38, 37.5, and 36 m.y. (Figure 20). Dates have also been identified for condensed sections within sequences 1 and 3 (Figure 20). The 36 m.y. date for the Eocene/Oligocene boundary agrees with the work of Hammes (1992, her Figure 1) working in the Oligocene Suwannee Formation on the Floridan Peninsula. Using these dates, the deposition of the Ocala Formation can be framed. A discrepancy arises where researchers have placed the Eocene/Oligocene boundary at the uppermost condensed section at 37 m.y. (Mancini and Tew 1991; Baum et al. 1994). Based on the lithological and paleontological continuity of the Ocala sediments throughout sequence #3, it is believed that the true position of the boundary is at the

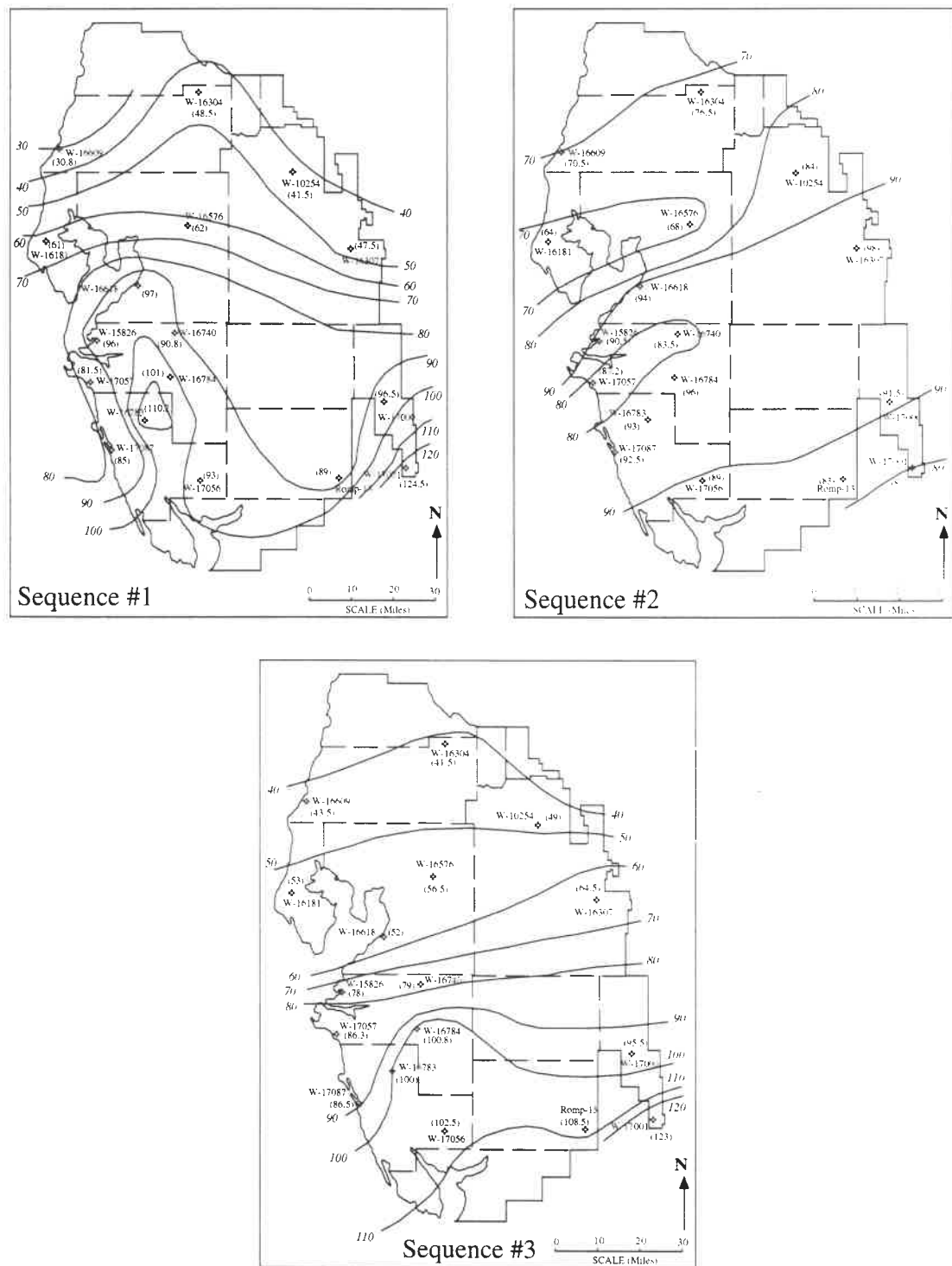
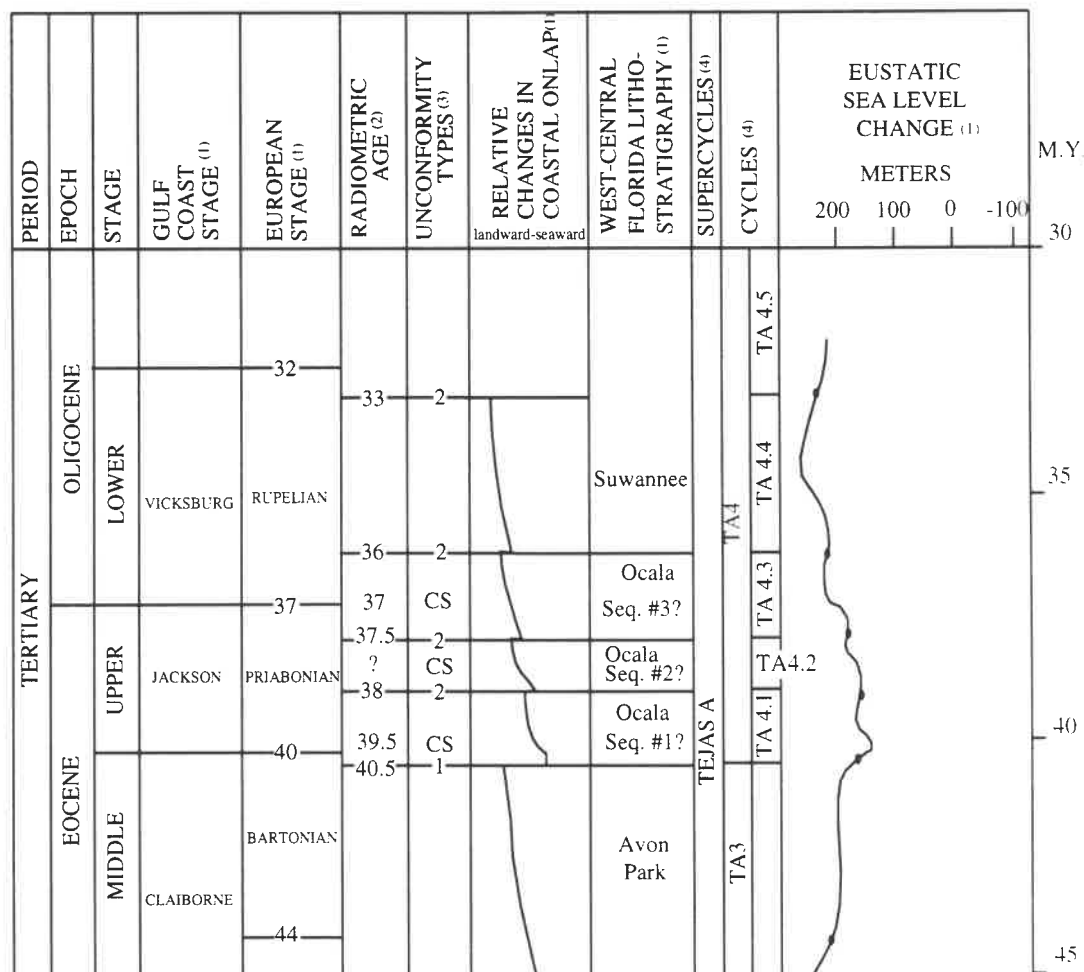


Figure 19: Isopach maps of the thicknesses of each of the three 3rd order sequences recognized within the Ocala Formation. These three sequences correspond to global cycles TA4.1, TA4.2, and TA4.3 of Haq et al. (1988) (see text). Note that the geometry of these units suggests downdip thickening wedges typical of some ramp deposits.



(1) Information taken directly from Baum et al., 1994

(2) Radiometric dates from Mitchum (pers. comm., 1995) and Hammes (1992)

(3) 1= Type 1 sequence boundary (Baum and Vail, 1988)

2= Type 2 sequence boundary (Baum and Vail, 1988)

CS= Condensed section (Baum and Vail, 1988)

(4) From Mesozoic-Cenozoic Cycle Chart (Haq et al., 1988)

Figure 20: Coastal onlap chart and eustatic sea-level curve (modified from Baum et al., 1994). The lithostratigraphy of west-central Florida has been added. If the three sequences observed within the Ocala (this study) correlate to the coastal onlap chart of the western Gulf of Mexico, then the sequence boundary dates can be used to frame the deposition of the Ocala.

uppermost sequence boundary at 36 m.y., in agreement with Combes (1993) and Hammes (1992).

B. Cycle Recognition, Facies Patterns, and Ramp Models

1. Cycle Recognition

Within each of the three sequences of the Ocala Formation there are tentatively identified higher order (4th or 5th) cycles. Cycles have been identified on cross-sections A-A' through E-E' based primarily on grain sizes (Figures 10-14). Across the region there appear to be 2 cycles within sequence #1 and 3 cycles in sequence #2 and #3, but it needs to be reiterated that these are tentative. Wells with good 4th or 5th order cyclic signatures were taken and extended into correlations with adjacent wells where the signatures were weaker.

The resolution of complex Ocala Formation cyclicity within the study area is hampered by the subaqueous origin of all the facies found within the area. Without abundant, correlatable exposure surfaces, or shallowing to peritidal facies, correlation must rely on facies stacking patterns, grain size distributions, and subtle marine flooding surfaces (Osleger 1991; Osleger and Read 1991). Such a detailed and exhaustive analysis of Ocala cyclicity was beyond the scope of this investigation. It is entirely feasible to make such correlations, however, as other researchers have succeeded in analogous paleo-ramp deposits (Markello and Read 1982; Calvet and Tucker 1988; Elrick and Read 1989; Elrick and Read 1991; Osleger and Read 1991; Hammes 1992). Combined with the complex cyclicity defined by Hammes (1992) in the Suwannee Formation, the resolution of the Ocala's cyclicity with good confidence could facilitate the extension of accommodation plots into the Late Eocene and perhaps shed light on the enigmatic eustatic driving mechanisms of the Eocene.

2. Facies Patterns

Distinct facies patterns are recognizable on the regional cross-sections (Figures 10-14). A cursory review indicates that the grainstone facies are restricted primarily to the updip (northern) sections of the ramp and the wackestone facies are primarily restricted to the downdip (southern) sections. The various packstone facies fill the areas in-between. This would agree with the broad environmental zonations found in generic ramp models (Ahr 1973; Read 1985).

In each of the three sequences identified in the Ocala Formation there appeared to be lateral variations in facies belt geometries. To facilitate facies mapping within each of the three sequences, total footages of each facies in each well and in each sequence were tallied. The total footage of each facies was then divided into the total thickness of the sedimentary package. For example, in well A, if sequence #1 was 60 feet thick and there were 25 feet of mixed skeletal grainstones, then the mixed skeletal grainstones made up 42% of that section. Facies were also lumped together to make the maps more legible. For example, the nummulites/lepidocyclina, nummulites, and lepidocyclina packstones were combined in one packstone facies called foraminiferal packstones. All wackestones were also combined as one facies. While it is obvious from the cross sections (Figures 10-14) that these facies interfinger in a complex architecture across the study area, lumping them into percentages of the total section eases the interpretation of their depocenters over the entire sequence's deposition.

a. Sequence #1

Facies distribution maps for sequence #1 are shown in Figure 21 and a summary map is shown in Figure 22 that highlights the main depocenter of each facies group. Miliolid grainstones are dominant in the northwest regions of the study area. The highest concentration of this facies occurs as a belt between wells W-16181 and W-16304. These high energy facies most likely formed broad shoals or sand sheets on

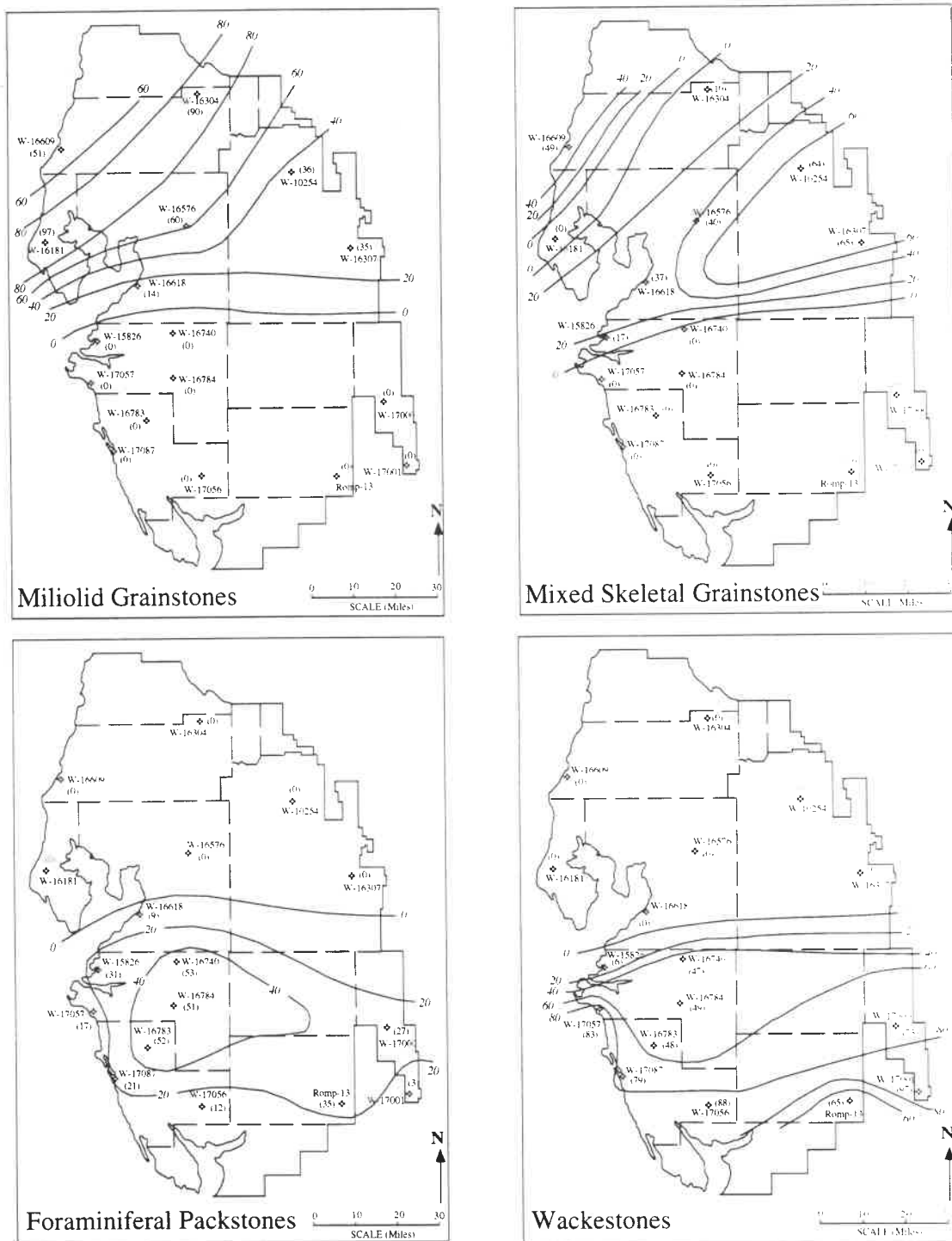


Figure 21: Isopach maps of sedimentary facies found in sequence #1. Contour intervals are in 20% increments of the total thickness of the sedimentary package. A fifth facies, mixed skeletal packstones, is limited in extent and is shown combined with the mixed skeletal grainstone facies in the composite facies map (Figure 22). The mixed skeletal packstone isopach map is presented alone in Appendix E. Note: certain facies have been combined.

the inner ramp, but with no evidence of subaerial exposure (see Table 2 and Appendix B). Framing this facies to the northwest and southeast are the mixed skeletal grainstones and packstones (combined) which most likely reflect laterally extensive sheet sand deposits adjacent to the miliolid sands in the high-energy inner ramp environment. Roughly half the study area (the northern half) was typified by these higher energy deposits and was probably subjected to wave sweeping in normal weather conditions. The grainstone nature of the basal Ocala Formation continues to the north of the study area into northern Florida as observed by prior researchers (Applin and Applin 1944; Puri 1957; Chen 1965; Miller 1986). While most subaqueous carbonate grainstones are commonly interpreted as shoal deposits, the laterally continuous nature of the grainstones observed in the Ocala Formation suggest sheet like deposits and not shoal deposits. Comparable thick, areally extensive carbonate sheet sands have been documented on the northern Great Barrier Reef (e.g., Orme and Riding 1995).

Moving down the ramp, the foraminiferal packstones dominated the region that crosses the middle portion of the study area. The packstone texture and occasional dense coquinas may reflect only occasional disturbances by storm swells. Wackestone facies are most common in the south, on the far reaches of the ramp, where they most likely went undisturbed by wave-impact on the sea floor. In each of the southern wells bioturbation is extensive at the base of the section and a sharp break marks a shift to less common bioturbation (e.g. W-30026). The zone of bioturbation may represent the transgressive systems tract (TST) and the upper zone the highstand systems tract (HST). The abundance of bioturbators would indicate a well oxygenated, low-energy environment with low sedimentation rates during the TST (Pedley 1992). During the early HST sediment accumulation would be in a "catch up" phase and during the late HST a "keep up" phase (Sarg 1988). During the late HST relative water depth would decrease with rapid sediment accumulation subjecting more of the ramp to periodic

wave sweeping. Both rapid sedimentation and periodic high energy disturbances would preclude abundant bioturbaters (Pedley 1992), as observed in most Ocala sections.

b. Sequence #2

Various facies abundances for sequence #2 are shown in Figure 23. The four maps show grainstones facies, foraminiferal packstones, mixed skeletal packstones, and wackestones. The miliolid and mixed skeletal grainstone facies were combined due to their limited extent and apparent lack of geographic zonation between them. As their map indicates, they were primarily restricted to the northwest in a belt comparable to the miliolid grainstones in sequence #1, but less abundant as a percentage of the sequence. The foraminiferal packstones were dominant across the study area during the deposition of this sequence. They represented greater than 60% of the sequence to the northwest and southeast of the grainstones all the way south into Highlands, Charlotte, and Sarasota Counties. The mixed skeletal packstones were limited in extent, displaying one small depocenter (>20%) to the northwest of the grainstone belt. The wackestones depocenter is concentrated in the southeast where they are most abundant (63%) in W-17001.

A composite map of facies depocenters during sequence #2 is shown in Figure 24. There are significant differences between this sequence and sequence #1 (Figure 22). The amount of the ramp covered in higher-energy grainstones is dramatically reduced, as evidenced by the lack of grainstones in Polk County in sequence #2. The higher energy inner ramp facies are now restricted to a belt between wells W-16181 and W-16304 where they are interpreted as representing shoal or sand sheet deposits. A second difference between sequences #1 and #2 is the dominance of the foraminiferal packstones throughout the study area in sequence #2. This widespread dominance suggests two things: (1) the nummulites and lepidocyclina had competitively evolved

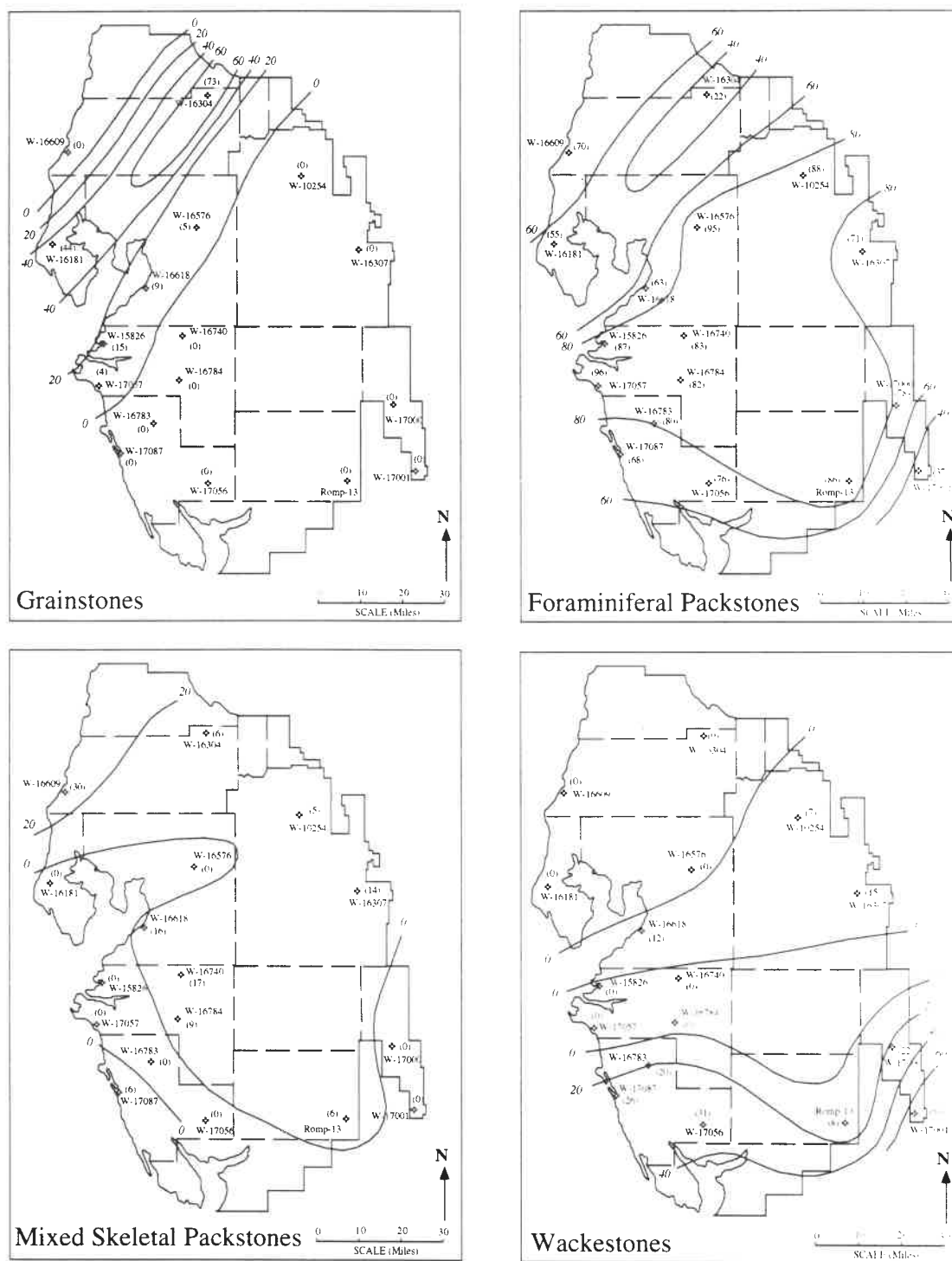


Figure 23: Isopach maps of sedimentary facies found in sequence #2. Contour intervals are in 20% increments of the total thickness of the sedimentary package. Note that a number of facies have been combined.

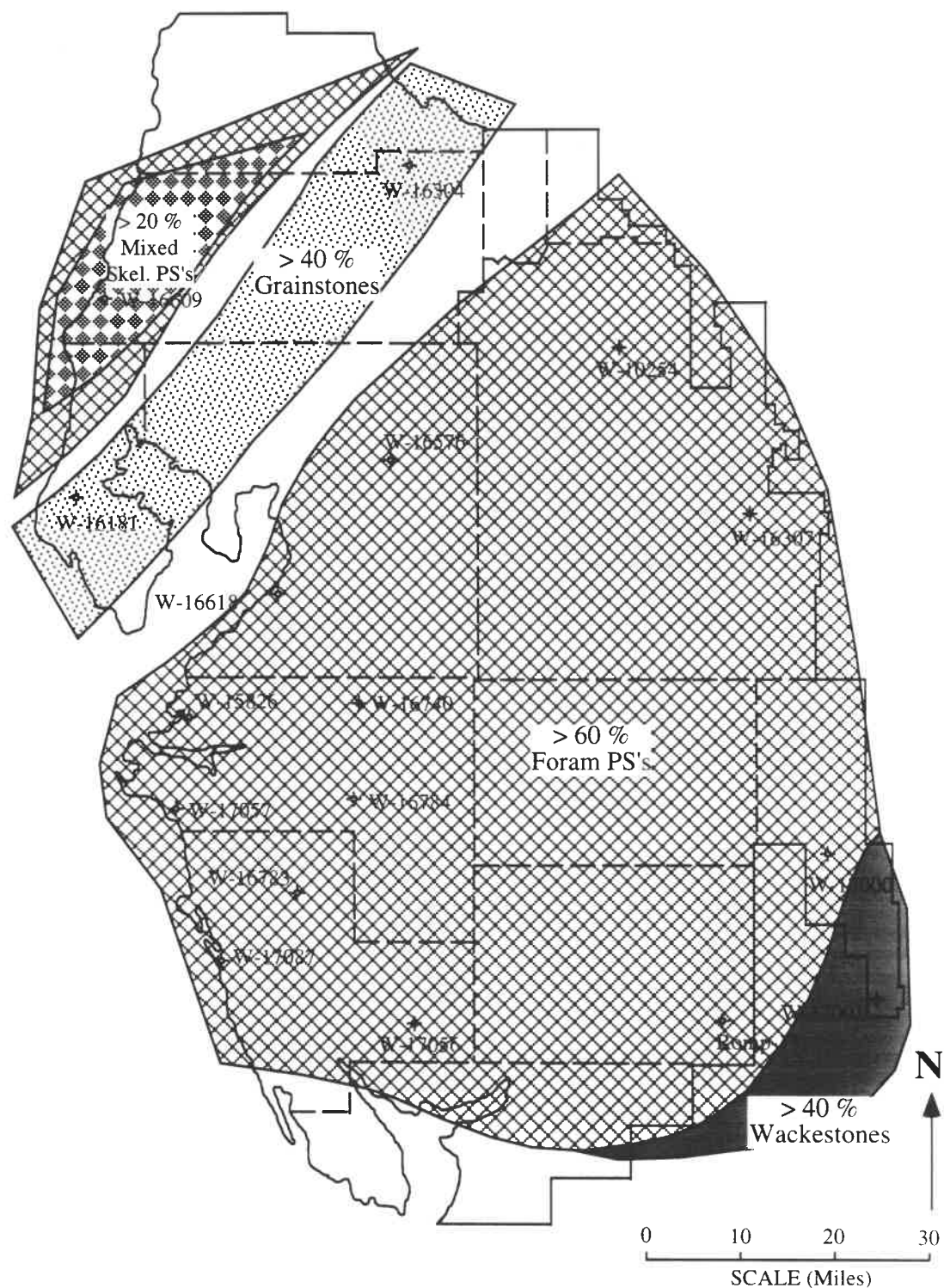


Figure 24: Composite map showing depocenters of various facies that are found in sequence #2. Note that a number of facies have been combined. The map suggests a change of facies zonation during the deposition of sequence #2 to a foraminiferal packstone dominated region. Areas in white indicate a lack of dominance by any one facies.

into a dominant Late Eocene biota and (2) the ramp geometry favored these foraminifera. Most likely, both these factors combined to produce the facies belts seen in Figure 24. The thick accumulation of sediments in the southern half of sequence #1 had the effect of reducing accommodation space and leveling out paleo-water depths on the ramp relative to the initial paleo-topography of the Middle Eocene. This is confirmed by the migration of the wackestone depocenter to the southeast. With the reduced ramp steepness, there was a large region of ramp during sequence #2 deposition that was periodically wave-swept, which pushed the wackestone depocenter further south. This broad region, however, remained significantly deep to preclude the shallow water biota typically found in the higher energy inner ramp setting, thus the foraminiferal packstone facies prevailed.

c. Sequence #3

Figure 25 shows isopach maps of facies abundances for sequence #3. The four maps show grainstones (combined), foraminiferal packstones, mixed skeletal packstones, and wackestones. The grainstones are most abundant in a belt that crosses Hillsborough and Polk Counties in the middle of the study area. The foraminiferal packstones are most abundant to the north of the grainstones, representing >80% of the section in wells W-16304 and W-10254. The mixed skeletal packstones occupy a large region in the study area, primarily in the southwest. The wackestones, similar to sequence #2, are restricted to the extreme southeast of the study area where they are less abundant than in sequence #2 but still indicate the deepest parts of the ramp during the deposition of sequence #3.

A composite map of facies depocenters during sequence #3 is shown in Figure 26. It shows a distinct change in facies patterns from the two underlying sequences. The grainstone belt has migrated to the southeast and crosses the study area perpendicularly. The foraminiferal packstones are most dominant to the north of the

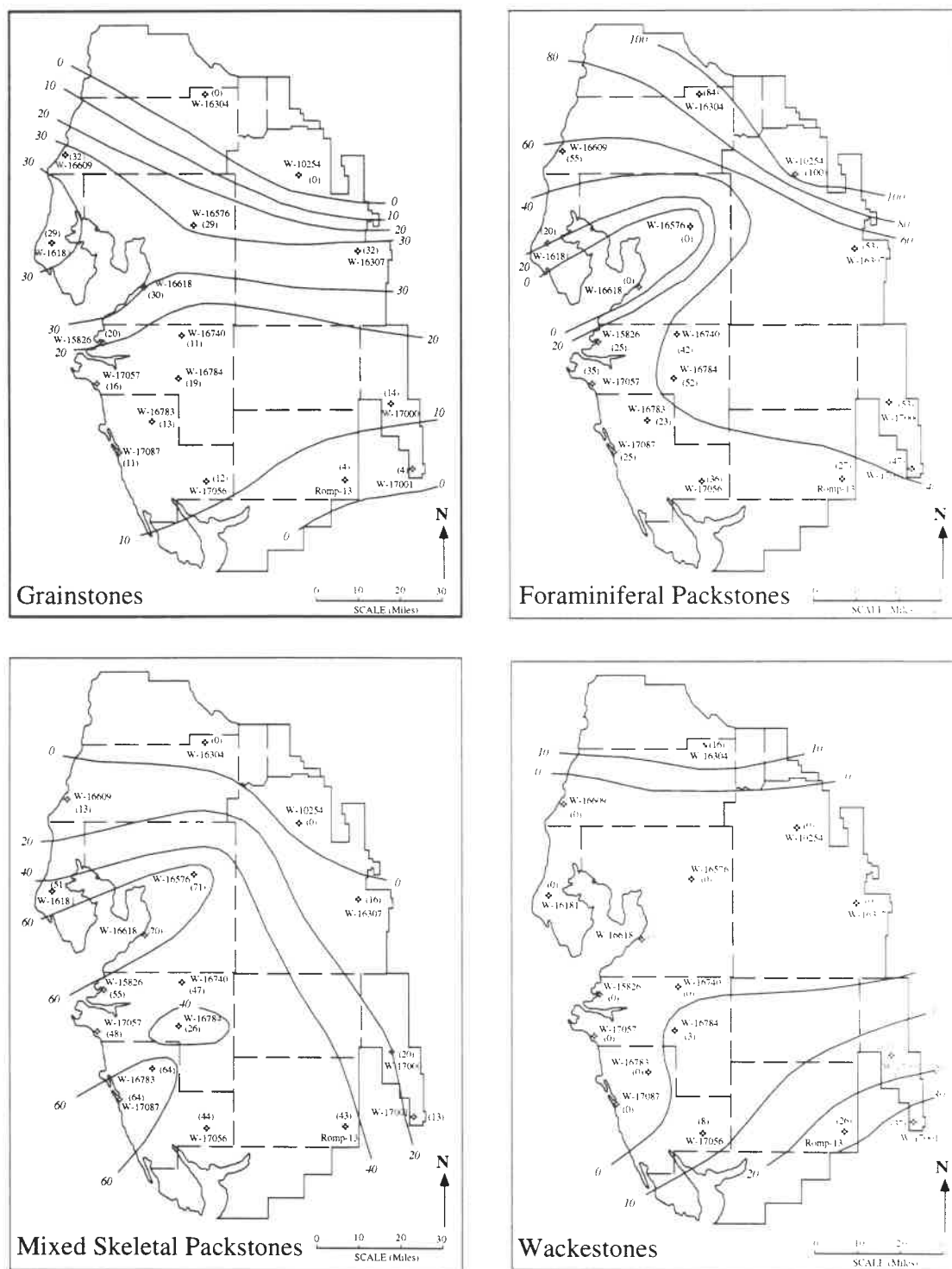


Figure 25: Isopach maps of sedimentary facies found in sequence #3. Contour intervals are either 10 or 20% increments of the total thickness of the sedimentary package. Note that some facies have been combined.

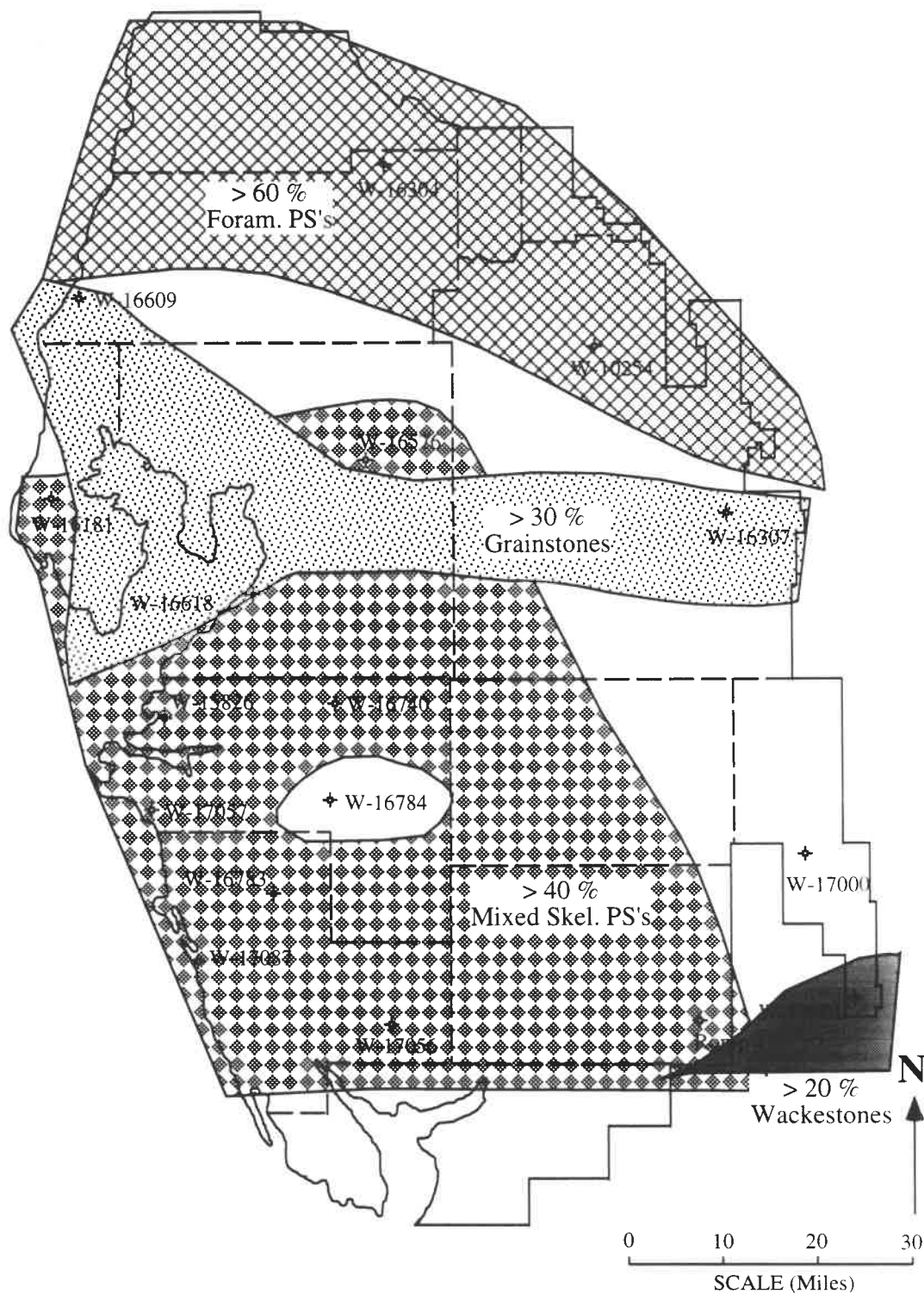


Figure 26: Composite map showing depocenters of various facies that are found in sequence #3. Note that a number of facies have been combined. The map suggests a change of facies zonation during the deposition of sequence #3 to a mixed skeletal packstone dominated region. Areas in white indicate a lack of dominance by any one facies.

grainstones, apparently occupying a niche higher on the ramp than the grainstones. The mixed skeletal packstones dominate the sequence to the south of the grainstone belt and the wackestones display a similar depocenter to sequence #2.

The apparent anomalous nature of the facies belts in the northern half of the study area are due to post-Eocene topographic erosion of the upper Ocala Formation. The combined effects of a eustatic fall (Haq et al. 1988) and the Ocala Uplift produced extensive erosion to the north and a grainstone belt that geometrically suggests a forced regression down the ramp. Grainstones are found capping sequence #3 all the way south through-out the study area (Figures 10-14). There is no evidence of such pervasive capping in either of the other two sequences. It suggests the eustatic fall in relative sea level was significantly greater at the end of sequence #3 than either of the other two prior sequences.

The dominance of the foraminiferal packstones in the northern regions of the study area is probably due to the topographic erosion of overlying grainstones. The initial deeper water deposits of sequence #3 (foraminiferal packstones dominated by lepidocyclina, see cross sections A-A' and C-C', Figures 10 and 12) are all that remains, thus giving a false impression on the facies map. The geographic coverage of this early deposit is known to extend far to the north as evidenced by the presence of foraminifera coquinas in the Upper Ocala Formation, as described by prior workers (Applin and Applin 1944; Miller 1986). These updip coquinas are probably a combined section of sequence #2 (also dominated by foraminiferal packstones to the north) and #3. Only by using subtle differences in paleontological zones were Vernon (1951) and Puri (1957) able to differentiate these upper two sequences.

The dominance of the mixed skeletal packstone facies in the central and southern portions of the study area may also be indicative of a forced regression at the end of Ocala deposition. This facies becomes dominant by the 2nd cycle in the sequence (see-cross section A-A', Figure 10) and may indicate the end of the sea level

transgression (marked by the dominance of foraminifera) and accumulation of sediments toward a static sea level (the "catch up" and "keep up" phases of Sarg. 1988).

d. Summary

The evolution of facies belts on the ramp during the deposition of the Ocala Formation (Figure 27) may reflect changes of ramp morphology and eustatic sea level during the Late Eocene. The continual demise of wackestone facies and increase in packstone facies within the study area suggests two things: 1) paleo water depths on the ramp were reduced slightly following the deposition of sequence #1 bringing more of the ramp in contact with storm wave base and/or 2) the magnitude of eustatic sea level rises decreased over the Late Eocene. It is believed that both these factors played a role in the observed facies belt evolution. The presence of 3 distinct sequences in west-central Florida and elsewhere in the Gulf of Mexico (Haq et al. 1988; Combes 1993; Baum et al. 1994), indicates that the sedimentary packages were deposited in response to eustatic sea level, not regional tectonic subsidence.

The global sea level curve (Figure 20) indicates that each pulse of eustasy transgressed higher than the previous with little intervening fall. This would agree with the observations documented here. The initial transgression of the sea onto the relatively steep ramp, following the post Middle Eocene Type 1 fall, produced the densely packed facies belts seen in sequence #1 (Figures 22 and 27). The sediments accumulated in a wedge shape (Figures 10, 11, and 12) that flattened the relative slope of the ramp. A second and third pulse of sea level transgression over the ramp provided accommodation space for the deposition of sequences #2 and #3. At the end of the Late Eocene a relative fall in eustatic sea level combined with the onset of the Ocala Uplift produced the signature of a forced regression at the top of the Ocala Formation.

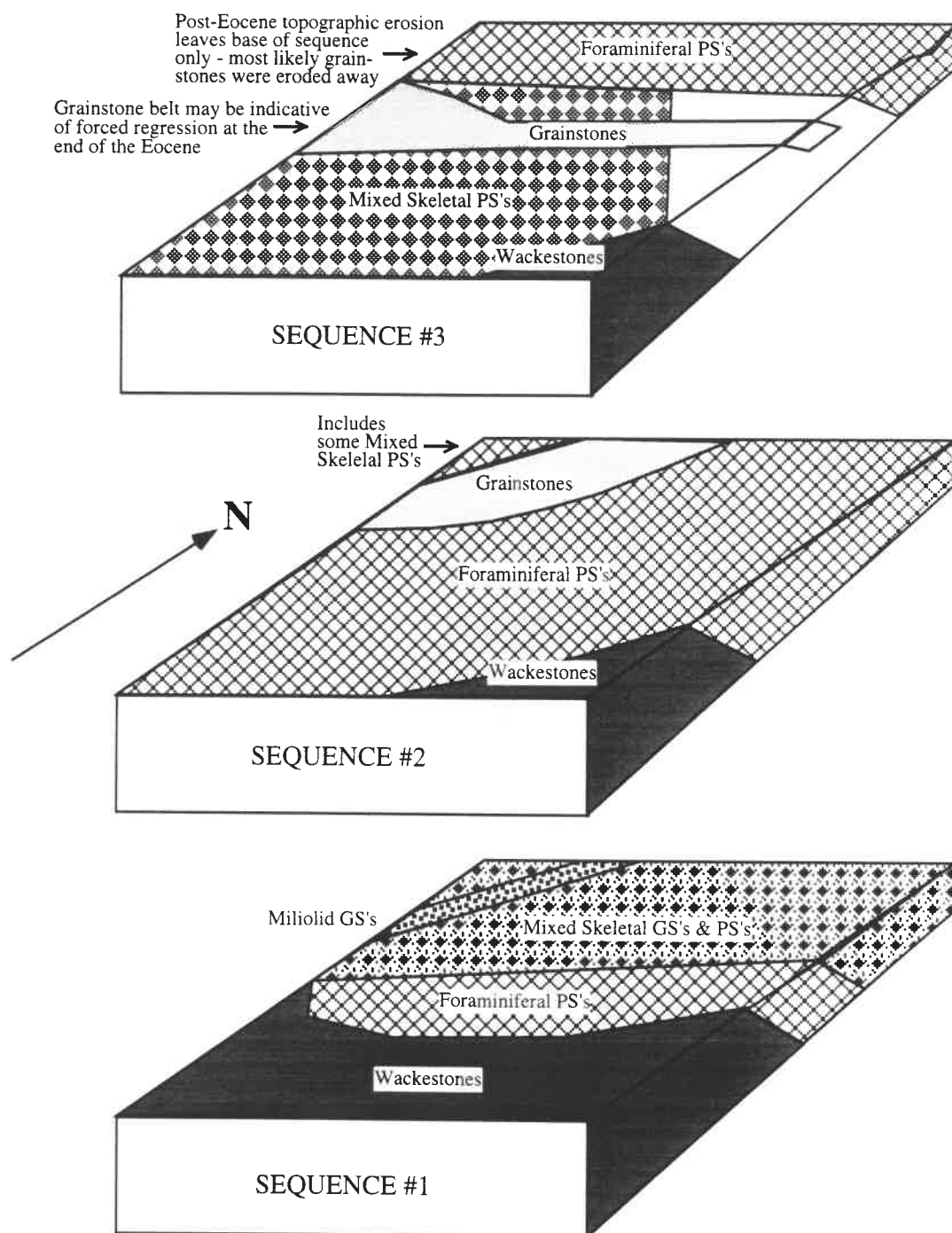


Figure 27: Schematic block diagrams showing facies depocenters throughout the three 3rd order sequences recognized within the Ocala Formation. The diagrams are derived from Figures 22, 24, and 26. Facies have been combined in order to emphasize facies zonation on the ramp. Note the gradual reduction in wackestones over time, the persistence of grainstone belts in the northwest through sequences #1 and #2, and the signature of a forced regression in sequence #3. Also note that subaerial erosion of the Ocala in the north after the Eocene gives a misleading suggestion that the upper ramp was dominated by foraminiferal packstones. See text for discussions of these observations.

3. Comparison of West-Central Florida to Generic Ramp Models

In Read's (1985) swell-dominated distally steepened ramp model the ramp is divided into four facies belts: (1) coastal complex of dunes, beach ridges, and beach deposits that grade into a (2) inner ramp blanket of skeletal sand that grades into a (3) outer ramp blanket of muddy lime sands (skeletal packstones) that grades into a (4) slope facies of highly bioturbated, fine skeletal wackestone. Except for the presence of beach/shoreface deposits, the facies belts of the swell-dominated distally steepened ramp fit observations from west-central Florida (Figure 28).

Criteria that eliminate Read's (1985) other ramp models for the study area include the absence of any barrier or bank deposits, lagoons, ooid shoals, linear reefs, incised channels, and tidal facies. Early researchers have speculated that the Floridan platform (now considered a ramp) was rimmed to the north of the study area (Cheetham 1963; Chen 1965), but continuous reef trends have never been identified (Bryan 1993). Other researchers have suggested low energy, protected environments behind a coarse grained "rim" in northern Florida and Georgia (Carter et al. 1989). While the paleo-environments of the Ocala Formation to the north of this study area remain enigmatic, the observations made in this thesis point towards the swell-dominated distally steepened ramp. The presence of washed packstones and grainstones on the upper slopes of the ramp suggest episodic and continuous wave-sweeping, respectively, and the wackestones to the south suggest depositional depths below wave oscillation impact. If the modern Gulf Coast climates can provide a proxy for the Late Eocene, then one might expect frequent tropical storms and hurricanes on the West Florida ramp.

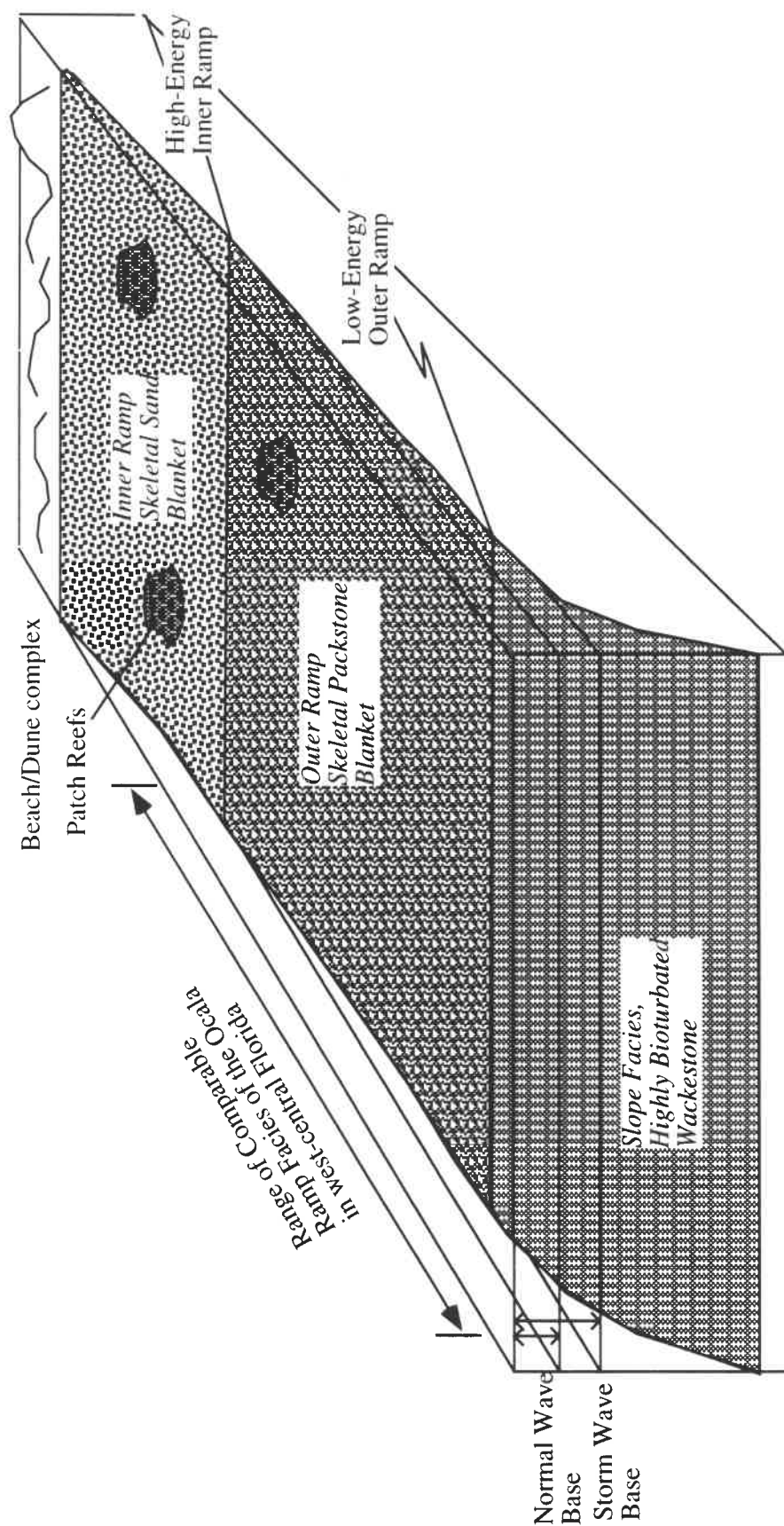


Figure 28: The swell-dominated distally steepened ramp model (modified from Read, 1985). Similar facies belts are found in the Ocala Formation of west-central Florida. All three sequences of the Ocala exhibit facies patterns like this (Figures 22, 24, and 26) but with slight shifts in location reflecting 3rd order relative eustatic sea-level changes.

CHAPTER 3

HYDROGEOLOGY OF THE OCALA FORMATION

I. Historical Background of the Floridan Aquifer System

The Floridan Aquifer System (FAS) extends over approximately 260,000 km², underlies all or parts of Alabama, Georgia, South Carolina and Florida, and is one of the United States's major sources of ground water (Johnston 1993). In the past decade numerous investigations have focused on the hydrologic framework of the aquifer (e.g., Ryder 1985; Miller 1986; Bush and Johnston 1988). The FAS is subdivided into two zones of higher permeabilities, the Upper and Lower Floridan Aquifers, separated by a confining unit (Figure 29). The Upper Floridan Aquifer within the study area is bound stratigraphically on the bottom by vertically persistent intragranular evaporites that have been shown to have extremely low permeabilities (Ryder 1985). The Upper FAS in the extreme northern regions of the study area is at or just below land surface and can be considered unconfined, with localized confining beds (Ryder 1985). Over the vast majority of the study area, however, the top of the Upper FAS is overlain by the relatively impermeable beds of the basal Tampa Limestone. In the southwest region of the study area the boundaries of the Upper FAS transgress the formation boundaries and there are local aquicludes within the Upper FAS (Hutchinson 1992).

On a large scale the Upper FAS is a highly transmissive unit. Model derived transmissivity values range from 17,000 ft²/day in southwest Pinellas County to 2,600,000 ft²/day in the middle of Hernando County (Ryder 1985). High transmissivity values in the northern area are attributed to near surface exposure of the aquifer and extensive development of solution channels in the aquifer carbonates. Lower transmissivities along the coast in the southwest are attributed to the thinning of

System	Series	Stratigraphic Unit	General Lithology	Major Lithologic Unit	Hydrogeologic Unit
Quaternary	Holocene and Pleistocene	Surficial sand, terrace sand, phosphorite	Predominantly fine sand; interbedded clay, marl, shell, limestone, phosphorite	Sand	Surficial aquifer
Tertiary	Pliocene	Undifferentiated deposits	Clayey and pebbly sand; clay, marl, shell, phosphatic	Clastic	Confining bed
	Miocene	Hawthorn Formation	Dolomite, sand, clay, and limestone; silty, phosphatic	Carbonate and clastic	Intermediate Aquifer and Confining Beds
		Tampa Limestone	Limestone, sandy, phosphatic, fossiliferous; sand and clay in lower part in some areas		
	Oligocene	Suwannee Limestone	Limestone, sandy limestone, fossiliferous	Carbonate	Upper Floridan Aquifer
	Eocene	Ocala Limestone	Limestone, chalky, foraminiferal, dolomitic near bottom		Carbonate with evaporites
		Avon Park Formation	Limestone and hard brown dolomite; intragranular evaporite in lower part in some areas		
		Oldsmar Formation	Dolomite and limestone, with intergranular gypsum in most areas		
	Paleocene	Ceder Keys Formation	Dolomite and limestone with beds of anhydrite		Lower Floridan Aquifer
				Lower confining unit	

Figure 29: Hydrologic framework of the west-central Floridan peninsula (modified from Ryder, 1985). The shaded area is the Ocala limestone, the focus of this investigation.

the freshwater lens within the aquifer. Sensitivity tests on the model have shown these transmissivity estimates to be conservative (Ryder 1982).

The geometries of the flow system within the Upper FAS change across the study area (Ryder 1985). In the north there is direct surficial recharge into the aquifer and shallow ground water is transported westward to discharge at surface springs along the coast. Some of the recharge waters in the north, however, flow south and travel deeper as the Upper FAS plunges toward the south and west. Additional influxes to the semi-confined Upper FAS occur along the Peninsular Arch (Polk & Highlands Counties) where lakes and sinkholes may be directly connected to the aquifer and through slow vertical leakage through the surficial and intermediate aquifer confining beds across the middle and southern regions of the study area. The relative percent influx from these three sources is unknown.

While the entire FAS comprises carbonate rocks of Paleocene to Miocene age, this study addresses the hydrogeologic role of the Upper Eocene Ocala Formation, which is part of the Upper Floridan Aquifer (Figure 29). Hydrogeologists acknowledge that the Ocala Formation contains relatively low permeabilities and the Suwannee and Avon Park Formations relatively high permeabilities. Despite the permeability contrasts, tests have shown that interformational connections exist in adequate abundance to analyze the entire Upper FAS as a single hydrologic unit on a regional basis (Ryder 1985).

While the model inputs of Ryder (1982, 1985) appear to have good geographic well coverage (x,y), the vertical intervals (z) are very large as they are derived from pump tests. Gross homogenization of the Upper FAS may be a necessity for modeling large regions, but it most likely over-simplifies complexities that may play a key role in future localized ground water management. A purpose of this investigation is to demonstrate that local facies controlled hydraulic conductivities within the Ocala

Formation may range across as many orders of magnitude as do the varying transmissivities of the entire FAS.

II. Methods Used in Hydrogeologic Characterization of the Ocala Formation

Falling head permeameter data were obtained from SWFWMD and FGS. Hydraulic conductivity values were derived using standard falling head apparatus in the FGS laboratory in Tallahassee, FL and therefore represent vertical hydraulic conductivity (K_Z). Selected intact core samples (3-4" in length, 2" diameter) were cleaned, dried, sealed on top and bottom with paraffin wax and placed in a plastic ring (commercial piping; 5" diameter). Clear modeling epoxy was poured between the sample and the plastic piping with care taken not to spill any epoxy on top of the sample. After the epoxy hardened for approximately 24 hours, the wax coating on top and bottom was removed and the samples were placed in the permeameter (R. Green, FGS, pers. comm., 1994). Vertical hydraulic conductivity was calculated from the following equation (R. Green, FGS, pers. comm., 1994):

$$K_Z = 2.303 aL/At * (\log(h_0/h_1))$$

where: K_Z = vertical hydraulic conductivity (cm/sec)

a = diameter of standpipe

L = length of core sample

A = cross-sectional area of core sample

$t = t_1 - t_0$ = elapsed time (sec)

h_0 = initial head (cm)

h_1 = final head (cm)

In certain instances of very low vertical hydraulic conductivity (e.g. sample 840.5' from W-16740) the FGS observed no flow through the core plug after 21 to 60 days and used a very low through-flow volume to calculate a flow rate (Dr. Jon Arthur, FGS, pers. comm., 1994). For samples that flowed, the falling head test was repeated

a total of 3 to 5 times and averaged arithmetically. There are a total of 44 permeameter test results from the Ocala Formation. Thirty data points had been collected prior to the onset of this investigation as part of SWFWMD's ongoing aquifer characterization efforts. Two data points from W-30026 were co-selected by this author and SWFWMD and the remaining 12 samples were chosen by this author and generously funded by SWFWMD.

To address the potential relationship between vertical hydraulic conductivity and matrix porosity, all 44 permeameter points were measured for bulk porosity. Porosity values were derived using modified methods for bulk density described by Singer and Janitzky (1986). Like the petrographic thin sections, samples were collected immediately adjacent to the falling head permeameter plugs. Samples were collected by the FGS and run by this author in Boulder, CO. Each sample was oven dried, weighed, and completely encased in paraffin wax heated to approximately 60°C. The wax was allowed to cool to room temperature and the sample was then weighed dry and weighed again suspended in a mesh basket in a beaker filled with water. With the known density of paraffin, calcite, and dolomite the bulk porosity was calculated using the following formula:

$$BP = ((M_W - ((M_O \div D_R) + ((M_W - M_O) \div D_W))) + M_W) \times 100$$

where: BP = Bulk porosity as a percent of whole rock

M_W = Mass of sample with wax coating

M_O = Mass of oven-dried sample

D_R = Density of rock (2.71 gm/cm³ for calcite and 2.85 gm/cm³ for dolomite)

D_W = Density of wax (0.89 gm/cm³)

It should be noted that for samples of mixed mineralogy a visual ratio of calcite to dolomite was obtained petrographically and a proportionate density value (D_R) was used.

After reviewing the initial porosity results and comparing them to their corresponding petrographic thin sections, the results of five samples were considered suspect. These five samples and seven control samples were boiled in water to remove the paraffin, soaked in Dichloromethane for 24 hours to remove residual paraffin, air dried, and re-run under the same protocol outlined above. The second set of porosity results from the five suspect samples averaged 10.3% different from their original measurements, compared to 1.3% for the control samples. Therefore, the new porosity values for the suspect samples were substituted for the original measurements. The error in the first set of measurements for these five samples probably occurred during paraffin encasement. If the surface of the rock sample was highly porous and/or the paraffin was too hot (i.e. not viscous enough), paraffin would have readily infiltrated the sample and yielded anomalously low porosity measurements.

III. Results of Falling-head Permeameter Tests and Porosity Measurements

A summary of the results of the falling-head permeameter analyses is presented in Table 3. Average vertical hydraulic conductivities are shown in centimeters per second and feet per day. The raw data (i.e. each run per plug) are presented in Appendix C. Conductivity rates for the 44 samples vary between 1.19×10^{-4} cm/sec (.337 ft/day) and 1.14×10^{-9} cm/sec (3.24×10^{-6} ft/day). The arithmetic average of the sample set is 2.26×10^{-5} cm/sec and the geometric average is 3.60×10^{-6} cm/sec.

In this investigation, all the vertical hydraulic conductivity data will be used in its log-transformed state, with geometric, not arithmetic averages. Log transformation of permeability data is commonly done because it normalizes the sample population allowing the application of parametric statistical analyses (Davis 1986). While there is some debate on the use of geometric means as a proxy for effective permeability (Jensen 1991) means have been demonstrated to be valid when permeabilities are

TABLE 3: Results of porosity and permeability (Kz) analyses. Permeability is listed in both cm/sec and ft/day. Note the four samples that are omitted from discussions of facies-permeability analyses and the one sample of these four that has also been omitted from facies-porosity analyses.

Well	Depth(1) (ft bgs)	Sedimentary Facies	Porosity (%)	Avg. Kz (2) (cm/sec)	Avg. Kz (2) (ft/day)	Comments
W-15826	690.0	Mixed Skeletal PS	38.7	3.91E-05	1.11E-01	Well washed, grainy
W-15826	742.0	Nummulitic PS	35.5	4.57E-06	1.30E-02	Muddy
W-15826	810.0	Numm/Lep PS	36.5	4.68E-06	1.33E-02	Washed
W-15826	870.0	Nummulitic PS	31.1	1.89E-06	5.35E-03	Dolomitized
W-16181	575.0	Mixed Skeletal PS	32.5	5.57E-06	1.58E-02	Washed, slightly cemented
W-16181	642.4	Mixed Skeletal GS	35.0	3.21E-05	9.09E-02	Mud slightly micritized
W-16181	683.4	Miliolid GS	31.8	4.29E-05	1.22E-01	Very loosely packed
W-16304	113.4	Nummulitic PS	36.5	1.60E-05	4.53E-02	Washed, compacted
W-16304	164.9	Mixed Skeletal GS	26.7	2.76E-04	7.82E-01	Compacted
W-16304	209.0	Miliolid GS	32.9	1.43E-04	4.06E-01	Compacted
W-16307	179.5	Mixed Skeletal PS	40.3	3.91E-05	1.11E-01	Slightly washed, dissolution
W-16307	212.8	Lepidocyliina PS	36.7	7.65E-06	2.17E-02	
W-16307	314.8	Numm/Lep PS	23.1	1.15E-07	3.26E-04	Foram rich, muddy matrix
W-16576	365.4	Mixed Skeletal PS	34.2	6.18E-06	1.75E-02	Very fine grained, muddy
W-16576	441.4	Numm/Lep PS	35.5	5.20E-06	1.47E-02	Foram rich, muddy matrix
W-16576	512.3	Mixed Skeletal GS	33.0	1.03E-05	2.92E-02	Poorly washed, compacted
W-16618	482.8	Mixed Skeletal PS	34.4	3.53E-05	1.00E-01	Very fine grained, muddy
W-16618	552.3	Nummulitic PS	36.6	1.14E-09	3.24E-06	(3).
W-16618	624.3	Mixed Skeletal GS	31.8	3.38E-05	9.58E-02	Poorly washed
W-16618	681.3	Nummulitic PS	24.7	2.80E-07	7.95E-04	

TABLE 3: Results of porosity and permeability (Kz) (cont'd).

Well	Depth (ft bgs)	Facies Assignment	Porosity (%)	Avg. Vert. K (cm/sec)	Avg. Vert. K (ft/day)	Comments
W-16740	797.0	Mixed Skeletal PS	36.6	3.01E-06	5.83E-03	Fine grained, muddy
W-16740	840.5	Numm/Lep PS	22.9	3.83E-09	1.09E-05	(3) Very dense mud, possible horizontal "seams"
W-16740	912.0	Nummulitic PS	29.4	2.02E-06	5.71E-02	Very fine grained
W-16783	640.9	Mixed Skeletal GS	31.9	1.64E-08	4.66E-05	(3) Peloid rich, compacted
W-16783	817.7	Numm/Lep PS	29.4	1.83E-06	5.19E-03	Dolomitized
W-16783	909.5	Lepidocyclina WS	26.6	6.13E-07	1.74E-03	Dolomitized
W-16784	805.0	Lepidocyclina PS	39.3	4.16E-06	1.18E-02	
W-16784	853.5	Numm/Lep PS	27.0	1.04E-06	2.95E-03	Very dense mud
W-16784	896.0	Numm/Lep PS	12.7	2.25E-06	6.38E-03	(4) Very dense mud, fractures present
W-17000	630.5	Mixed Skeletal PS	40.8	1.28E-05	3.63E-02	Very fine grained, muddy
W-17000	712.4	Numm/Lep PS	36.5	2.09E-06	5.93E-03	Muddy matrix
W-17000	772.0	Lepidocyclina PS	31.4	4.15E-06	1.18E-02	Foram rich
W-17000	849.5	Nummulitic WS	33.2	4.96E-06	1.41E-02	Very fine grained
W-17001	693.4	Mixed Skeletal GS	24.6	1.19E-04	3.37E-01	Slightly cemented
W-17056	920.9	Nummulitic PS	36.7	8.05E-06	2.28E-02	Washed
W-17056	1002.9	Numm/Lep PS	31.1	2.48E-06	7.04E-03	Slightly dolomitized
W-17056	1102.4	Nummulites WS	27.4	6.95E-06	1.97E-02	100% Dolomitized, abundant molds
W-17057	740.1	Nummulitic PS	40.0	8.81E-06	2.50E-02	Washed
W-17057	797.0	Nummulitic PS	35.9	7.46E-06	2.12E-02	
W-17057	887.0	Numm/Lep WS	26.5	9.11E-05	2.58E-01	100% fine sucrosic dolomite
W-17087	940.0	Nummulitic PS	29.9	4.38E-06	1.24E-02	Washed
W-17087	1064.4	Numm/Lep PS	11.9	1.31E-08	3.71E-05	100% Dolomitized, abundant molds

TABLE 3: Results of porosity and permeability (Kz) (cont'd).

Well	Depth (ft bgs)	Facies Assignment	Porosity (%)	Avg. Vert. K (cm/sec)	Avg. Vert. K (ft/day)	Comments
Romp-13	860.3	Lepidocyclina PS	39.0	3.08E-06	8.74E-03	Sparse lepidocyclina, very fine grained
Romp-13	1019.4	Nummulitic WS	31.2	2.25E-06	6.37E-03	

(1) Sample depth is $\pm 4''$

(2) Average Kz is the arithmetic mean of 3-5 separate falling head permeameter runs on each plug (Appendix C)

(3) Permeability value is a statistical outlier within that sedimentary facies and is therefore omitted from facies-permeability analysis.

(4) The presence of fractures in rock obfuscates original matrix permeability and porosity. Sample is therefore omitted from facies-permeability analysis.

log-normally distributed, of low variance, and the domain of uniform flow is two-dimensional.

Figure 30 shows that the log-transformed Ocala Formation data does indeed approximate a normal distribution and its variance (1.29) is not considered anomalously high. The final requirement, a two-dimensional flow domain cannot be achieved practically, as the configuration of the falling-head apparatus is three-dimensional. This is not considered a major problem, as the purpose of this phase of the investigation is to compare the geometric mean hydraulic conductivities between various facies of the Ocala Formation, so all data subsets are mathematically treated the same. The final assumption has also been waived in numerous other studies in carbonate sediments where the flow domain has been three dimensional (e.g. Enos and Sawatsky 1981; Rovey and Cherkauer 1994a).

The primary flaw of the geometric mean is its extreme sensitivity to very low values. The geometric mean will be lowered dramatically by the presence of small values that may be erroneous (Jensen 1991). Rather than adopt the modified mathematical techniques of Jensen (1991), simple statistical tests were employed to identify possible outliers within the data set, both very low and very high. To do this, populations of hydraulic conductivity values from each sedimentary facies were taken and the geometric means and standard deviations were calculated. Samples that fell into the tails of the distribution curve beyond 5% and 95% were omitted from further analyses. This "outlier range" was calculated by adding and subtracting 1.6 standard deviations from the geometric mean. The constant of 1.6 was derived from the Gaussian probability distribution, with the area between these boundaries representing 90% of the sample distribution (Bevington 1969).

Using this procedure three hydraulic conductivity values were omitted from the database (see Table 3), all of them anomalously low. It is unclear why these samples displayed anomalously low conductivities, but the causes most likely involved either

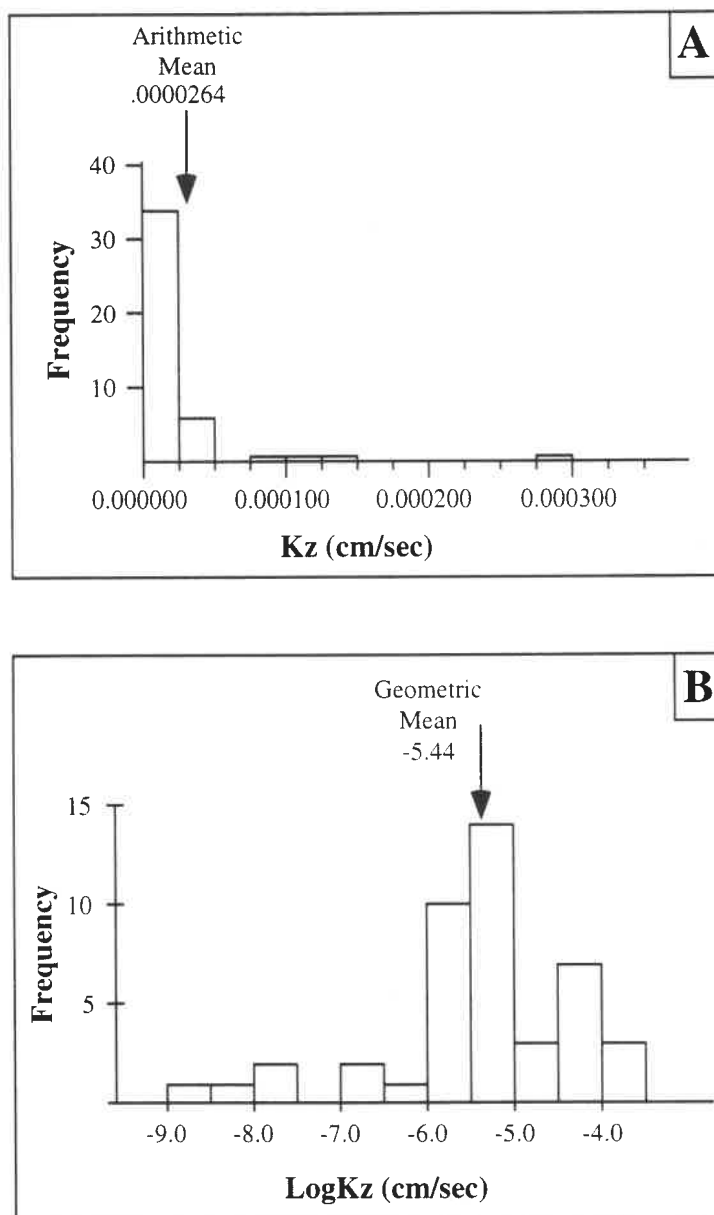


Figure 30: Graphs demonstrating the permeability data distribution untransformed (A) and log transformed (B). Log transforming the data set provides a near normal distribution, a necessity for standard parametric statistical analyses.

human errors in sample preparation (e.g. epoxy blocking vertical flow paths), a disparity between in-situ ambient aquifer conditions and laboratory conditions, or a lack of sensitivity to low conductivities in the experimental apparatus. In at least one of these samples (W-16783 at 640.9') petrographic observations show a highly porous grainstone matrix that should have displayed a high K_z . A fourth sample was also omitted from the database (Table 3) based on observed fractures in petrographic thin section. The presence of fractures, by default, obfuscates any measurement of matrix hydraulic conductivity, and requires the removal of the sample from the data base. With forty data points left in the data base the revised limits of hydraulic conductivities range from 1.19×10^{-4} cm/sec (.337 ft/day) to 1.31×10^{-8} cm/sec (3.71×10^{-5} ft/day), with the geometric average of 6.03×10^{-6} cm/sec.

The distribution of permeameter data points throughout the 12 sedimentary facies identified for the Ocala Formation is shown in Figure 31. The chart reflects the removal of the four samples from the original 44 data points. Of the 12 facies, nine are represented by the 40 permeameter samples. The remaining three facies are rare in core. The two pelagic wackestone facies are limited to the most basal Ocala Formation in the extreme south of the study area in three wells. The mixed skeletal wackestones are slightly more common than the pelagic facies, but the three facies combined make up an insignificant percentage of Ocala lithologies and should behave hydrogeologically similar to the other wackestones. It is clear from Figure 31 that more permeameter data is needed from the wackestone facies which dominate sequence #1 in the southern half of the study area.

The results of the bulk porosity measurements are presented with the hydraulic conductivity data in Table 3. The calculation of bulk porosities is included as Appendix D and includes visual estimates of calcite/dolomite ratios. Only the sample displaying fractures was discarded from the porosity data base. The matrix porosities of the three samples with anomalously low hydraulic conductivities are not believed to be suspect.

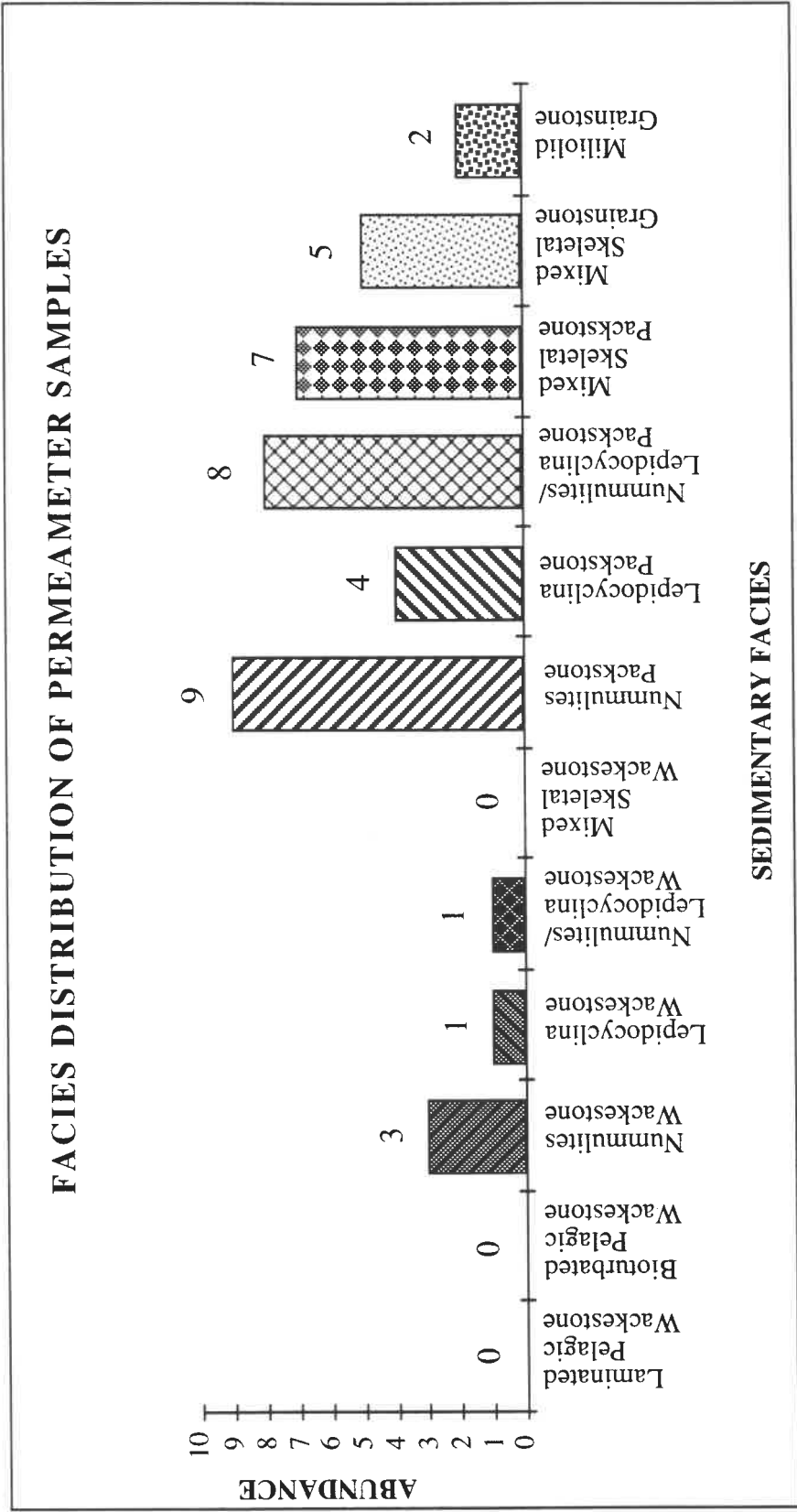


Figure 31: Distribution of permeameter samples among the 12 identified sedimentary facies in the Ocala Formation. The two pelagic facies are rare in cores and are restricted to the basal ± 10 ft. of the extreme southern wells. Bar graph patterns are consistent with those used in cross sections and maps in Chapter 2.

so they are considered in facies-porosity analyses. The range of porosities for the 43 analyses in the data base is 11.91% to 40.85%. The average porosity is 32.2%.

IV. Discussion on the Ocala Formation's Hydrogeology

A. Facies-Controlled Hydraulic Conductivity

The operating hypothesis in this investigation is that hydraulic conductivity and thus ground water flow in the Ocala Formation are strongly affected by sedimentary facies. Facies that were originally deposited in higher energy environments should display coarser grain sizes, better sorting, and fewer fines, all combining to produce higher hydraulic conductivities within the modern aquifer. Conversely, the facies deposited in lower energy environs should be dominated by finer grain sizes, abundant fines, poorer sorting, smaller pore spaces, and narrower pore throats, resulting in lower hydraulic conductivities. Other factors suspected to influence hydraulic conductivity within the Ocala Formation, along with sedimentary facies, include depth, effective porosity, mechanical compaction, chemical diagenesis, karst solution channels, and fractures.

A plot of sedimentary facies versus vertical hydraulic conductivity is shown in Figure 32. The plot confirms the original hypothesis outlined above. The miliolid and mixed skeletal grainstone facies have vertical hydraulic conductivities with geometric means of 7.77×10^{-5} and 5.13×10^{-5} cm/sec, respectively. At the other extreme are five packstone and wackestone facies which have mean vertical hydraulic conductivities between 6.17×10^{-7} and 4.47×10^{-6} cm/sec. One packstone facies, the mixed skeletal, displays mean vertical hydraulic conductivity between these two end member groups at 1.32×10^{-5} cm/sec, and has been isolated in its own box in Figure 32. The one sample from the nummulites/lepidocyclus wackestone displays anomalously high vertical hydraulic conductivity for a low energy facies. This sample, from the southwest coast (W-17057 at 887'), has been diagenetically altered to sucrosic dolomite. In

petrographic thin section the sample displays large, uniform-sized, dolomite rhombs. with little or no mud-sized sediment, and therefore behaves hydrogeologically as a grainstone (Figure 32).

To evaluate the strength of the observed relationships, statistical tests are used to discern whether a given facies' K_Z values are significantly different from other facies' K_Z values. These results are shown in Table 4 (2 sample t -test) and Table 5 (Mann-Whitney U test). In both tests, the mixed skeletal grainstone is uniformly dissimilar from the lower hydraulic conductivity facies. The mixed skeletal packstone and the miliolid grainstone show only partial dissimilarity to these facies. At a confidence level of 85%, however, the 2 sample t -test uniformly separates the three higher K_Z facies from the remainder of the facies, as well as create a new statistically dissimilar group for the nummulites/lepidocyclina packstone (Table 6). The dissimilarity relationships at the 85% confidence interval are weaker for the Mann-Whitney U test than the 2-sample t -test (Table 7). The lack of complete statistical differentiation of these facies, at a 95% confidence level, is attributed to low sample sizes. The miliolid grainstone has only two data points and four other facies have four or fewer data points (Figure 31). The addition of more data points per sedimentary facies would ideally strengthen the observed dissimilarity relationships.

If the log distribution of K_Z within each facies is normal, then the 2 sample t -test would be the more valid statistical test (Tables 4 and 6). However, the assumption of normality for the K_Z value distribution is problematic due to the low sample sizes per sedimentary facies. Histograms for each facies are included in Appendix E and they demonstrate the need for more hydraulic conductivity data per facies. For this reason the results of the Mann-Whitney U test are included as well (Tables 5 and 7), as this test is for non-parametric data sets and does not require the assumption of normal distribution. Based on the normal distribution of the entire data set (Figure 30), however, it may be safe to assume that data points within each facies would also be

Table 5: Results of Mann-Whitney U test comparing vertical hydraulic conductivities from the various sedimentary facies. Two facies, the lepidocyclina wackestone and the nummulites/lepidocyclina wackestone, are omitted because their low sample size (1) precludes analysis.

FACIES *	Numm. WS	Numm. PS	Lep. PS	N/L PS	Mx.Sk. PS	Mx.Sk. GS	Mil. GS
Numm.WS	X	1.00	0.86	0.14	0.17	0.037	0.22
Numm. PS		X	0.7	0.093	0.09	0.002	0.037
Lep. PS			X	0.11	0.15	0.02	0.10
N/L PS				X	0.003	0.002	0.046
Mx.Sk. PS					X	0.25	0.056
Mx.Sk. GS						X	0.60
Mil. GS							X

Note: H_0 states that $\text{Median}(\text{faciesX}) = \text{Median}(\text{faciesY})$

H_a states that $\text{Median}(\text{faciesX}) \neq \text{Median}(\text{faciesY})$

Numbers in boxes are probabilities of H_0 being true

- * = Numm.WS = Nummulites Wackestone
 Numm.PS = Nummulites Packstone
 Lep.PS = Lepidocyclina Packstone
 N/L PS = Nummulites/Lepidocyclina Packstone
 Mx.Sk.PS = Mixed Skeletal Packstone
 Mx.Sk.GS = Mixed Skeletal Grainstone
 Mil.GS = Miliolid Grainstone

X Indicates statistically dissimilar (at a confidence level of 95%)

Table 4: Results of 2-sample t-test comparing vertical hydraulic conductivities from the various sedimentary facies. Two facies, the lepidocyclina wackestone and the nummulites/lepidocyclina wackestone, are omitted because their low sample size (1) precludes analysis.

FACIES *	Numm. WS	Numm. PS	Lep. PS	N/L PS	Mx.Sk. PS	Mx.Sk. GS	Mil. GS
Numm.WS	X	0.85	0.9	0.086	0.067	0.013	0.15
Numm. PS		X	0.73	0.11	0.047	0.007	0.15
Lep. PS			X	0.069	0.041	0.015	0.14
N/L PS				X	0.009	0.001	0.009
Mx.Sk. PS					X	0.093	0.25
Mx.Sk. GS						X	0.67
Mil. GS							X

Note: H_0 states that $\mu(\text{faciesX}) - \mu(\text{faciesY}) = 0$

H_a states that $\mu(\text{faciesX}) - \mu(\text{faciesY}) \neq 0$

Numbers in boxes are probabilities of H_0 being true

- * =
 Numm.WS = Nummulites Wackestone
 Numm.PS = Nummulites Packstone
 Lep.PS = Lepidocyclina Packstone
 N/L PS = Nummulites/Lepidocyclina Packstone
 Mx.Sk.PS = Mixed Skeletal Packstone
 Mx.Sk.GS = Mixed Skeletal Grainstone
 Mil.GS = Miliolid Grainstone

X Indicates statistically dissimilar (at a confidence level of 95%)

Table 6: Results of the 2-sample t-test (Table 4), but with an 85% confidence level used to delineate statistically dissimilar facies (Table 4 is at a 95% confidence level).

FACIES *	Numm. WS	Numm. PS	Lep. PS	N/L PS	Mx.Sk. PS	Mx.Sk. GS	Mil. GS
Numm.WS	X	0.85	0.9	0.086	0.067	0.013	0.15
Numm. PS		X	0.73	0.11	0.047	0.007	0.15
Lep. PS			X	0.069	0.041	0.015	0.14
N/L PS				X	0.009	0.001	0.009
Mx.Sk. PS					X	0.093	0.25
Mx.Sk. GS						X	0.67
Mil. GS							X

Note: H_0 states that $\mu(\text{faciesX}) - \mu(\text{faciesY}) = 0$

H_a states that $\mu(\text{faciesX}) - \mu(\text{faciesY}) \neq 0$

Numbers in boxes are probabilities of H_0 being true

- * = Numm.WS = Nummulites Wackestone
 Numm.PS = Nummulites Packstone
 Lep.PS = Lepidocyclina Packstone
 N/L PS = Nummulites/Lepidocyclina Packstone
 Mx.Sk.PS = Mixed Skeletal Packstone
 Mx.Sk.GS = Mixed Skeletal Grainstone
 Mil.GS = Miliolid Grainstone

X Indicates statistically dissimilar (at a confidence level of 85%)

Table 7: Results of Mann-Whitney U test (Table 5), but with an 85% confidence level used to delineate statistically dissimilar facies (Table 5 is at a 95% confidence level).

FACIES *	Numm. WS	Numm. PS	Lep. PS	N/L PS	Mx.Sk. PS	Mx.Sk. GS	Mil. GS
Numm.WS	X	1.00	0.86	0.14	0.17	0.037	0.22
Numm. PS		X	0.7	0.093	0.09	0.002	0.037
Lep. PS			X	0.11	0.15	0.02	0.10
N/L PS				X	0.003	0.002	0.046
Mx.Sk. PS					X	0.25	0.056
Mx.Sk. GS						X	0.60
Mil. GS							X

Note: H_0 states that $\text{Median}(\text{faciesX}) = \text{Median}(\text{faciesY})$

H_a states that $\text{Median}(\text{faciesX}) \neq \text{Median}(\text{faciesY})$

Numbers in boxes are probabilities of H_0 being true

- * =
 Numm.WS = Nummulites Wackestone
 Numm.PS = Nummulites Packstone
 Lep.PS = Lepidocyclina Packstone
 N/L PS = Nummulites/Lepidocyclina Packstone
 Mx.Sk.PS = Mixed Skeletal Packstone
 Mx.Sk.GS = Mixed Skeletal Grainstone
 Mil.GS = Miliolid Grainstone

X Indicates statistically dissimilar (at a confidence level of 85%)

distributed normally. Ideally, with more data, the K_z value distributions would approach normality around a mean (central limits theorem) for each facies (Davis 1986). The assumption of normal distribution was necessary for the identification of statistical outliers within each facies (see methods section above).

The vertical hydraulic conductivity results of this investigation suggest a number of things about the spectrum of the Ocala's hydrogeology. Within the Upper Floridan Aquifer System, researchers recognize lithologies with higher vertical hydraulic conductivities as those typified by K_z values on the order of 1.00×10^{-5} cm/sec or higher, and lower vertical hydraulic conductivity lithologies as those typified by K_z values on the order of 1.00×10^{-8} cm/sec or lower (Green et al. 1995). The geometric means of the nine facies studied here suggest that three facies (the mixed skeletal packstone, mixed skeletal grainstone, and miliolid grainstone) should be classified as high vertical hydraulic conductivity (Figure 32) or "aquifer" facies. The remainder of the facies, however, do not have geometric means below the 1.00×10^{-8} threshold and do not fit "aquitard" classification. Rather, they fall into the gray area between aquifer and aquitard, and should be considered "aquiclude" facies. Overall, the Ocala's lithologies appear to be vertically conductive.

Recognition of facies controlled permeabilities (or hydraulic conductivities) in carbonate ground water aquifers appears to be a developing research field. For example, recent work in the Silurian dolomitic aquifer of Wisconsin by Rovey and Cherkauer (1994a) has described results similar to those found in the Ocala Formation. The dolomite units originally deposited under higher energy conditions display the highest hydraulic conductivities in the modern aquifer (1.00×10^{-3} to 1.00×10^{-4} cm/sec) whereas the wackestone and mudstone facies have much lower mean hydraulic conductivities (1.00×10^{-5} to 1.00×10^{-7} cm/sec). While the quantitative results differ slightly between this study and Rovey and Cherkauer's (1994a), the spectrum of hydraulic conductivities through various textures is identical.

B. Assessment of Factors Controlling Vertical Hydraulic Conductivity

It has been shown that sedimentary facies within the Ocala Formation have statistically significant differences in hydraulic conductivity, so questions arise as to *why* the hydraulic conductivities vary between facies. Is it a function of bulk porosity and if so, do the bulk porosities and associated K_z values change with depth (mechanical compaction)? Are certain facies characterized by chemical diagenesis that alters original porosity and permeability? Finally, what roles do sedimentologic criteria such as mean grain size and sorting play? As the central tenet of this thesis is to determine whether the facies are the dominant control on hydraulic conductivity (Figure 32), the following discussion will answer many of these questions, but also demonstrate the need for further research.

A plot of porosity versus vertical hydraulic conductivity is presented in Figure 33 and it suggests that hydraulic conductivity is a function of porosity, but with different relationships for each of the three vertical hydraulic conductivity classes identified. The trends show a relationship where K_z increases with porosity for the packstone/wackestone group and decreases with an increase in porosity for the grainstones. The third data subset identified on the graph is the mixed skeletal packstones. As this facies is characterized by a packstone texture with hydraulic conductivities more analogous to the grainstones (Figure 32 and Tables 4 and 5), it is considered a "transitional" class between lower energy packstones and wackestones and higher energy grainstones.

The strength of the regressions is strongest for the packstone/wackestone group ($R^2=.76$) and is attributed to a large sample set. The lack of a better regression may be partially attributed to the fact that porosity and permeability measurements were made on adjacent rock samples and not the same sample. Micro-scale heterogeneity over 6" of core could account for the "noise" observed in the regression. The regression for the

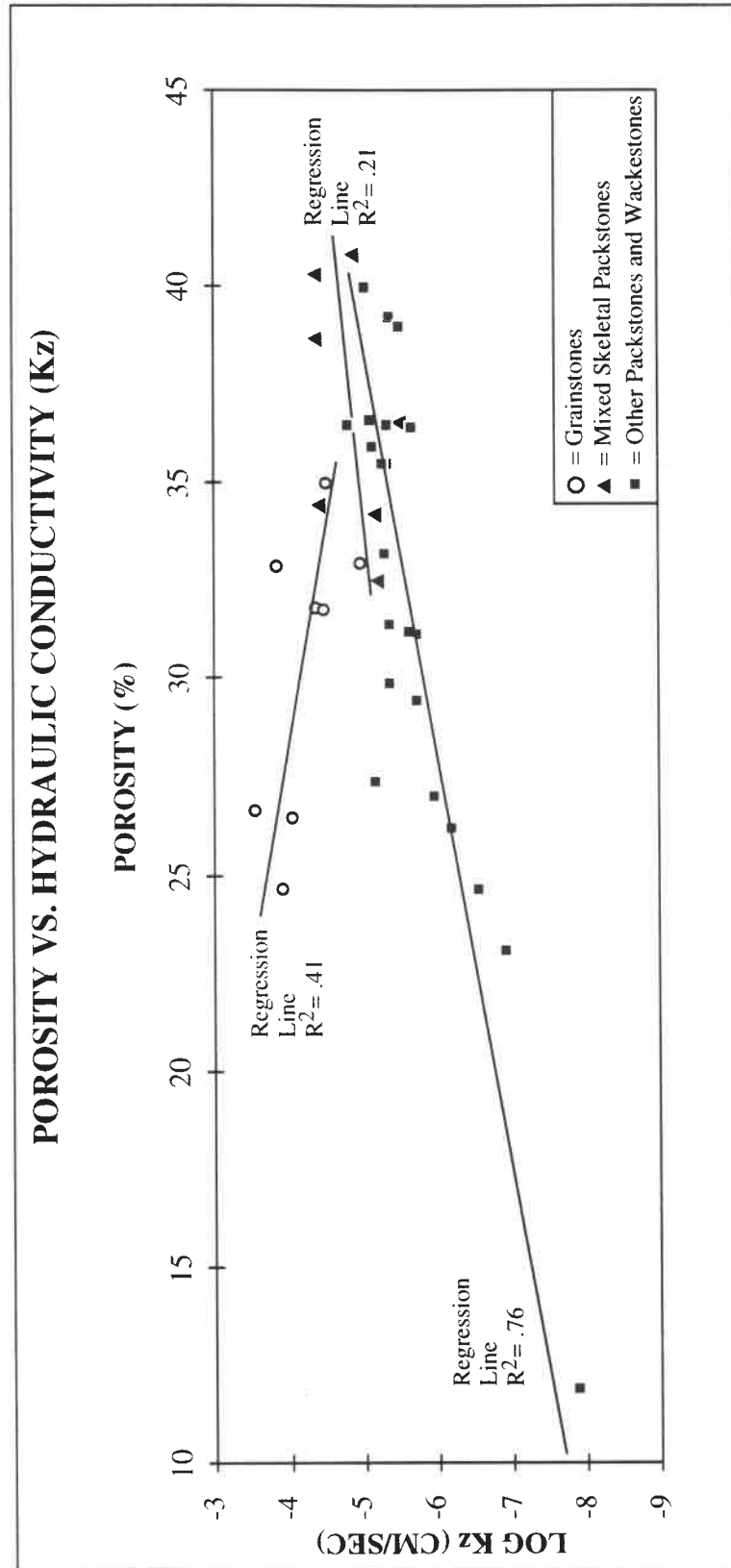


Figure 33: Graph showing the relationships between porosity and vertical hydraulic conductivity (Kz). There are three data sets: one for the grainstones (including a diagenetic sucrosic dolomite), one for most of the packstones and all the wackestones, and a final "transitional" facies, the mixed skeletal packstones. See text for the discussion on these data sets.

grainstones is only moderate in strength ($R^2=.41$) and the mixed skeletal packstone even weaker ($R^2=.21$). Both these sample sets have a low number of cases (8 and 7, respectively), making the regression difficult.

The cause of the porosity-hydraulic conductivity relationships may vary for each of the three classes. Petrographic point counts (300 points per thin section; Appendix E-3) show that the dominant control within the packstone/wackestone group is mud content (Figure 34). The samples with higher porosities contain less mud (i.e., are partially washed *sensu* Folk, 1959) and therefore have more voids for flow paths as well as fewer micro-scale pore throats, both resulting in higher K_z values (Figure 34). It is suspected that the mixed skeletal packstones reflect the same control, mud content, but as all seven samples display relatively high porosities ($> 32\%$) and are all washed to some extent, they cluster to the right in Figure 33 and display weak statistical correlations between matrix porosity and vertical hydraulic conductivity.

The vast majority of packstones in the Ocala Formation display varying degrees of mud winnowing. The origin of these washed packstones remains an enigma in the Ocala Formation and most other carbonate bodies. Possible mechanisms include incomplete winnowing of fines by wave sweeping (Osleger 1991), lime mud infiltration into depositional stabilized grainstones, prolific grain production in low energy environments, mixing by bioturbators (Dunham 1962), and post-depositional selective solution of lime mud within a grain matrix (Choquette and Pray 1970). Of these possibilities, the incomplete winnowing of fines from episodic events and bioturbation seem the most plausible for the Ocala packstones. As documented in Chapter 2, the paleo-ramp on which the Ocala rocks were deposited exhibits an allochemic and textural gradient from north to south reflecting relative water energies, and evidence of bioturbation is prevalent throughout the Ocala packstones. The geographic preponderance of the packstone facies between the grainstones and the wackestones (Figures 22 and 24) would suggest they also lie somewhere between

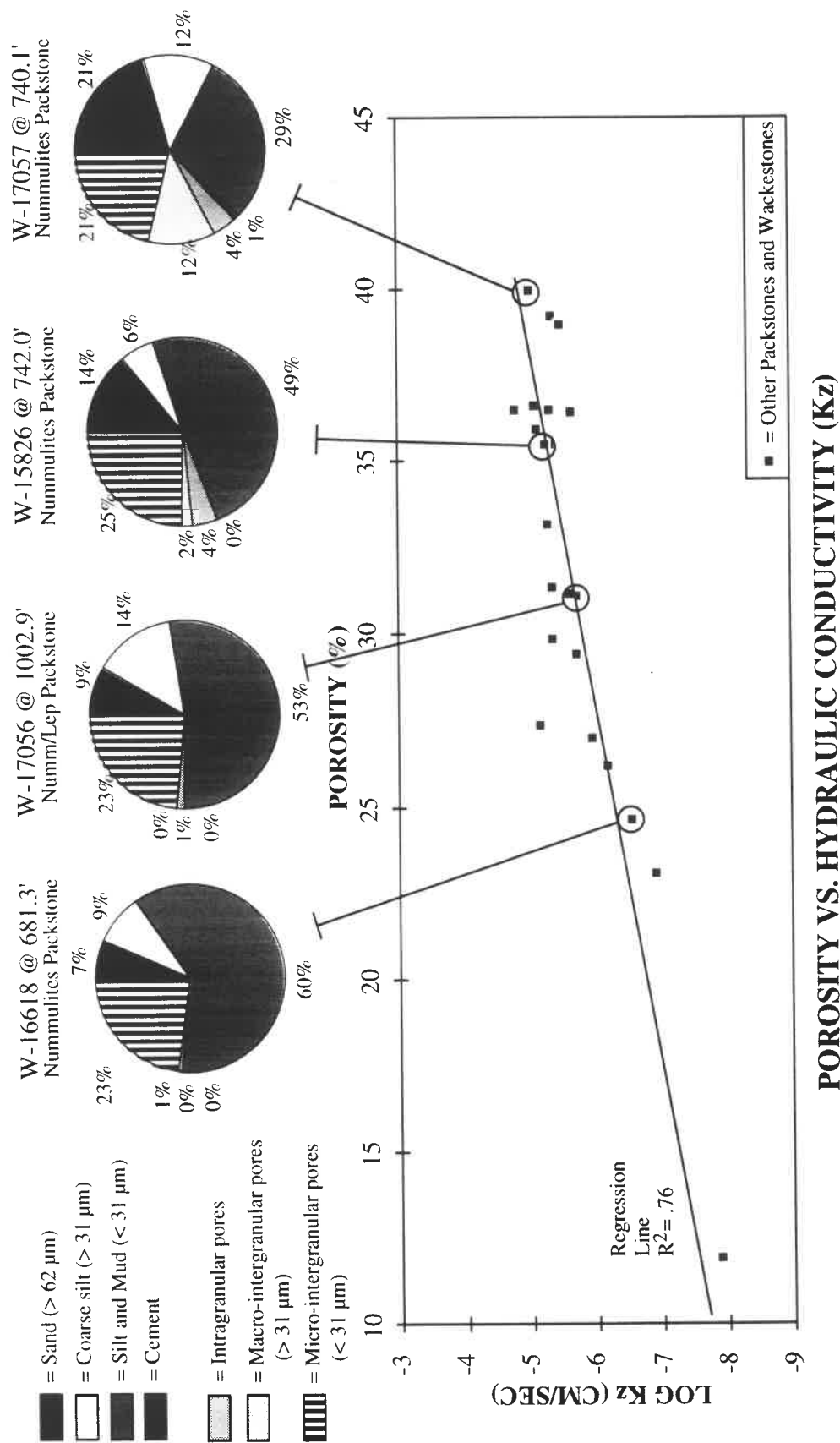


Figure 34: Plot of porosity and vertical hydraulic conductivity for the packstone/wackestone class. Four samples were selected along the regression line for point counting. The pie graphs illustrate the relationship between mud content and porosity/hydraulic conductivity. Within the four samples, porosity and Kz increase as mud content decreases from 60% to 29%.

complete mud winnowing and non-existent winnowing. Further study might entail the delineation of geographic location of the packstone samples on the ramp and a correlation to washing, porosity, and hydraulic conductivity.

The grainstones, by definition, contain little or no mud, and may therefore be subject to a different vertical hydraulic conductivity-porosity control. The relative low porosities found in the grainstone facies compared to other facies may reflect a number of syn- or post-depositional processes. Carbonate sand bodies typically display porosities on the order of 40-70% upon deposition (Choquette and Pray 1970). A potential process reducing overall porosity in the Ocala grainstones is cementation. Petrographic review of the rocks used in the porosity study indicates, however, that there is no pervasive cementation. The most common cementation is limited to syntaxial calcite overgrowths on echinoderm grains.

A second major process that may reduce primary porosity in grainstones is compaction. Although no evidence for chemical compaction has been found in Ocala rocks, there is ample evidence for simple mechanical compaction. The number of grain to grain contacts is much higher than modern carbonate sand bodies, indicating some compaction. In addition, there are numerous broken grains, especially of linear macro-fossil fragments (e.g. thin-shelled foraminifera, echinoderms, and bivalves). It is likely that early mechanical compaction plays a large role in primary porosity loss in these grainstones. While the grainstones show lower or equivalent porosities compared with the other facies, petrographic review shows that void spaces and pore throats are much larger and perhaps connected by less tortuous paths in the grainstones relative to the packstones (see Figure 7). This most likely accounts for the higher vertical hydraulic conductivities in the grainstone facies.

Petrographic point counts (300 points per thin section; Appendix E-3) suggest that the relationship among the grainstones in Figure 33 is due to a combination of factors mentioned above (Figure 35). Between the samples from W-16304 @ 164.9'

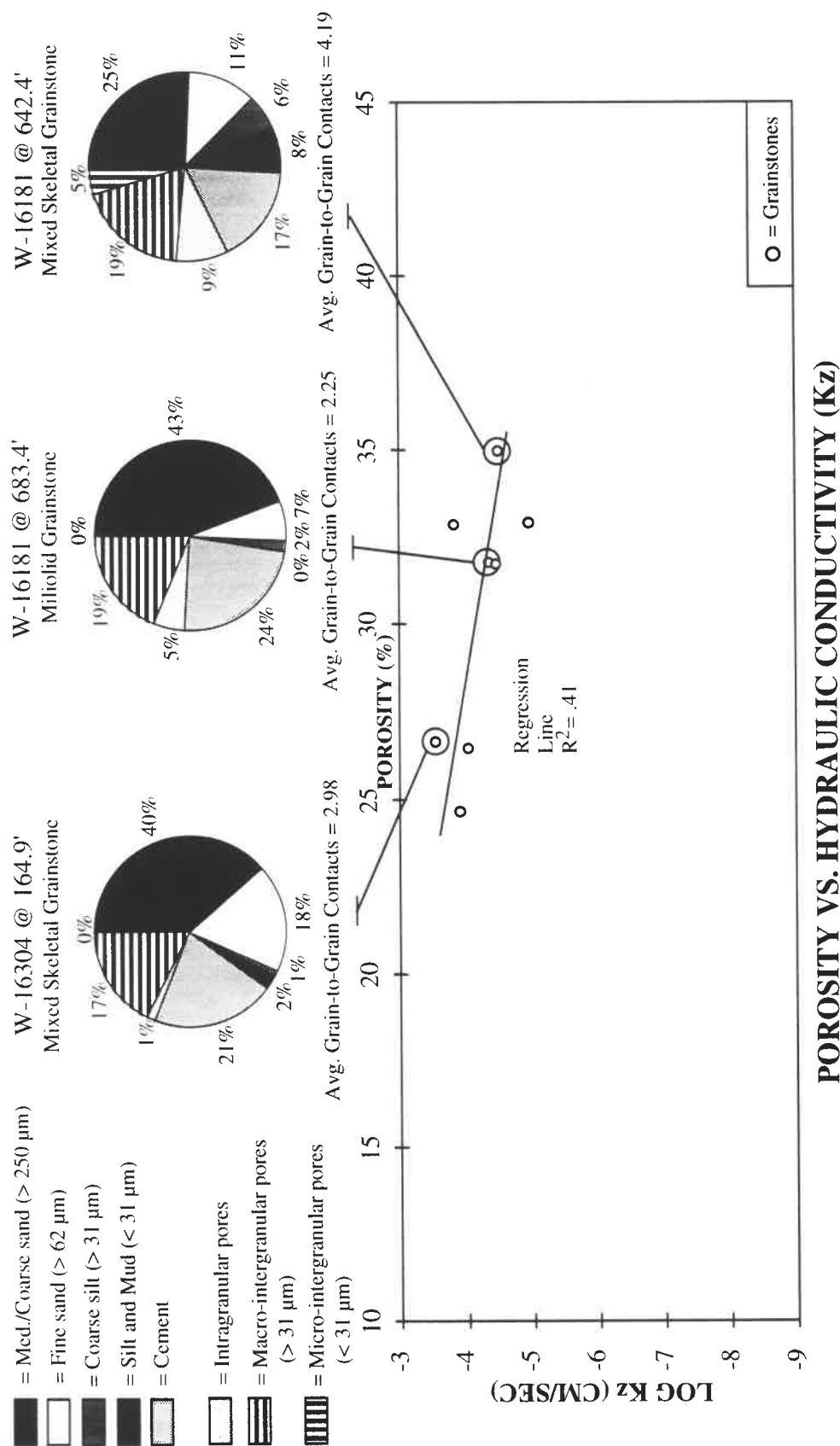


Figure 35: Plot of porosity and vertical hydraulic conductivity for the grainstone class. Three samples were selected along the regression line for point counting. The differences in porosity and hydraulic conductivity between these samples appear to be controlled primarily by compaction, cementation, and mud content. See text for discussion of these factors.

and W-16181 @ 683.4' the most probable factor causing the reduction in vertical hydraulic conductivity is the increase of cement from 21% to 24% (Figure 35). Much of the increased porosity in sample W-16181 @ 683.4' may be attributed to an increase in intraparticle porosity (from 1% to 5%), which would fail to influence the *effective* porosity of the sample. Between samples W-16181 @ 683.4' and W-16181 @ 642.4' the most likely factors causing further reduction in K_z are higher compaction (grain-to-grain contacts), poorer sorting, and the presence of mud sized components in the intergranular voids (Figure 35). The effects of greater compaction on sample W-16181 @ 642.4' would include reduced intergranular voids and narrower or closed pore throats. The effects of poorer sorting and mud sized constituents would also include pore space reduction, but more importantly an increase in flow path tortuosity. Again, much of the increased porosity that was point counted can be attributed to an increase in intragranular porosity (5% to 9%), which would have no bearing on effective porosity.

Two relationships pursued to further understand the hydrogeology of the Ocala Formation are the effect depth has on both matrix porosity and hydraulic conductivity. A plot of depth versus matrix porosity is presented in Figure 36. Regression lines are superimposed through the data for each of the three hydraulic conductivity groups identified. All three regressions show there is almost no relation between depth and matrix porosity in the Ocala Formation. The lack of a significant depth versus porosity trend has also been observed in the overlying Suwannee Formation (Noble 1994). Halley and Schmoker (1983), however, working on carbonates on the Floridan Peninsula have found that a relationship exists between depth and total porosity. Their investigation has a database with over 180 measurement intervals, spanning 2,600 vertical feet, and numerous lithologies and formations. The data sets from this study (Figure 36) and Noble's (1994) span only 1,100 and 100 feet, respectively, one formation each, and exclude vugs and cavernous porosity. For these reasons it may

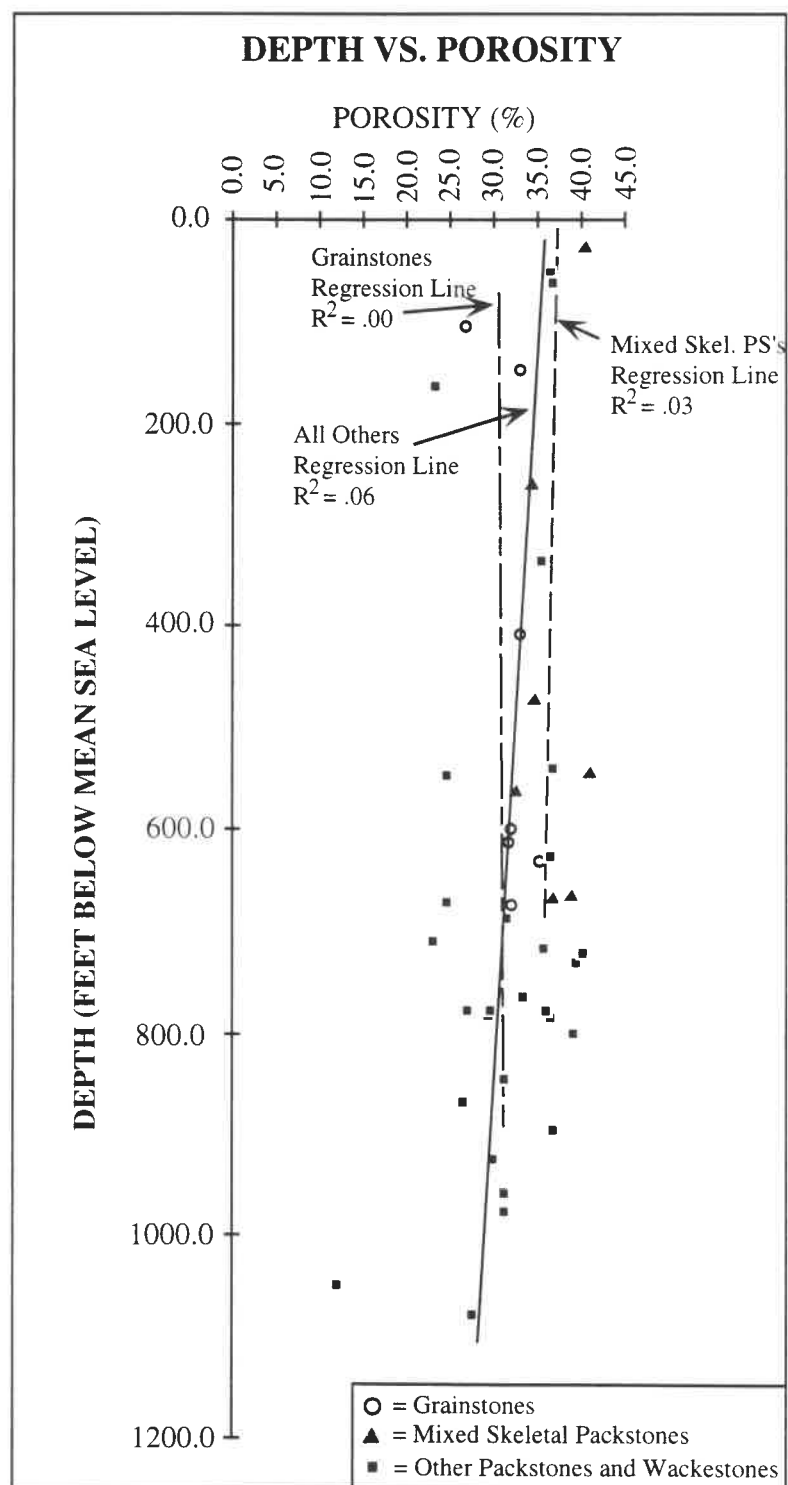


Figure 36: Plot of depth vs. bulk porosity for each of the three hydraulic conductivity classes identified in Figure 32. The figure shows there is little or no correlation between depth and matrix porosity in the Ocala Formation.

not be surprising that no trend is evident. Halley and Schmoker's (1983) equation for porosity loss predicts a 7-8% porosity loss in the west-central Florida Ocala Formation. In addition, as the Ocala Formation is a relatively shallow and/or young formation compared to some of the formations used by Halley and Schmoker (1983), it may not have been subjected to the burial, compaction, and cementation histories attributed to the deeper Cenozoic carbonates of Florida. Finally, it should be emphasized that their porosity measuring instrument (a borehole gravity meter) measures *total* porosity on a meter scale (including cavernous porosity), whereas this Ocala Formation study only measured matrix porosity on a small scale (1-2" of core).

Like the relationship between depth and porosity, the relationship between depth and hydraulic conductivity is weak in the Ocala Formation (Figure 37). The strongest regression ($R^2=.16$) is for the grainstones. As it has been shown that the porosity of the grainstones does not change with depth (Figure 36), it is unlikely that the slight overall decrease in vertical hydraulic conductivity is due solely to compaction.

C. Other Controls on Vertical Hydraulic Conductivity

The thesis of this study only argues that sedimentary facies is a significant factor affecting vertical hydraulic conductivity, but it is acknowledged that facies is not the only control. The influence of three other factors must also be addressed. The first two factors are those historically attributed to the bulk of ground water flow in the Ocala Formation, karstification and fracture flow. The third factor is dolomitization.

While there is no doubt that modern karstification plays a large role in transmissivity where the Ocala Formation is unconfined north of this study area (Ryder 1985), almost no evidence of karstification was found in the Ocala Formation within the study area. This may be partially attributed to sample design and bias in well location. SWFWMD does not site wells in known karst depressions (modern or ancient) and the cores selected for study had to display stratigraphic completeness.

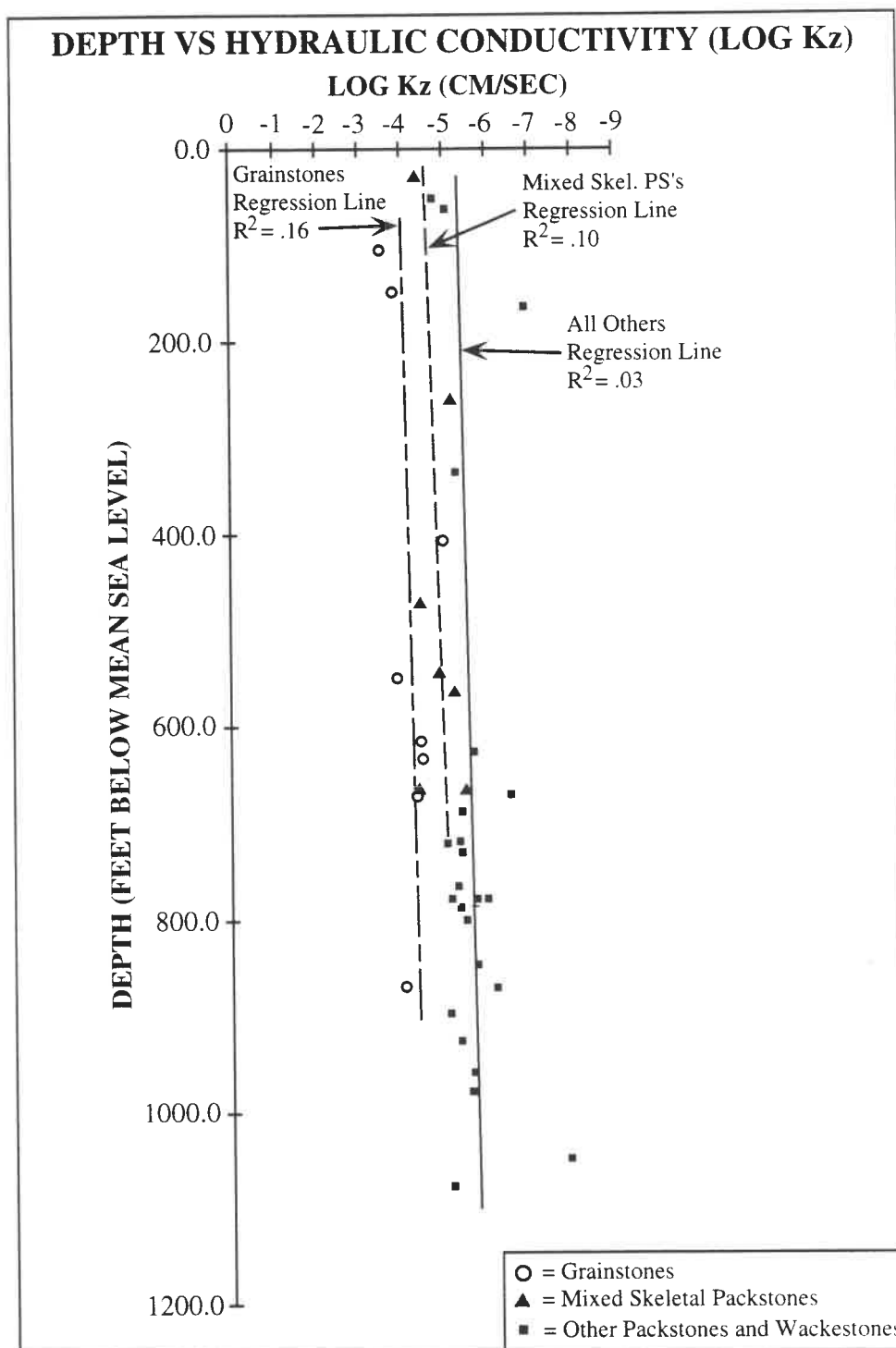


Figure 37: Plot of depth vs. hydraulic conductivity (Log K_z) for each of the three conductivity classes identified in Figure 32. The plot shows a slight (if not insignificant) trend towards lower permeabilities with increased depth for the grainstones and the mixed skeletal packstones.

South of the known karst influence, within the boundaries of this study area, only two cores (W-16307 and W-16576) displayed evidence of paleo-karst, and in both cases, the evidence was stratigraphically in the middle of the Ocala Formation. In only one other core was an overlying formation's sediments found within the Ocala Formation (W-17001). It is therefore believed that paleo-karst features play almost no role in Ocala hydraulic conductivities where the Ocala Formation is confined. It should be noted, however, that the nature of the rock coring hinders the recognition of karst solution channels. If the core barrel is advanced through a macro-void, the field geologist's notes may only reflect a zone of no recovery. In addition, the 2" diameter core represents only a small cross-sectional area and the chance of this area recording an exposure event may be slim (Noble 1994).

Similar to the absence of karst features, very few fractures were observed during core logging and their effect on permeability is believed to be minor in the Ocala Formation in the study area. The number of observed fractures was extremely low, but there was a relative increase in fractures in the dolomite sections compared to the limestones. In the dolomite sections of the Avon Park Formation, beneath the Ocala Formation, much of that unit's high transmissivity is attributed to solution channels along fractures (Hutchinson 1992). It is therefore likely that the presence of thick dolomite sections may dictate the occurrence of fracture flow. Where the Ocala Formation is dolomitized it has been hydrologically lumped together with the Avon Park Formation and is called the "Ocala-Avon Park moderately permeable zone" (Hutchinson 1992). Despite the recognition of fracture flow within the Ocala Formation, the presence of dolomite within the formation is restricted to the basal portions of the unit along the southern Gulf Coast (Manatee and Charlotte Counties, Figure 1) and it is believed to play a minor role in the formation's overall permeability.

It should be noted that the estimates of hydraulic conductivity made by researchers and consultants in the coastal regions are derived from fully penetrating

pump tests (both drawdown and injection). This type of hydrological characterization may have two significant oversights as a result. (1) The presence of fractures within the dolomite *may be facies controlled* and (2) sedimentary facies may be the more dominant effect on hydraulic conductivity *regardless* of fractures. Both factors were found to operate in the comparable dolomitic Silurian aquifer of Wisconsin (Rovey and Cherkauer 1994a, b).

The Silurian dolomitic aquifer is considered analogous to the Ocala-Avon Park dolomite zone because of its mineralogy, similar stratigraphic depths below land surface, and its occurrence in a relatively stable tectonic region. Flow in the Silurian dolomitic aquifer had historically been attributed to jointing and secondary dissolution along joints. It was shown by Rovey and Cherkauer (1994a) that jointing was controlled by facies distribution, where the finer-grained units (wackestones) contained more fractures per meter than the coarse-grained units (packstones and grainstones). The fractures were found to be the dominant control on hydraulic conductivities within the fine-grained units, but overall these hydraulic conductivities were considerably lower than those observed in the coarse-grained units. In the coarse-grained units macro-porosity was found to be the dominant control on hydraulic conductivity and, within the framework of the entire aquifer, these units were found to be the dominant contributor to gross transmissivities. As no such comparable research has been undertaken on the dolomite sections of the Floridan Aquifer to date, alternative hypotheses to fracture control on hydraulic conductivity can only be proposed.

The final potential factor influencing vertical hydraulic conductivity in the Ocala Formation is the nature of the dolomite diagenesis. While no quantitative analyses have been performed on this relationship, cursory petrographic reviews indicate that dolomite diagenesis plays a significant role on porosity evolution, and therefore may impact vertical hydraulic conductivity. Seven of the 40 permeameter samples showed evidence of dolomitization, varying from slight (15% dolomite) to complete (100%).

In most cases, the original sedimentary facies of the dolomites were primarily wackestones and foraminiferal packstones (Figures 10-14) and moderate dolomite diagenesis had little effect on the original low hydraulic conductivities. One sample (W-17057 at 887'), however, represents an extreme case of dolomite diagenesis found in the Ocala Formation. This sample, discussed previously, has been altered to sucrosic dolomite. What was originally a relatively low conductivity wackestone facies has been altered to a texture that approximates a high conductivity grainstone. At the other extreme, another sample displays many molds (W-17087 at 1064.4'), but the dolomite crystals are packed so densely, that high-pressure epoxy infiltration failed in thin section production, and the sample displays the lowest hydraulic conductivity of the 40 samples analyzed. The effect of dolomitization on conductivity for the remaining five samples is believed to be minor. None of the samples appear as anomalies in Figure 33, but the dolomitization may have reduced or enhanced primary porosity (and therefore hydraulic conductivity), sliding the original placement of the sample up or down the regression line.

CHAPTER 4

SYNTHESIS OF SEDIMENTOLOGY, STRATIGRAPHY, AND HYDROGEOLOGY

The first phase of this investigation comprised the identification of sedimentary facies and the delineation of their geographical distribution on the paleo-ramp during the Late Eocene (Chapter 2). The second phase entailed establishing facies-hydraulic conductivity relationships (Chapter 3). The results of the second phase support the original hypothesis that higher energy facies display the highest vertical hydraulic conductivities in the modern aquifer. The lower energy facies, dominated by mud sized constituents, display vertical hydraulic conductivities more than an order of magnitude lower than the higher energy facies. By combining the results of the two investigations, a detailed hydrogeologic framework for the Ocala Formation in west-central Florida can be produced. If one uses a conservative estimate of the K_z to $K_{x,y}$ ratio of 1:10 (Walton 1991) then the extent of the heterogeneity of this hydrogeologic framework becomes even more apparent.

The central tenet of facies controlled hydraulic conductivity has been demonstrated in Chapter 3. The miliolid grainstones, mixed skeletal grainstones, and mixed skeletal packstones are the three facies that display mean vertical hydraulic conductivity on the order of 1.00×10^{-5} cm/sec. The remainder of the packstones and the wackestones have mean vertical hydraulic conductivities on the order of 1.00×10^{-6} and 1.00×10^{-7} cm/sec (Figure 32). The division of these groups has been shown to be statistically significant (Tables 4-7). A general spectrum of facies from north to south of grainstones to wackestones has been shown to characterize the general depositional packaging within each of the first two depositional sequences of the Ocala Formation (Figures 22 and 24). Sequence #3 displays comparable facies belts at its base, but a eustatic fall at the end of the Late Eocene left much of the sequence eroded in the north and the signature of a forced regression (i.e. shallower water, grain rich

sediments) at the top of the sequence across the remainder of the study area (Figure 26). Because hydraulic conductivities are closely linked to the environmental energy in which the facies were deposited, it is reasonable to convert facies cross sections into hydrogeological sections of hydraulic conductivities. The conceptual basis for this conversion is illustrated in Figure 38.

Figures 39 through 43 show cross sections A-A' through E-E' from Chapter 2, with vertical hydraulic conductivity zonations superimposed. The miliolid and mixed skeletal grainstones have been combined as one conductivity class, the mixed skeletal packstone is a second class, and all other packstones and wackestones are grouped as a third class.

Along the western and west-central portions of the study area (Figures 39, 40, and 41), the northern portion of sequence #1 should display laterally continuous high vertical conductivities. The lithology is dominated by coarse grainstones with good matrix porosity. The presence of these grainstone facies should make the lower Ocala Formation a highly transmissive unit throughout Hernando, Pasco, Pinellas, Hillsborough and Polk Counties. Moving down the ramp to the south there is a wedge of "transitional" mixed skeletal packstones that should also be transmissive (e.g. Figures 39 and 40). Low vertical hydraulic conductivity, mud-rich, facies prevail throughout sequence #1 in the southern counties of Manatee, Hardee, Highlands, Sarasota, Desoto, and Charlotte and the transmissivity of this portion of the Ocala Formation should be low. There may be local regions of high conductivity where the dolomite is sucrosic (e.g. W-17057 at 887'), but detailed core logging indicates this type of dolomitization is not pervasive. Similarly, there may be localized regions of high transmissivity where fractures in the dolomite are large and common, but such zones were rarely observed. Along the southern boundary of the study area, sequence #1 is dominated by extremely low conductivity ($\leq 1.00 \times 10^{-6}$ cm/sec) wackestone facies (Figure 42).

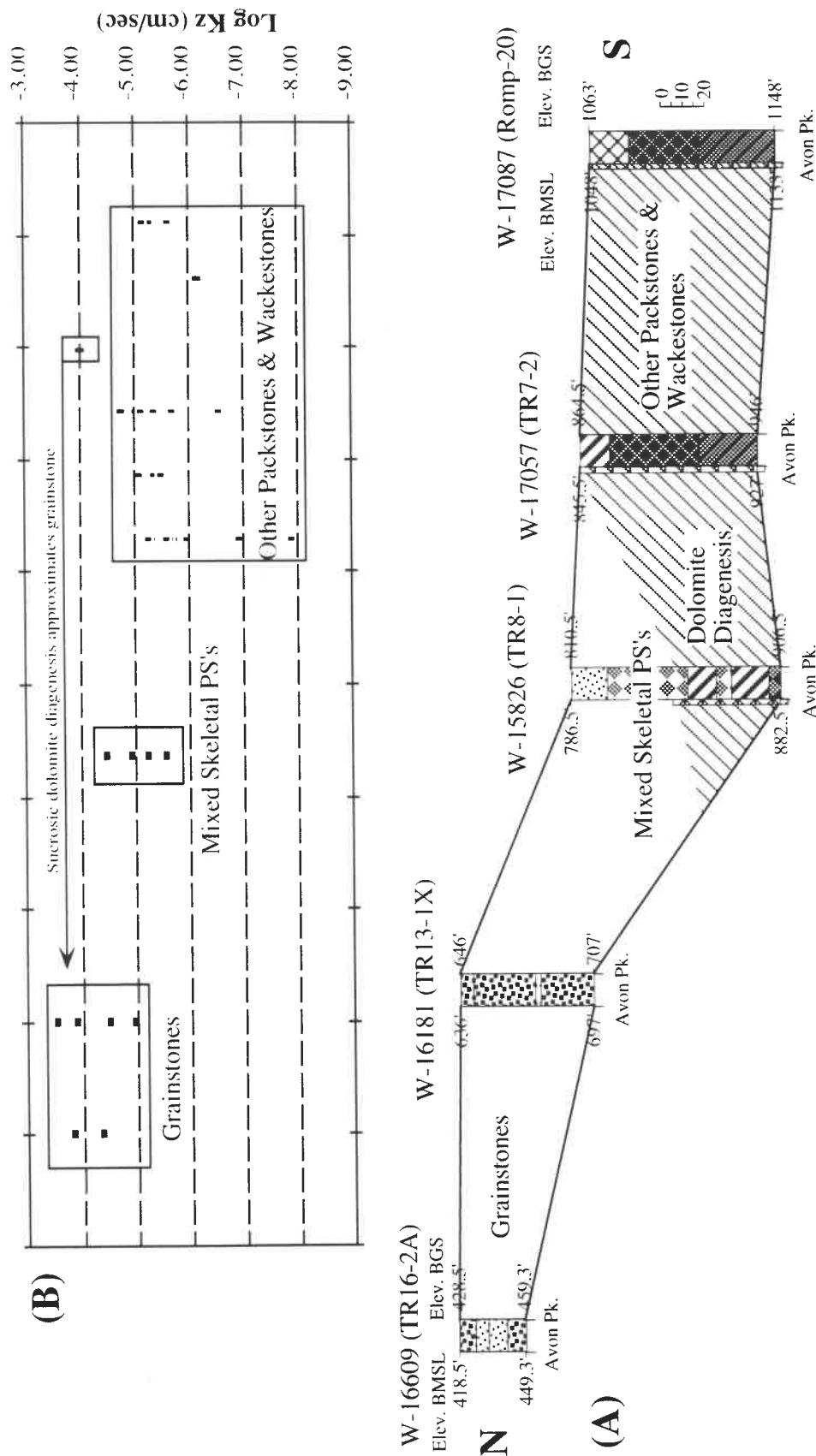


Figure 38: (A) Sequence #1 along the western coast (cross section A-A') showing grainstones to the north and packstones to wackestones to the south (facies symbols as per Figure 9). (B) Kz data from Figure 32. The facies zonation of the Kz data suggests that paleo-environmental energies (depth on the ramp) will largely control vertical hydraulic conductivities within the modern aquifer. In the case of sequence #1, this means high Kz to the north and low Kz to the south.

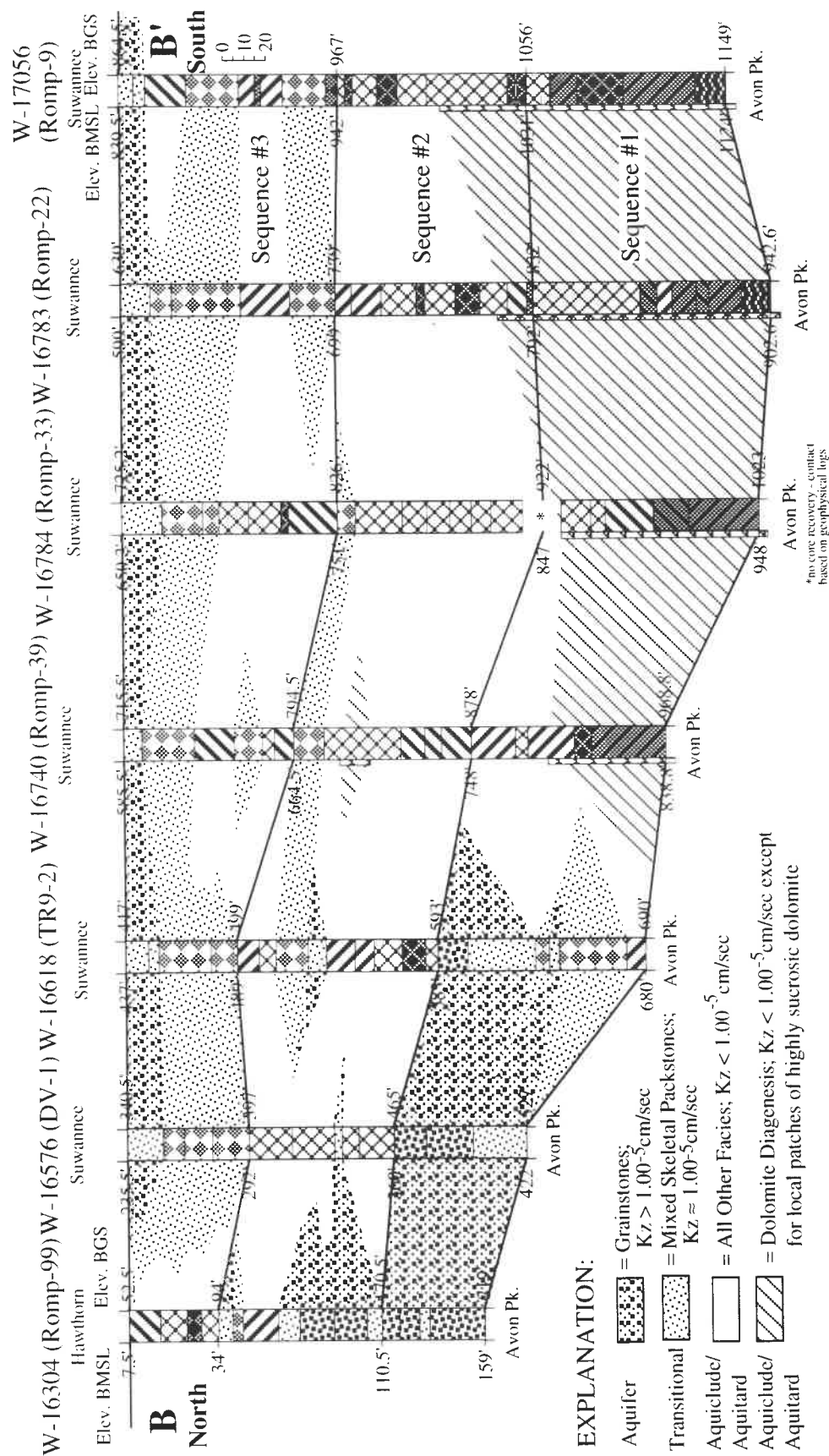


Figure 40: Cross section B-B' along the west-central portion of the study area (see Figures 8 and 9 for cross section location and facies patterns). Superimposed on the cross section are vertical hydraulic conductivity zones based on the results of Chapter 3. Care was taken to shape conductivity zone geometries based on sequence boundaries and tentative cycle boundaries (Figure 11). Note that higher conductivity zones are primarily restricted to sequences #1 and #3.

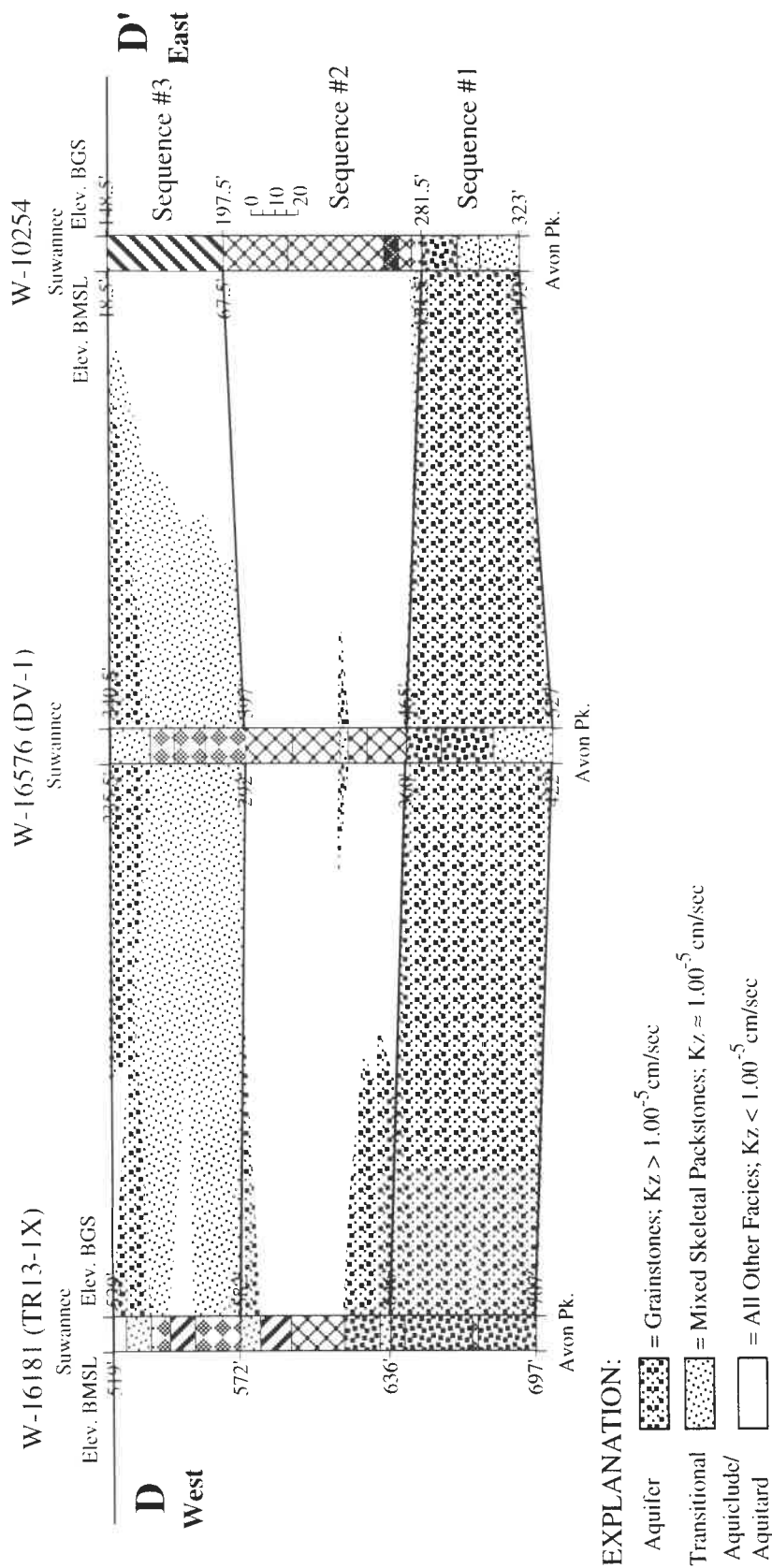


Figure 41: Cross section D-D' along the northern portion of the study area (see Figures 8 and 9 for cross section location and facies patterns). Superimposed on the cross section are vertical hydraulic conductivity zones based on the results of Chapter 3. Care was taken to shape conductivity zone geometries based on sequence boundaries and tentative cycle boundaries (Figure 13). Note that the higher conductivity zones blanket sequence #1 and most of sequence #3.

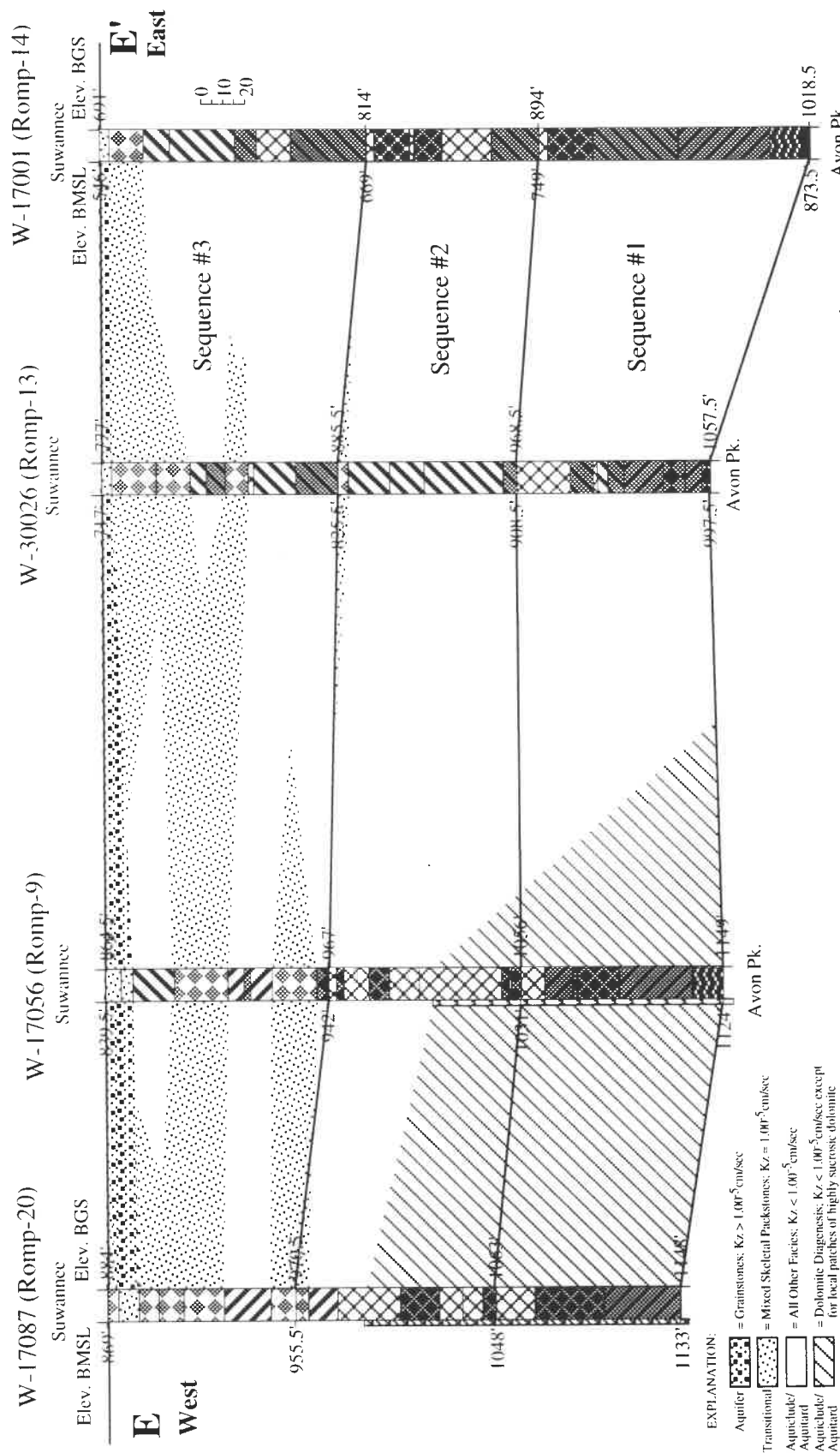


Figure 42: Cross section E-E' along the southern portion of the study area (see Figures 8 and 9 for cross section location and facies patterns). Superimposed on the cross section are vertical hydraulic conductivity zones based on the results of Chapter 3. Care was taken to shape conductivity zone geometries based on sequence boundaries and tentative cycle boundaries (Figure 14). Note that higher conductivity zones are exclusively limited to sequence #3.

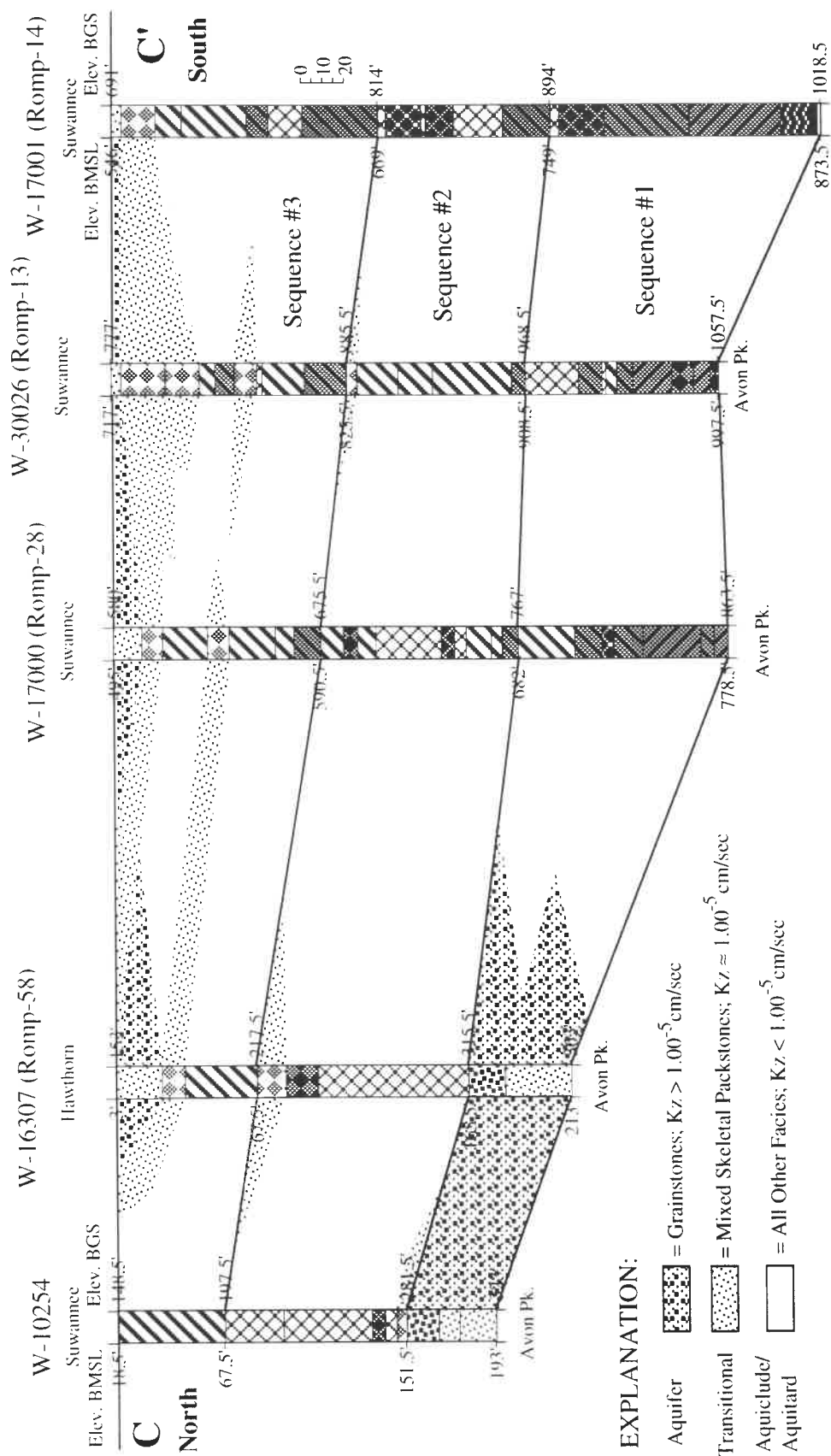


Figure 43: Cross section C-C' along the eastern portion of the study area (see Figures 8 and 9 for cross section location and Avon Pk. facies patterns). Superimposed on the cross section are vertical hydraulic conductivity zones based on the results of Chapter 3. Care was taken to shape conductivity zone geometries based on sequence boundaries and tentative cycle boundaries (Figure 12). Note that higher conductivity zones are primarily restricted to sequences #1 and #3.

Sequence #2 in the west-central and coastal regions (Figures 39 and 40) contains few zones of high conductivity facies. They are primarily limited to the north and north-western reaches of the sequence (Figures 39-41), and immediately overlie the high K_z zones of sequence #1. There are also thin, areally limited zones of grainstones and mixed skeletal packstones at the top of sequence #2 in the middle of the study area (Figures 39, 40, 41, and 43). However, across most of the study area, this sequence is dominated by macro-foraminiferal packstones which have been shown to have relatively low hydraulic conductivities. South of Manatee and Hardee Counties, all of sequence #2 should display uniformly low hydraulic conductivities (Figure 42).

Sequence #3, the upper Ocala Formation, along the western portions of the study area should be a moderately to highly transmissive unit (Figures 39-41). The sequence is dominated by mixed skeletal packstone facies across the southern 2/3 of the study area (Figure 26) and is capped across the middle of Hillsborough and Polk Counties by grainstone facies. In addition, the widespread occurrence of karst solution channels to the north, where the Ocala Formation is unconfined, should provide a good recharge for the upper Ocala Formation as it dips to the south and west. The presence of abundant high conductivity facies makes this sequence of the Ocala Formation the most geographically transmissive sequence across west-central Florida. Along the southern boundary of the study area, sequence #3 is the only sequence that should display intervals of high vertical hydraulic conductivity (Figures 39-42).

As evidenced by Figures 41 and 42 the Ocala Formation high conductivity facies appear to thin and terminate to the east. Cross section C-C' (Figure 43), along the eastern boundary of the study area, confirms this observation. The blanket of grainstone facies remains present throughout Polk County within sequence #1, but there are almost no high conductivity facies in sequence #2. In sequence #3 there are fewer zones of mixed skeletal packstones than the west (compare to Figures 39 and 40). The overall scarcity of higher energy facies to the east may reflect greater paleo-

geographic distance on the ramp from prevailing wave energies during the Late Eocene. W-17001, in the extreme southeast, is dominated by wackestone facies throughout and may even be indicative of distal ramp deposition into the South Florida Basin (see Figure 2).

Figures 44-46 show map views of the three sequences contoured by the percentage of the sequence represented by either high or low vertical hydraulic conductivity facies. For these maps the grainstone facies and the mixed skeletal packstones were lumped as higher K_z facies and the remainder of the facies as lower K_z facies. The maps accentuate many of the observations made from the hydrogeologic cross sections (Figures 39-43). Sequence #1 (Figure 44) is dominated by higher vertical hydraulic conductivity facies across the northern portions of the study area and this rapidly grades into the lower K_z facies which prevail in the southern portions of the study area. Sequence #2 (Figure 45) is dominated by lower K_z facies across most of the study area, except for a swath of higher K_z facies extending from Pinellas County through the middle of Pasco County. Sequence #3 (Figure 46) dramatically shows the eastward thinning out of higher K_z facies that are dominant along the coast. The final map of this series (Figure 47) shows the distribution of higher and lower K_z facies for the entire Ocala Formation. The Ocala lithologies contain the highest concentration of vertically conductive facies across most of Pinellas, Hillsborough, and Pasco Counties. Counties dominated by the lower hydraulically conductive facies include Polk, Manatee, Sarasota, Hardee, DeSoto, Highlands, and Northern Charlotte.

Combining the five cross sections displaying the hydrogeologic framework of the Ocala Formation (Figures 39-43) produces a 3-dimensional fence diagram (Figure 48). This diagram condenses all the results of this investigation to summarize the hydrogeology of the Ocala Formation in west-central Florida. All high conductivity facies have been combined as one in this figure (indicated in blue). The white spaces on the fences indicate lower conductivity facies. In 3-dimensions, the observations

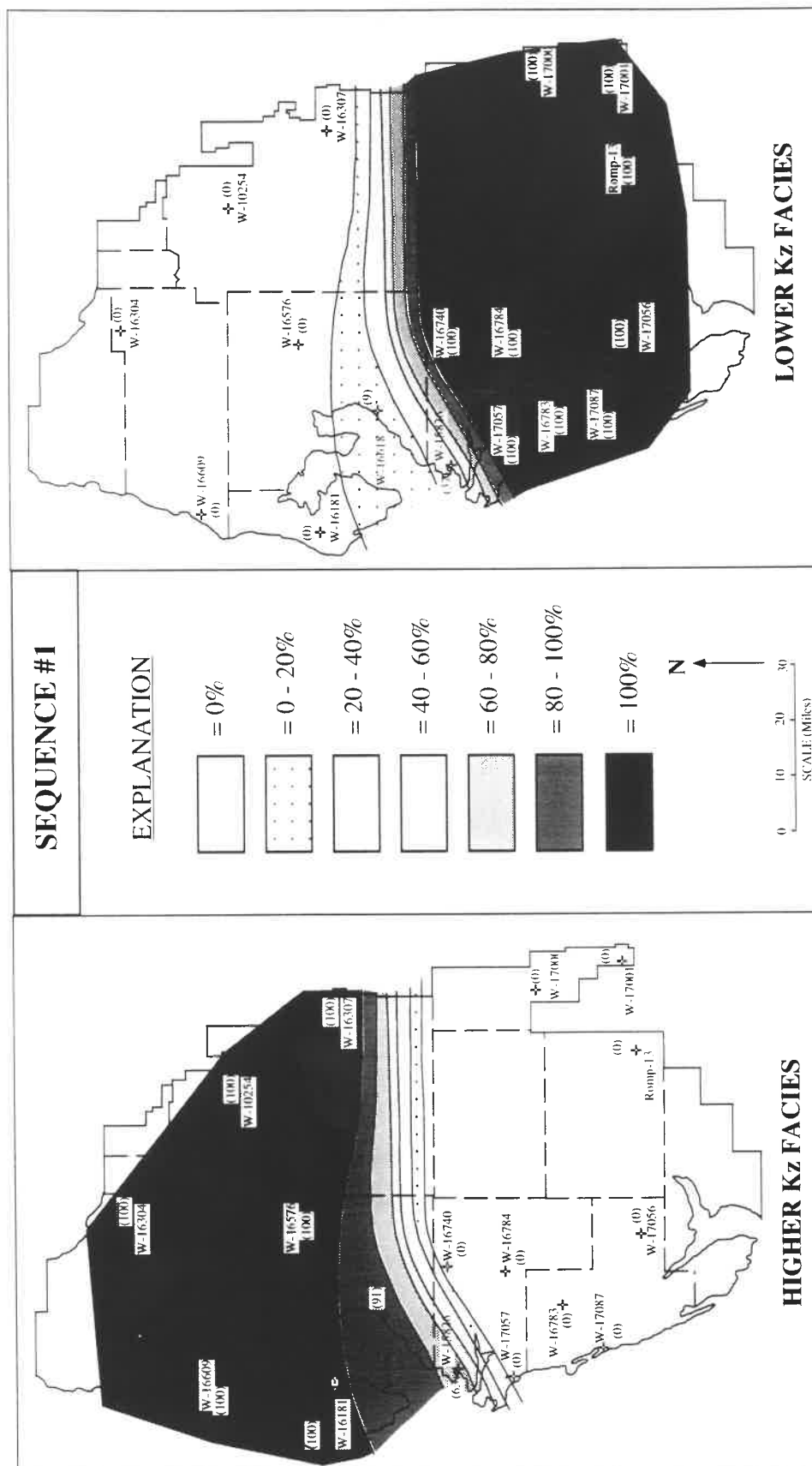


Figure 44: Contour maps of higher and lower vertical hydraulic conductivity (Kz) facies found in sequence #1. Contour interval is in 20% increments of the total thickness of the sequence in that well. The higher Kz facies are concentrated across the northern 1/2 of the study area. The lower Kz facies are dominant in the southern 1/2 of the study area.

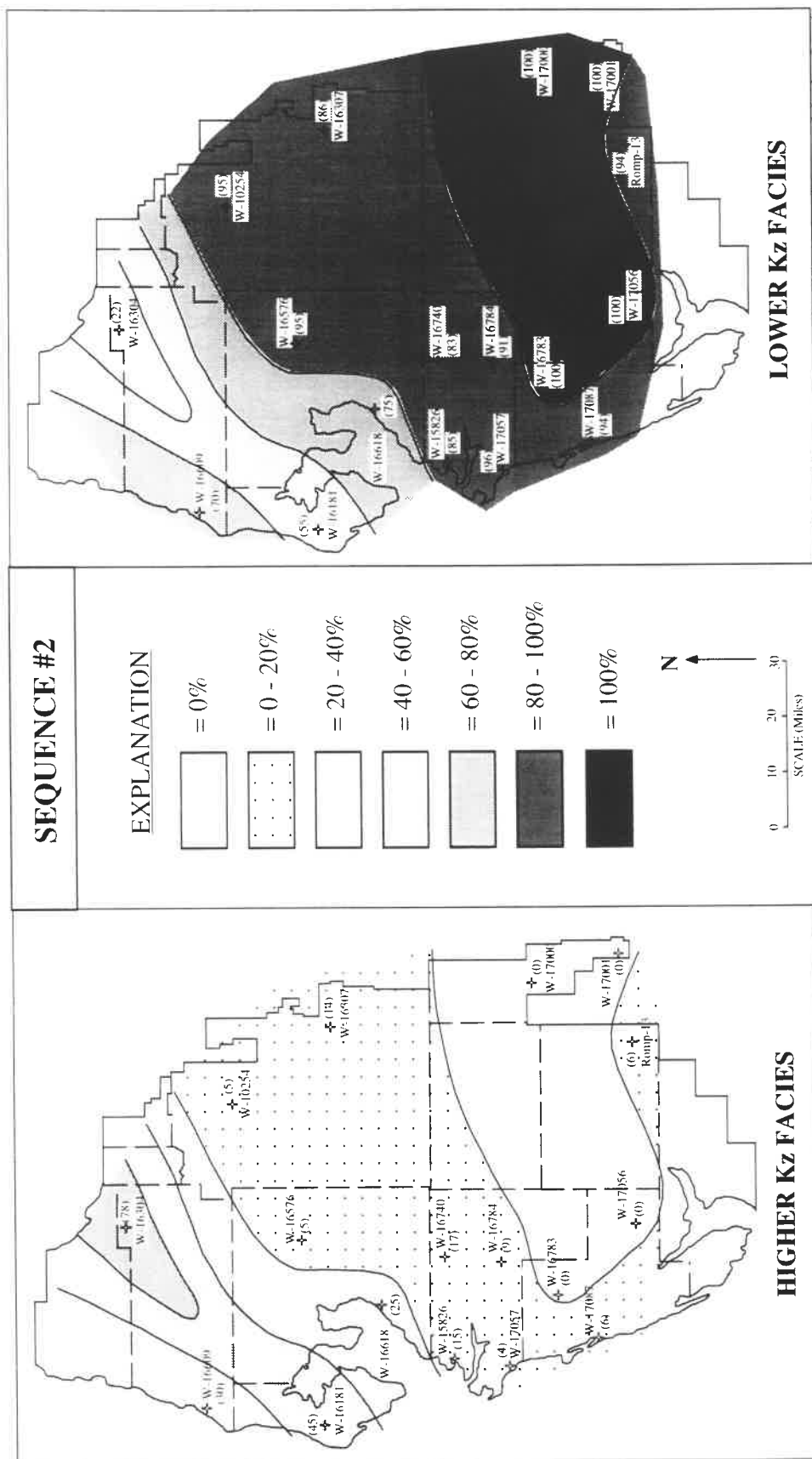


Figure 45: Contour maps of higher and lower vertical hydraulic conductivity (Kz) facies found in sequence #2. Contour interval is in 20% increments of the total thickness of the sequence in that well. The higher Kz facies are concentrated in a narrow belt across Pinellas, Hillsborough, and Pasco Counties. The lower Kz facies dominate most of sequence #2. This sequence may act a regionally confining aquiclude/aquitard across most of Hillsborough County, and south and east across Polk, Manatee, Sarasota, Hardee, Highlands, Desoto, and Charlotte Counties.

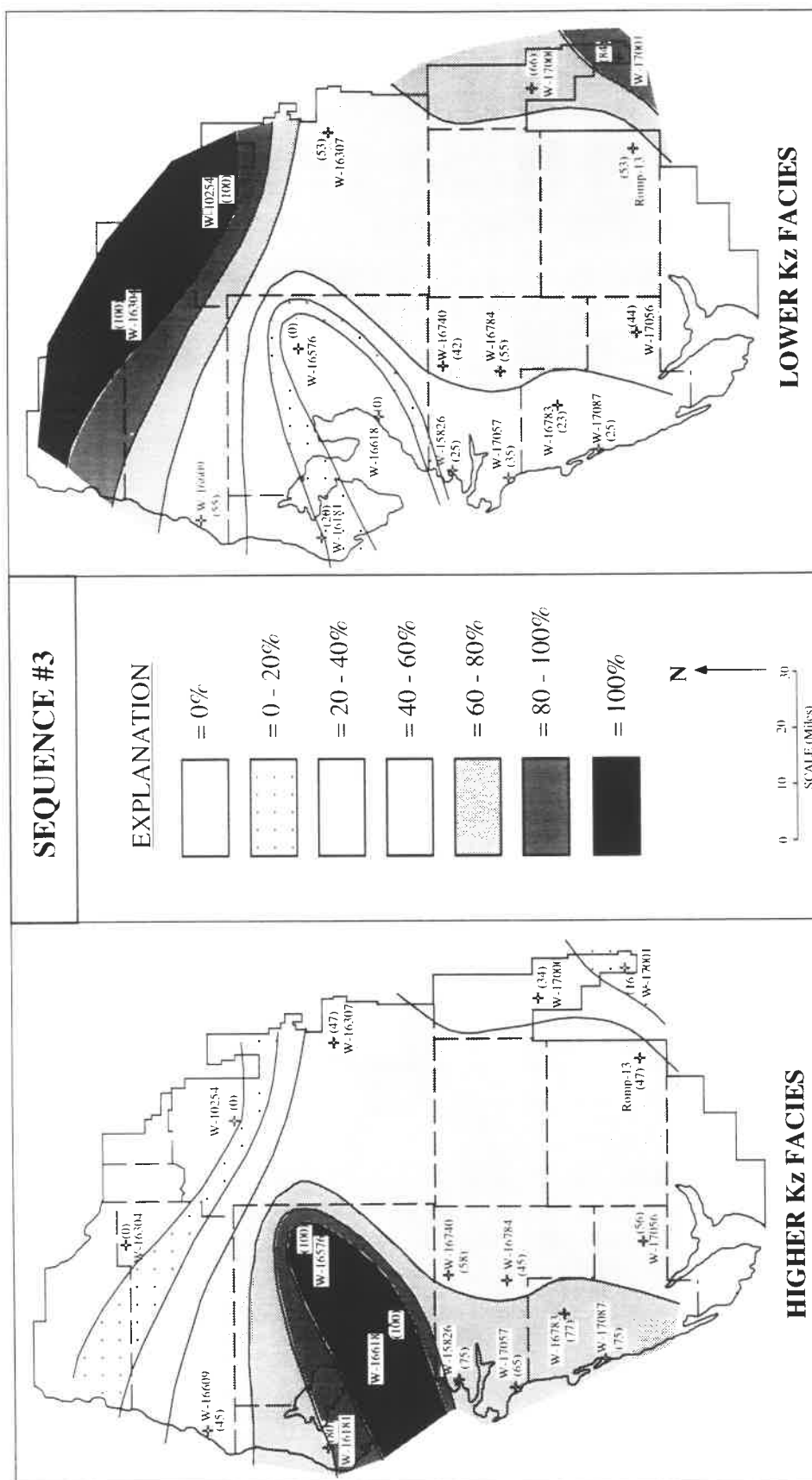


Figure 46: Contour maps of higher and lower vertical hydraulic conductivity (Kz) facies found in sequence #3. Contour interval is in 20% increments of the total thickness of the sequence in that well. The higher Kz facies are concentrated underneath the modern Tampa Bay Embayment and along the coast to the north and south of the embayment. The lower Kz facies are dominant in the extreme southeast and along the northern portion of the study area. The sediments of the northern region are what remains of sequence #3 following post-Eocene topographic erosion, resulting in a biased distribution of lower Kz facies.

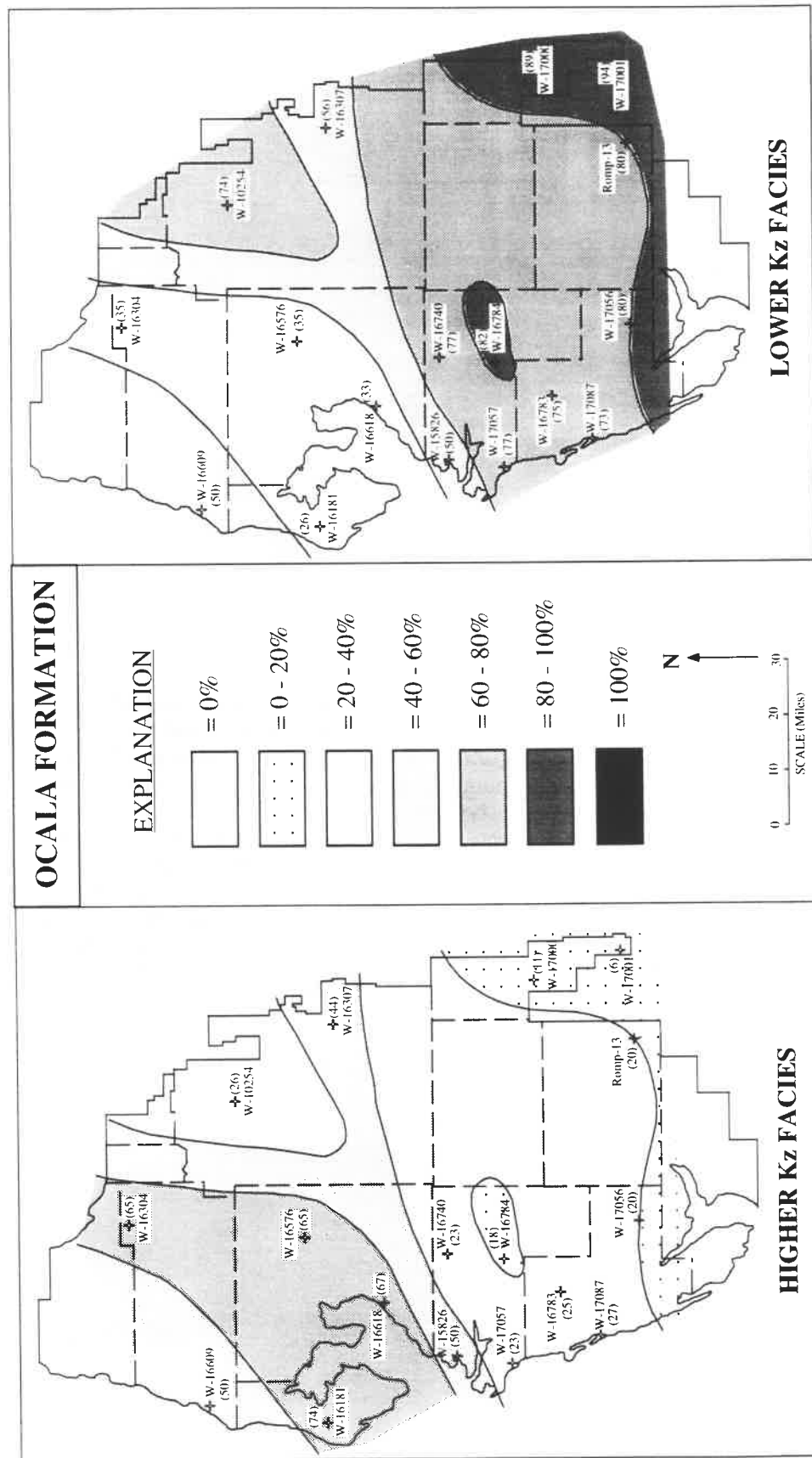
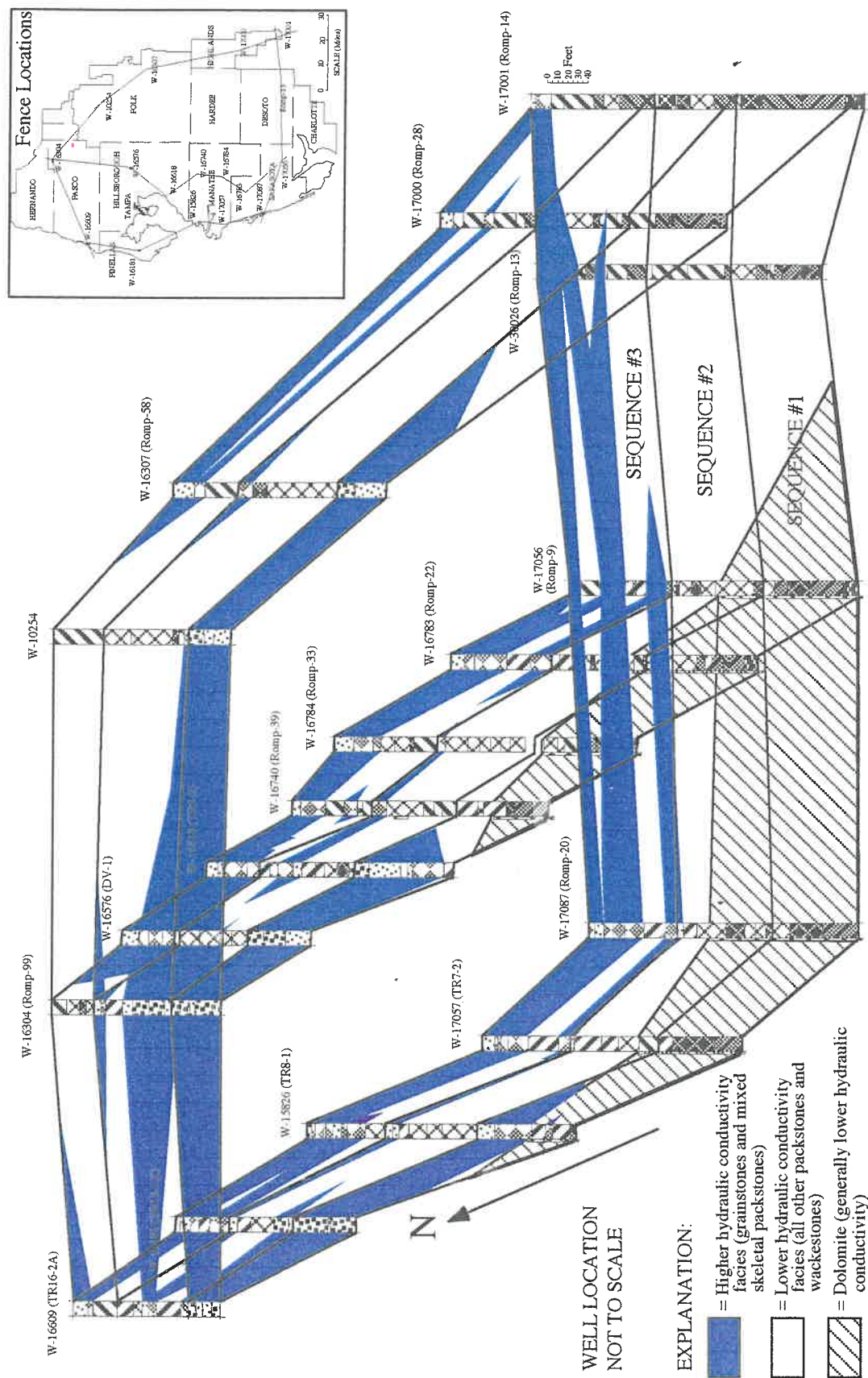


Figure 47: Contour maps of higher and lower vertical hydraulic conductivity (Kz) facies found in the Ocala Formation. Contour interval is in 20% increments of the total thickness of the Ocala Formation in that well. The higher Kz facies are concentrated in a swath across Pinellas, Hillsborough, and Pasco Counties. The lower Kz facies are dominant in parts of Polk County, and south across Manatee, Hardee, Highlands, Sarasota, Desoto, and Charlotte Counties.

Figure 48: Three-dimensional fence diagram showing regions of higher and lower conductivities in the Ocala Formation. Zones colored blue are those facies identified as having higher conductivities and zones colored white are those facies identified as having lower conductivities. The diagram was constructed using the sedimentary framework of the Ocala from Chapter 2 and the hydrogeological analyses of the sedimentary facies from Chapter 3. The figure shows sequence #1 is conductive in the north, sequence #2 is primarily comprised of lower conductivity facies, and sequence #3 is conductive across most of the region. Note that cross section D-D' has been omitted and replaced with a fence that encompasses the three most northern wells. The other four fences are cross sections A-A', B-B', C-C', and E-E'. Fence and well locations are shown in the inset map.



made on the individual cross sections stand out with greater resolution. Sequence #1 should be highly transmissive across the northern half of the study area, sequence #2 should be relatively non-transmissive across the study area, and sequence #3 should be moderately transmissive where it is confined and highly transmissive where it is eroded and unconfined to the north of this study area due to modern karst derived solution channels.

The observations made here on the Ocala Formation may prove useful for regional ground water planning. As the Ocala Formation is considered a relatively non-transmissive unit compared to the overlying Suwannee Formation and underlying Avon Park Formation the question arises as to how effective it is as an aquitard between these two transmissive formations. This is especially critical along the southwest coast where the Suwannee Formation is utilized for potable water extraction and the Avon Park is utilized for waste water injection (D. DeWitt, SWFWMD, pers. comm., 1994). The cross-sections, maps, and fence diagram (Figures 39-48) demonstrate the heterogeneous nature of the Ocala Formation's hydrogeology, and as a whole, it should not be considered an aquitard/aquiclude between the Suwannee and Avon Park Formations. Only sequence #2 demonstrates geographically continuous lower vertical hydraulic conductivity facies across the southern 3/4 of the study area and could be considered an aquiclude/aquitard. Sequence #1 also contains a broad region of lower K_z facies in the southern 1/2 of the study area. As sequence #1 in much of this region has been dolomitized, however, there may be diagenetic alterations on the original low hydraulic conductivity. In summary, the presence of three distinct sequences containing fine-scale heterogeneous facies warrants the label "leaky" to either higher or lower conductivity zones of the Ocala Formation.

It should be noted that there remains a large geographic region that lacks any good facies or K_z data in southwestern Polk County, Hardee County, and most of Desoto County. The lack of data has also been recognized by SWFWMD, as the

majority of their near-term field efforts will be focused on this region (SWFWMD pers. comm., 1994). With the addition of more continuous cores and falling head permeameter data, the delineation of the Ocala's hydrogeologic framework will be resolved with more detail and higher confidence. The detailed framework, as first defined here, however, provides a good working conceptual model for ground water resource utilization.

CHAPTER 5

CONCLUSIONS

The results of this investigation document, for the first time, a detailed sedimentologic, stratigraphic, and hydrogeologic framework for the Ocala Formation in west-central Florida. A similar sedimentologic and stratigraphic model was produced for the Suwannee in the same study area by Hammes (1992). The breadth of research that is emerging from west-central Florida should provide invaluable tools for a diverse array of geologists, from hydrogeologists, to Gulf Coast sequence stratigraphers, and carbonate sedimentologists. A number of significant conclusions can be summarized from the results of this investigation.

- The Ocala Formation in west-central Florida is the result of 4.5 million years of carbonate sediment deposition on the West Florida ramp during the Late Eocene. Its heterogeneity was recognized by the delineation of facies within the formation. Twelve sedimentary facies are identified that reflect allochemic variations on three broad textures: grainstones, packstones, and wackestones. Mudstones are extremely rare in this study area as is any evidence of subaerial exposure. Within the study area, the West Florida ramp was almost entirely beneath base level, resulting in subaqueous deposits throughout the Ocala Formation. Extensive topographic erosion during the Late Eocene sea level fall and the Ocala Uplift event produced a partially eroded top of the Ocala in the northern reaches of the study area.

- Two internal sequence boundaries are recognized within the Ocala in addition to the two sequence boundaries that bound the whole formation. The recognition of three 3rd order sequences in the Late Eocene agrees with most

researchers on the Floridan Peninsula (Vernon 1951; Puri 1953), the central Gulf of Mexico (Baum et al. 1994), and Texas (Mitchum, pers. comm., 1995). The four sequence boundaries recognized in this study are interpreted in ascending order as Type 1, Type 2, Type 2, and Type 2. The most recent sequence boundary, that of the Eocene/Oligocene boundary, has been interpreted elsewhere as a Type 1 boundary, but localized structural events on the West Florida ramp (Ocala Uplift) left the lithologic imprint of a Type 2 boundary on most of the study area.

- The twelve sedimentary facies identified are: laminated pelagic wackestone, bioturbated pelagic wackestone, mixed skeletal wackestone, nummulites wackestone, lepidocyclina wackestone, nummulites/lepidocyclina wackestone, nummulites packstone, lepidocyclina packstone, nummulites/lepidocyclina packstone, mixed skeletal packstone, mixed skeletal grainstone, and miliolid grainstone. These facies were distributed through time and space in distinct facies belts on the paleo-ramp. The grainstone facies occupy a region in the northern portion of the study area and are interpreted as representing an upper ramp environment. The mixed skeletal packstones occupy the region immediately adjacent to the grainstones, and are interpreted as having originated in slightly deeper paleo-water depths. The depositional range of the foraminiferal packstones varies significantly over the three sequences identified, but always represents a middle ramp position seaward of the facies mentioned above. The wackestone facies represent the deepest water facies found on the ramp and are restricted primarily to the southern portions of the study area where they probably indicate a transition into the South Florida basin.

- The subaqueous nature of the Ocala's deposition makes recognition of 4th and 5th order eustatic cycles difficult. The cycles recognized in this study are tentative and are based primarily on discrete shifts in mean grain size. Identification and correlation of these cycles with a high degree of confidence proved to be beyond the scope of this investigation, but this may be a feasible and worthwhile exercise for future researchers.
- Vertical hydraulic conductivity values, derived from falling head permeameter tests, indicate they are directly related to sedimentary facies. The highest conductivity facies are the miliolid grainstones and mixed skeletal grainstones, with geometric means of 7.77×10^{-5} and 5.13×10^{-5} cm/sec, respectively. A third facies, the mixed skeletal packstones, displays mean hydraulic conductivities on the order of the grainstones at 1.32×10^{-5} cm/sec. These three facies, taken together, represent the aquifer lithologies of the Ocala. The remainder of the sedimentary facies display geometric mean hydraulic conductivities on the order of 1.00×10^{-6} to 1.00×10^{-7} cm/sec. The flow rates for these facies do not represent aquitard conditions and should be considered aquicludes.
- Porosity measurements taken on Ocala samples show that porosity ranges from 11.9% to 40.9%, with a mean of 32.3%. These measurements, taken adjacent to the permeameter samples, suggest a number of relationships between porosity, vertical hydraulic conductivity, and sedimentary facies. For the grainstones, K_z decreases with an increase in porosity. This trend may be an inaccurate fabrication of low sample size or may be attributable to varying combinations and degrees of cementation and compaction. The mixed skeletal packstones appear to have uniformly high porosities and hydraulic

conductivities, but the correlation suggests an increase in K_z with an increase in porosity. This relationship also proves strongly true for the remainder of the packstone facies and the wackestone facies. The relationship is attributed to the relative abundance of mud sized particles; when abundant they reduce matrix porosity, clog pore throats, and increase the tortuosity of flow paths.

- The effects of depth on both porosity and hydraulic conductivity have been shown to be minor in the Ocala. Similarly, within the study area, core logging revealed rare karst features and fractures. Calcite cementation in the Ocala was restricted primarily to thin (< 2 ft), coarse grained units at the tops of sequences. These observations, combined with the facies and hydraulic conductivity correlations, suggest sedimentary, not diagenetic, control on limestone conductivities.

One diagenetic factor that does play a significant role in the conductivity of the Ocala along the southwest coast is dolomitization. Dolomite diagenesis can either enhance or reduce primary limestone porosity and conductivity, with examples of both documented in this study. It is clear that more research needs to be devoted to the dolomite sections of the Ocala Formation to discern the effects that dolomitization has on K_z and fracture-controlled flow. Obviously, this type of study would have to address scale issues and synthesize laboratory derived data (e.g. falling head permeameters) with field derived data (e.g. pump tests and flow meters).

- The spectrum of sedimentary facies and their corresponding geometric mean vertical hydraulic conductivities is closely linked to paleo-environmental position on the West Florida ramp. Facies deposited under higher energy regimes on the upper ramp, display larger grain and pore sizes and less mud

sized particles, all resulting in the higher conductivities observed in the modern aquifer. Conversely, the facies deposited in the deeper, lower energy environs of the ramp are dominated by abundant mud sized particles and poorer sorting resulting in the lower hydraulic conductivities observed.

- The results of sedimentologic, stratigraphic, and hydrogeologic phases of this investigation enabled the construction of a 3-dimensional hydrogeologic framework for the Ocala Formation in west central Florida. The upper and lower sequences of the formation (sequence #1 and #3) contain broad geographic regions of high conductivity facies. Sequence #2, for the most part, is dominated by lower conductivity facies and may serve as a regionally persistent aquiclude/aquitard between the regional transmissive zones of the Suwannee and Avon Park Formations. Conservatively estimating the K_z to $K_{x,y}$ ratio to be 1:10 should prove useful in predicting zones of the Ocala Formation that would be regionally transmissive or relatively non-transmissive.

As an outcome of this investigation the pursuit of answering previously unanswered questions has generated as many new questions as it answered. Future research efforts in this region could include (1) the assessment of high-frequency cyclicity within the Ocala Formation, (2) detailed quantitative petrographic definition of sedimentary facies, (3) the use of detailed foraminiferal paleoecology to refine paleo-environmental interpretations, (4) the addition of more laboratory-scale hydrogeologic tests and the addition of continuous flow meter logs and pump tests to verify and strengthen facies controlled conductivity observations, (5) investigations on K_z heterogeneity and scale-dependent effects, and (6) detailed analyses of the dolomite sections to provide more insight on the hydrologic significance of this post-depositional

diagenesis. The need for such additional research is paramount to the intelligent utilization and maintenance of the ground water resources in west-central Florida.

BIBLIOGRAPHY

- Ahr, W. M., 1973, The carbonate ramp: An alternative to the shelf model: Gulf Coast Association of Geological Societies Transactions, v. 23, p. 221-225.
- Aigner, T., 1982, Event-stratification in nummulite accumulations and in shell beds from the Eocene of Egypt, *in* Einsele, G. and A. Seilacher, eds., *Cyclic and Event Stratification*: Berlin, Springer-Verlag, p. 248-262.
- Aigner, T., 1985, Biofabrics as dynamic indicators in nummulite accumulations: *Journal of Sedimentary Petrology*, v. 55, p. 131-134.
- Anderson, M. P., 1989, Hydrogeologic facies models to delineate large-scale spatial trends in glacial and glaciofluvial sediments: *Geological Society of America Bulletin*, v. 101, p. 501-511.
- Applin, P. L. and Applin, E. R., 1944, Regional subsurface stratigraphy and structure of Florida and Southern Georgia: *American Association of Petroleum Geologists Bulletin*, v. 28, p. 1673-1753.
- Baum, J. S., Baum, G. R., Thompson, P. R. and Humphrey, J. D., 1994, Stable isotopic evidence for relative and eustatic sea level changes in Eocene to Oligocene carbonates, Baldwin County, Alabama: *Geological Society of America Bulletin*, v. 106, p. 824-839.
- Bevington, P. R., 1969, *Data Reduction and Error Analysis for the Physical Sciences*: New York, McGraw-Hill, 336 p.
- Blair, T. C., Baker, R., and Turner, J., 1991, Cenozoic fluvial-facies architecture and aquifer heterogeneity, Oroville, California, Superfund Site and vicinity, *in* Tyler, N., and Miall, A.D., eds., *Three Dimensional Facies Architecture of Terrigenous Clastic Sediments and Its Implications for Hydrocarbon Discovery and Recovery: SEPM Concepts in Sedimentology and Paleontology* 3, p. 147-159.
- Bryan, J. R., 1993, Late Eocene and Early Oligocene carbonate facies and paleoenvironments of the eastern gulf coastal plain: *Southeastern Geological Society Guidebook*, v. 33, p. 23-47.
- Budd, D. A. and Vacher, H. L., 1991, Predicting the thickness of fresh-water lenses in carbonate paleo-islands: *Journal of Sedimentary Petrology*, v. 61, p. 43-53.
- Bush, P. W. and Johnston, R. H., 1988, Ground-water hydraulics, regional flow, and ground-water development of the Floridan Aquifer System in Florida and in parts of Georgia, South Carolina, and Alabama: *USGS Prof. Paper*, v. 1403-C, 79 p.
- Buxton, M. W. N. and Pedley, H. M., 1989, Short paper: A standardized model for Tethyan Tertiary carbonate ramps: *Jour. of the Geol. Soc. London*, v. 146, p. 746-748.
- Calvet, F. and Tucker, M. E., 1988, Outer ramp cycles in the Upper Muschelkalk of the Catalan basin, northeast Spain: *Sedimentary Geology*, v. 57, p. 185-198.

- Carter, B. D., Beisel, T. H., Branch, W. B. and Mashburn, C. M., 1989. Substrate preferences of Late Eocene (Priabonian/Jacksonian) echinoids of the eastern Gulf Coast: *Journal of Paleontology*, v. 63, p. 495-503.
- Chaproniere, G. C. H., 1975, *Palaeocology of Oligo-Miocene larger Foraminiferida. Australia: Alcherina*, v. 1, p. 37-58.
- Cheetham, A. H., 1963, Late Eocene zoogeography of the eastern Gulf Coast region: *Geological Society of America, Memoir* 91, 113 p.
- Chen, C. S., 1965, The regional lithostratigraphic analysis of Paleocene and Eocene rocks of Florida: *Florida Geological Survey Bulletin*, v.45, 105 p.
- Choquette, P. W. and Pray, L. C., 1970, Geologic nomenclature and classification of porosity in sedimentary carbonates: *American Association of Petroleum Geologists Bulletin*, v. 54, p. 207-250.
- Combes, J. M., 1993, The Vicksburg Formation of Texas: Depositional systems distribution, sequence stratigraphy, and petroleum geology: *American Association of Petroleum Geologists Bulletin*, v. 77, p. 1942-1970.
- Cooke, C.W., 1915, The age of the Ocala limestone: *USGS Prof. Pap.*, v. 95-I, p. 107-117.
- COSUNA (Correlation of Stratigraphic Units of North America Project), 1988. Lindberg, F. A., ed., *Gulf Coast Region: American Association of Petroleum Geologists Correlation Chart Series*, 1988.
- Crevello, P. D. and Harris, P. M., Eds., 1985, Deep-water carbonates - a core workshop: *SEPM Core Workshop 6: Tulsa, OK. SEPM*, 527 p.
- Croft, M., 1980, Ecology and stratigraphy of the echinoids of the Ocala Limestone (Late Eocene). MS thesis, Florida State University, Tallahassee, 74+ p.
- Dall, W. H. and Harris, G. D., 1892, The Neocene of North America: *USGS Bulletin*, v. 84, 349 p.
- Darga, R., 1990, The Eisenrichterstein near Hallthurm, Bavaria: An Upper Eocene carbonate ramp (Northern Calcareous Alps): *Facies*, v. 23, p. 17-36.
- Davis, J. C., 1986, *Statistics and Data Analysis in Geology*: New York. John Wiley & Sons. 646 p.
- Davis, J. M., Lohmann, R. C., Phillips, F. M., Wilson, J. L., and Love, D. W., 1993, Architecture of the Sierra Ladrone Formation, central New Mexico: Depositional controls on the permeability correlation structure: *Geological Society of America Bulletin*, V. 105, p. 998-1007.
- Dockery, D. T. I., 1992, The Eocene-Oligocene boundary in the northern Gulf Coastal Plain-a type I sequence boundary: *GSA South-Central Section Meeting, Abstracts with Programs*, v. 24, p. 9.

- Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture, *in* Ham, W.E., ed., *Classification of Carbonate Rocks*, AAPG Memoir 1: Tulsa, p. 108-121.
- Ebanks, W. J. J., 1987, Geology in enhanced oil recovery, *in* Tillman, R. W. and Weber, K. J., eds., *Reservoir Sedimentology: SEPM Spec. Pub. No. 40*: Tulsa, OK, p. 1-14.
- Eisenberg, R. A., Harris, P. M., Grant, C. W., Goggin, D. J. and Conner, F. J., 1994, Modeling reservoir heterogeneity within outer ramp carbonate facies using an outcrop analog, San Andres Formation of the Permian Basin: *American Association of Petroleum Geologists Bulletin*, v. 78, p. 1337-1359.
- Elrick, M. and Read, J. F., 1989, Development of Lower Mississippian cyclic carbonates, Montana and Wyoming [abs]: *American Association of Petroleum Geologists Bulletin*, v. 73, p. 353.
- Elrick, M. and Read, J. F., 1991, Cyclic ramp-to-basin carbonate deposits, Lower Mississippian, Wyoming and Montana: A combined field and computer modeling study: *Journal of Sedimentary Petrology*, v. 61, p. 1194-1224.
- Enos, P. and Sawatsky, L. H., 1981, Pore networks in Holocene carbonate sediments: *Journal of Sedimentary Petrology*, v. 51, p. 961-986.
- Eva, A.N., 1976, The paleoecology and sedimentology of Middle Eocene large foraminifera in Jamaica, *in* Schafer, C.T. and Pelletier, B.R., eds., *First Int. Symp. on Benthonic Foraminifera of Continental Margins*: Halifax, Maritime Sediments, p. 467-475.
- Fenk, E. M., 1979, Sedimentology and stratigraphy of Middle and Upper Eocene carbonate rocks, Lake, Hernando and Levy Counties, Florida. MS thesis. University of Florida, Gainesville, 133 p.
- Folk, R. L., 1959, Practical petrographic classification of limestones: *American Association of Petroleum Geologists Bulletin*, v. 43, p. 1-38.
- Frost, S. H., 1981, Oligocene reef coral microfacies of the Vicentin, Northeast Italy, *in* Toomey, D. F., ed., *European Fossil Reef Models: SEPM Spec. Pub. No. 30*: Tulsa, OK, p. 483-540.
- Gardulski, A. F., Gowen, M. H., Milsark, A., Weiterman, S. D., Wise, S. W. J. and Mullins, H. T., 1991, Evolution of a deep-water carbonate platform: Upper Cretaceous to Pleistocene sedimentary environments on the west Florida margin: *Marine Geology*, v. 101, p. 163-179.
- Goggin, D. J., Chandler, M. A., Kocurek, G. and Lake, L. W., 1988, Patterns of permeability in eolian deposits: Page Sandstone (Jurassic), Northeastern Arizona: *Society of Petroleum Engineers Formation Evaluation*, p. 297-306.
- Grant, C. W., Goggin, D. J. and Harris, P. M., 1994, Outcrop analog for cyclic-shelf reservoirs, San Andres Formation of Permian Basin: stratigraphic framework, permeability distribution, geostatistics, and fluid-flow modeling: *American Association of Petroleum Geologists Bulletin*, v. 78, p. 23-54.

- Green, R., Arthur, J. D. and DeWitt, D., 1995, Lithostratigraphic and hydrostratigraphic cross sections through Pinellas and Hillsborough Counties. Southwest Florida: Florida Geological Survey Open File Report #61. 30 p.
- Halley, R. B. and Loucks, R. G., Eds., 1980, Carbonate reservoir rocks. SEPM Core Workshop 1: Tulsa, OK, 183 p.
- Halley, R. B. and Schmoker, J. W., 1983, High-porosity Cenozoic carbonate rocks of South Florida: Progressive loss of porosity with depth: American Association of Petroleum Geologists Bulletin, v. 67, p. 191-200.
- Hallock, P., 1981, Algal symbiosis: a mathematical analysis: Marine Biology, v. 62, p. 249-255.
- Hallock, P., 1982, Evolution and extinction in larger foraminifera, *in* Mamet, B. and Copeland, M.J., eds., Third North American Paleontological Convention: Proceedings: Toronto, p. 221-225.
- Hammes, U., 1992, Sedimentation patterns, sequence stratigraphy, cyclicity, and diagenesis of Early Oligocene carbonate ramp deposits, Suwannee Formation, Southwest U.S.A. Ph.D. thesis, University of Colorado, Boulder, 344 p.
- Haq, B. U., Hardenbol, J. and Vail, P. R., 1987, Chronology of fluctuating sea levels since the Triassic: Science, v. 235, p. 1156-1166.
- Haq, B. U., Hardenbol, J., Vail, P. R., Wright, R. C., Stover, L. E., Baum, G., Loutit, T., Gombos, A., Davies, T., Pflum, C., Romine, K., Posamentier, H. and Jan Du Chene, R., 1988, Cenozoic cycle chart, *in* Wilgus, C. K., Hastings, B.S., Posamentier, H., Ross, C. A. and Kendall, C. G., eds., Sea-Level Changes: An Integrated Approach: SEPM Spec. Pub. 42: Tulsa, OK. Chart.
- Harris, P. M., Ed., 1983, Carbonate buildups - a core workshop. SEPM Core Workshop 4: Tulsa, OK, 593 p.
- Harris, P. M., Ed., 1984, Carbonate sands - a core workshop. SEPM Core Workshop 5: Tulsa, OK, 464 p.
- Hickey, J. J., 1982, Hydrogeology and results of injection tests at waste-injection test sites in Pinellas County, Florida: USGS Water-Supply Paper, v. 2183, 42 p.
- Hull, J. P. D. Jr., 1962, Cretaceous Suwannee Strait, Georgia and Florida: American Association of Petroleum Geologists Bulletin, v. 46, p. 118-122.
- Hunt, D. and Tucker, M. E., 1992, Stranded parasequences and the forced regressive wedge systems tract: Sedimentary Geology, v. 81, p. 1-9.
- Hutchinson, C. B., 1992, Assessment of hydrogeologic conditions with emphasis on water quality and wastewater injection, Southwest Sarasota and West Charlotte Counties, Florida: USGS Water-Supply Paper, v. 2371, 74 p.

- James, N. P. and Von Der Borch, C. C., 1991, Carbonate shelf edge off southern Australia: A prograding open-platform margin: *Geology*, v. 19, p. 1005-1008.
- Jee, J. L., 1993, Seismic stratigraphy of the Western Florida carbonate platform and history of Eocene strata. Ph.D. thesis, University of Florida, Gainesville. 215 p.
- Jensen, J. L., 1991, Use of geometric average for effective permeability estimation: *Mathematical Geology*, v. 23, p. 833-840.
- Johnson, R. A., and Budd, D. A., 1994, The utility of continual reservoir description: and example from Bindley Field, western Kansas: *American Association of Petroleum Geologists Bulletin*, v. 78, p. 722-743.
- Johnston, R. H., 1993, Historical development of concepts of regional ground water flow in the Floridan Aquifer System, Southeastern United States: *Hydrogeological Processes in Karst Terranes*, IAHS Pub. 207, p. 351-357.
- Jordan, L., 1954, Oil possibilities in Florida: *Oil and Gas Journal*, v. 53, p. 370-375.
- Loeblich, A.R.J. and Tappan, H., 1964, Protista 2. Sarcodina, Chiefly "Thecamoebians" and Foraminifera: Lawrence, Univ. of Kansas Press. 510 p.
- Loizeaux, N. T. and Budd, D. A., 1994, Relationship between sedimentary facies and ground-water flow in the Suwannee Formation, Upper Floridan Aquifer, West-Central Florida [abs]: AAPG Annual Convention Abstracts with Programs, Denver, p. 200-201.
- Mancini, E. A. and Tew, B. H., 1991, Relationships of Paleogene Stage and planktonic foraminiferal zone boundaries to lithostratigraphic and allostratigraphic contacts in the eastern Gulf Coastal Plain: *Journal of Foraminiferal Research*, v. 21, p. 48-66.
- Markello, J. R. and Read, J. F., 1982, Upper Cambrian intrashelf basin, Nolichucky Formation, southwest Virginia Appalachians: *American Association of Petroleum Geologists Bulletin*, v. 66, p. 860-878.
- McKinney, M. L., 1984, Suwannee Channel of the Paleogene coastal plain: Support for the carbonate "suppression" model of basin formation: *Geology*, v. 12, p. 343-345.
- Miller, J. A., 1986, Hydrogeologic framework of the Floridan Aquifer System in Florida and in parts of Georgia, Alabama, and South Carolina: USGS Professional Paper, v. 1403-B, 91 p.
- Miller, K. G., Fairbanks, R. G. and Mountain, G. S., 1987, Tertiary oxygen isotope synthesis, sea level history, and continental margin erosion: *Paleoceanography*, v. 2, p. 1-19.
- Miller, K. G., Kent, D. V., Brower, A. N., Bybell, L. M., Feigenson, M. D., Olsson, R. K. and Poore, R. Z., 1990, Eocene-Oligocene sea level changes on the New Jersey coastal plain linked to the deep-sea record: *Geological Society of America Bulletin*, v. 102, p. 331-339.

- Mitchum, R. M. J., Vail, P. R. and Thompson, S. I., 1977, Seismic stratigraphy and global changes of sea level, part 2: The depositional sequence as a basic unit for stratigraphic analysis, *in* Payton, C. E., ed., *Seismic Stratigraphy-Applications to Hydrocarbon Exploration*, AAPG Memoir 26: Tulsa, p. 53-62.
- Mresah, M., 1993, Facies patterns and stratal geometries: clues to the nature of the platform margin during the Paleocene, northeast Sirte Basin, Libya: *Sedimentary Geology*, v. 84, p. 149-167.
- Mullins, H. T., Gardulski, A. F., Hinchey, E. J. and Hine, A. C., 1988a, The modern carbonate ramp slope of Central West Florida: *Journal of Sedimentary Petrology*, v. 58, p. 273-290.
- Mullins, H. T., Gardulski, A. F., Hine, A. C., Melillo, A. J., Wise, S. W. J. and Applegate, J., 1988b, Three-dimensional sedimentary framework of the carbonate ramp slope of central west Florida: A sequential seismic stratigraphic perspective: *American Association of Petroleum Geologists Bulletin*, v. 100, p. 514-533.
- Noble, R. S., 1994, Carbonate subaerial exposure indicators and porosity development within the Floridan Aquifer: A high-resolution quantitative core analysis of the Lower Oligocene Suwannee Formation in West-Central Florida. MS thesis. University of Colorado, Boulder, 257 p.
- Orme, G. R., and Riding, R., 1995, The green alga *Halimeda* - its dominant role in Holocene sedimentation in the northern Great Barrier Reef, Australia [abs]: *Linked Earth Systems, The 1st SEPM Congress on Sedimentary Geology*, St. Petersburg, FL, p. 96.
- Osleger, D., 1991, Subtidal carbonate cycles: Implications for allocyclic vs. autocyclic controls: *Geology*, v. 19, p. 917-920.
- Osleger, D. and Read, J. F., 1991, Relation of eustasy to stacking patterns of meter-scale carbonate cycles, Late Cambrian, U.S.A.: *Journal of Sedimentary Petrology*, v. 61, p. 1225-1252.
- Pedley, M., 1992, Bio-retexturing: early diagenetic fabric modifications in outer-ramp settings - a case study from the Oligo-Miocene of the Central Mediterranean: *Sedimentary Geology*, v. 79, p. 173-188.
- Pinet, P. R. and Popenoe, P., 1985., A scenario of Mesozoic-Cenozoic ocean circulation over the Blake Plateau and its environs: *Geological Society of America Bulletin*, v. 96, p. 618-626.
- Popenoe, P., Henry, V. J. and Idris, F. M., 1987, Gulf Trough - the Atlantic connection: *Geology*, v. 15, p. 327-332.
- Puri, H. S., 1953, Zonation of the Ocala Group in the peninsular Florida [abs]: *Journal of Sedimentary Petrology*, v. 23, p. 130.
- Puri, H. S., 1957, Stratigraphy and zonation of the Ocala group: *Florida Geological Survey Bulletin*, v. 38, 248 p.

- Purser, B. H., Ed., 1973, *The Persian Gulf: Holocene Carbonate Sedimentation and Diagenesis in a Shallow Epicontinental Sea*: Berlin, Springer-Verlag, 471 p.
- Randazzo, A. F., 1976, The significance of the Williston and Inglis Formations in stratigraphic nomenclature and classification, *in* *Tertiary Carbonates: Citrus, Levy, Marion Counties, West Central Florida*: Southeastern Geological Society Field Trip Guide Book, v. 18, p. 49-56.
- Randazzo, A. F., 1982, Comments on the geology of the fieldtrip area, *in* Smith, D.L., ed., *Southeastern Geological Society Guidebook*, v. 24, p. 5-12.
- Read, J. F., 1985, Carbonate platform facies models: *American Association of Petroleum Geologists Bulletin*, v. 69, p. 1-21.
- Roehl, P. O. and Choquette, P. W., 1985, *Carbonate Petroleum Reservoirs*: Berlin, Springer-Verlag, 622 p.
- Rovey, C. W. I. and Cherkauer, D. S., 1994a, Relation between hydraulic conductivity and texture in a carbonate aquifer: *Observations: Ground Water*, v. 32, p. 53-62.
- Rovey, C. W. I. and Cherkauer, D. S., 1994b, Relation between hydraulic conductivity and texture in a carbonate aquifer: *Regional continuity: Ground Water*, v. 32, p. 227-238.
- Ryder, P. D., 1982, Digital model of predevelopment flow in the Tertiary limestone (Floridan) aquifer system in west-central Florida: *USGS Water-Resources Investigations*, v. 81-54, 61 p.
- Ryder, P. D., 1985, *Hydrology of the Floridan Aquifer System in West-Central Florida*: USGS Professional Paper, v. 1403-F, 63 p.
- Ryder, P. D., Johnson, D. M. and Gerhart, J. M., 1980, Model evaluation of the hydrogeology of the Morris Bridge Wellfield and vicinity in West-Central Florida: *USGS Open File Report*, v. 80-29, 92 p.
- Saller, A. H., Budd, D. A. and Harris, P. M., 1994, Unconformities and porosity development in carbonate strata: Ideas from a Hedberg conference: *American Association of Petroleum Geologists Bulletin*, v. 78, p. 857-872.
- Salvador, A., 1991, Origin and development of the Gulf of Mexico Basin, *in* Salvador, A., ed., *The Geology of North America Vol. J*: Boulder, Geological Society of America, p. 389-444.
- Sarg, J. F., 1988, Carbonate sequence stratigraphy, *in* Wilgus, C. K., Hastings, B. S., Posamentier, H., Ross, C.A., and Kendall, C. G., eds., *Sea Level Changes - An Integrated Approach*: SEPM Spec. Pub. No. 42: Tulsa, p. 155-181.
- Schmoker, J. W. and Halley, R. B., 1982, Carbonate porosity versus depth: A predictable relation for South Florida: *American Association of Petroleum Geologists Bulletin*, v. 66, p. 2561-2570.

- Scott, T. M., 1988, The lithostratigraphy of the Hawthorn Group (Miocene) of Florida: Florida Geological Survey Bulletin, v. 59, 148 p.
- Scott, T. M., Lloyd, J. M. and Maddox, G., Eds., 1991, Florida's ground water quality monitoring program - hydrogeologic framework: Tallahassee, Florida Geological Survey Spec. Pub. 32, 97 p.
- Singer, M. J. and Janitzky, P., 1986, Field and laboratory procedures used in a soil chronosequence study: USGS Bulletin, v. 1648, 49 p.
- Trappe, J., 1992, Microfacies zonation and spatial evolution of a carbonate ramp: marginal Moroccan phosphate sea during the Paleogene: *Geologische Rundschau*, v. 81, p. 105-126.
- Vacher, H. L., 1988, Dupuit-Ghyben-Herzberg analysis of strip-island lenses: *Geological Society of America Bulletin*, v. 100, p. 580-591.
- Vail, P. R., Audemard, F., Bowman, S. A., Eisner, P. N. and Perez-Cruz, C., 1991, The stratigraphic signatures of tectonics, eustasy and sedimentology - an overview, *in* Einsele, G., Ricken, W., and Seilacher, A., eds., *Cycles and Events in Stratigraphy*: Berlin, Springer-Verlag, p. 617-659.
- Van Wagoner, J. C., Posamentier, H. W., Mitchum, R. M., Vail, P. R., Sarg, J. F., Loutit, T. S. and Hardenbol, J., 1988, An overview of the fundamentals of sequence stratigraphy and key definitions, *in* Wilgus, C. K., Hastings, B. S., Posamentier, H., Ross, C.A., and Kendall, C. G., eds., *Sea Level Changes - An Integrated Approach*: SEPM Spec. Pub. No. 42: Tulsa, p. 39-45.
- Vernon, R. O., 1951, Geology of Citrus and Levy Counties, Florida: Florida Geological Survey Bulletin, v. 33, 256 p.
- Walton, W. C., 1991, *Principles of Groundwater Engineering*: Chelsea, MI, Lewis Publishers, Inc., 546 p.
- White, W. B., 1988, *Geomorphology and Hydrology of Karst Terrains*: Oxford, Oxford Univ. Press, 464 p.
- Wilson, J. L., 1975, *Carbonate Facies in Geologic History*: New York, Springer-Verlag, 471 p.
- Winston, G. O., 1976, Florida's Ocala uplift is not an uplift: *American Association of Petroleum Geologists Bulletin*, v. 60, p. 992-994.
- Zachos, L. G., 1978, Stratigraphy and petrology of two shallow wells, Citrus and Levy Counties, Florida. MS thesis, University of Florida, Gainesville, 105 p.

APPENDICES

APPENDIX A

CORES LOGGED

The seventeen Ocala Formation cores used in this investigation are presented in this appendix. Hand drafted core logs were prepared in the field and later modified to reflect petrographic thin section observations and more detailed observations of core sections under a binocular microscope. Sections of the Ocala Formation logged at the FGS core repository were whole and slabbed 2" diameter cores. The location of these cores is shown in Figure 1. Cores were described using the following attributes: mineralogy, porosity types, physical/biogenic structures, surfaces, contacts, depositional fabric, mean grain size, allochem and fossil types, induration, and sedimentary facies interpretations. Non-lithologic information provided for each core includes the laboratory samples available (e.g., thin sections, hand samples) and core recovery.

The explanation for core logs is presented below. Core sections are presented in this appendix in order of their FGS core number. For ease in cross-referencing the SWFWMD core number is also presented. Individual core logs can be found on the following pages:

<u>FGS Well Number</u>	<u>SWFWMD Well Number</u>	<u>Page</u>
W-10254	Lakeland #1	128
W-15826	TR8-1	135
W-16181	TR13-1X	145
W-16304	Romp-99	152
W-16307	Romp-58	159
W-16576	Dover Elementary #1	167
W-16609	TR16-2A	175
W-16618	TR9-2	181
W-16740	Romp-39	190
W-16783	Romp-22	199
W-16784	Romp-33	210
W-17000	Romp-28	221
W-17001	Romp-14	231
W-17056	Romp-9	243
W-17057	TR7-2	254
W-17087	Romp-20	264
W-30026 (temporary designation)	Romp-13	274

EXPLANATION FOR CORE LOGS

Thin Section / Rock (Rx) Sample:

- Petrographic thin section
- Rock sample
- ▤ Falling-head permeameter test

Lithology:

- ▤ Limestone
- ▤ Dolomitic limestone to limy dolomite
- ▤ Dolomite
- ▤ Chert

Pore Type:

- ▤ Dominant
- ▤ Common
- ▤ Absent

Physical/biogenic structures, surfaces, contacts:

- ▤ Burrow
- ▤ Walled burrow
- ▤ Intraclast
- ▤ Laminations
- ▤ Organics
- ▤ Solution cavity with infill sediments
- ▤ Undulatory sharp contact
- ▤ Even sharp contact

Mean Grain Size:



Approximations
of 5% and 95% limits
of sediment size

Fossil Types:

- ▤ Abundant
- ▤ Common
- ▤ Present
- ▤ Trace
- ▤ Absent

*Other Forams:

- B Biserials
- D Dictyoconus americanus (Avon Park)
- P Various pelagics
- R Rotalids

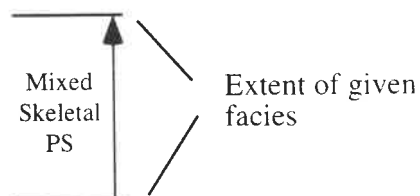
*Other:

- C Coral
- G Gastropods
- P Pellets

Induration:

- ▤ Heavy
- ▤ Medium
- ▤ Light
- ▤ Absent

Facies:



▤ Sequence/Formation Boundary

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DESCRIBER: NIL LOCATION: OCALA STRATIGRAPHIC UNIT: 41'-336' PAGE: 4 OF 7
 WELL NAME: Q-10254 COUNTY: POLK INTERVAL DESCRIBED: 41'-336'

Thin Sec/ Rx Sample	LITHOLOGY	DEPTH (ft)	RECOVERY	PORE TYPE	PHYSICAL/ BIOGENIC STRUCTURES, SURFACES, CONTACTS	FABRIC	Mean Grain Size (TEXTURE)	FOSSIL TYPES	FACIES	COMMENTS
		220		WELL-SORTED SAND	Well Sorted Normal Sand	Wackestone PS GS	WELL-SORTED SAND	Other Forams Echinoids Bryozoans Red Algae Green Algae Bivalves Intraclasts Peloids Other*		
		225		WELL-SORTED SAND	Well Sorted Normal Sand	Wackestone PS GS	WELL-SORTED SAND	Other Forams Echinoids Bryozoans Red Algae Green Algae Bivalves Intraclasts Peloids Other*		
		230		WELL-SORTED SAND	Well Sorted Normal Sand	Wackestone PS GS	WELL-SORTED SAND	Other Forams Echinoids Bryozoans Red Algae Green Algae Bivalves Intraclasts Peloids Other*		
		235		WELL-SORTED SAND	Well Sorted Normal Sand	Wackestone PS GS	WELL-SORTED SAND	Other Forams Echinoids Bryozoans Red Algae Green Algae Bivalves Intraclasts Peloids Other*		
		240		WELL-SORTED SAND	Well Sorted Normal Sand	Wackestone PS GS	WELL-SORTED SAND	Other Forams Echinoids Bryozoans Red Algae Green Algae Bivalves Intraclasts Peloids Other*		
		245		WELL-SORTED SAND	Well Sorted Normal Sand	Wackestone PS GS	WELL-SORTED SAND	Other Forams Echinoids Bryozoans Red Algae Green Algae Bivalves Intraclasts Peloids Other*		
		250		WELL-SORTED SAND	Well Sorted Normal Sand	Wackestone PS GS	WELL-SORTED SAND	Other Forams Echinoids Bryozoans Red Algae Green Algae Bivalves Intraclasts Peloids Other*		

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DESCRIPTOR: NTL		LOCATION: HILLSBOROUGH COUNTY		STRATIGRAPHIC UNIT: OCALA		PAGE: 8 OF 9				
WELL NAME: W-16618 (TR9-a)				INTERVAL DESCRIBED: 431' - 700'						
LITHOLOGY	DEPTH (ft)	RECOVERY	PORE TYPE	PHYSICAL/BIOGENIC SURFACES, CONTACTS	FABRIC	Mean Grain Size (TEXTURE)	FOSSIL TYPES	INDURATION	FACIES	COMMENTS
	640				Mudstone Wackestone Silty Muds Normal Mud Well Washed Poorly Washed Siltsone GS	MUD SILT FINE GRAVEL L.FINE L.MEDIUM L.COARSE G.COARSE GRAVEL	Lepidocyclusinae Nummulitidae Miliolidae Other Forams Echinoids Bryozoans Red Algae Green Algae Bivalves Intraclasts Pelloids Other*		MIXED SKELETAL PS	
	645			U						
	650			U						MIXED SKELETAL GS
	655			U						
	660			U						
	665			U						MIXED SKELETAL PS
	670			U						

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DESCRIBER: NTL
 WELL NAME: 16-16-710 (20MP-38)
 LOCATION: NTL
 COUNTY: MAJATEE
 STRATIGRAPHIC UNIT: Ocala
 INTERVAL DESCRIBED: 710' - 980'
 PAGE: 8 OF 9

LITHOLOGY	DEPTH (ft)	RECOVERY	PORE TYPE	PHYSICAL/ BIOGENIC STRUCTURES	CONTACTS	FABRIC			Mean Grain Size (TEXTURE)	FOSSIL TYPES														FACIES	COMMENTS
						Mudstone	Wackestone	Silty Wacke		PS	GS	Normal Sand	Normal	Very Fine	Coarse	Medium	Coarse	Gravel	Other Forams	Echinoids	Bryozoans	Red Algae	Green Algae		
Thin Sec/ Rk Sample	920		INTER-PART	2	2	2	Poorly Wadcd	Normal Sand	SLT	Lepidocyclinidae	Nummulitidae	Miliolidae	Other Forams	Echinoids	Bryozoans	Red Algae	Green Algae	Bivalves	Intraclasses	Peloids	Other	INDURATION	FACIES	COMMENTS	
	925		INTER-PART	2	2	2	Poorly Wadcd	Normal Sand	SLT	Lepidocyclinidae	Nummulitidae	Miliolidae	Other Forams	Echinoids	Bryozoans	Red Algae	Green Algae	Bivalves	Intraclasses	Peloids	Other	INDURATION	FACIES	COMMENTS	
	930		INTER-PART	2	2	2	Poorly Wadcd	Normal Sand	SLT	Lepidocyclinidae	Nummulitidae	Miliolidae	Other Forams	Echinoids	Bryozoans	Red Algae	Green Algae	Bivalves	Intraclasses	Peloids	Other	INDURATION	FACIES	COMMENTS	
	935		INTER-PART	2	2	2	Poorly Wadcd	Normal Sand	SLT	Lepidocyclinidae	Nummulitidae	Miliolidae	Other Forams	Echinoids	Bryozoans	Red Algae	Green Algae	Bivalves	Intraclasses	Peloids	Other	INDURATION	FACIES	COMMENTS	
	940		INTER-PART	2	2	2	Poorly Wadcd	Normal Sand	SLT	Lepidocyclinidae	Nummulitidae	Miliolidae	Other Forams	Echinoids	Bryozoans	Red Algae	Green Algae	Bivalves	Intraclasses	Peloids	Other	INDURATION	FACIES	COMMENTS	
	945		INTER-PART	2	2	2	Poorly Wadcd	Normal Sand	SLT	Lepidocyclinidae	Nummulitidae	Miliolidae	Other Forams	Echinoids	Bryozoans	Red Algae	Green Algae	Bivalves	Intraclasses	Peloids	Other	INDURATION	FACIES	COMMENTS	
	950		INTER-PART	2	2	2	Poorly Wadcd	Normal Sand	SLT	Lepidocyclinidae	Nummulitidae	Miliolidae	Other Forams	Echinoids	Bryozoans	Red Algae	Green Algae	Bivalves	Intraclasses	Peloids	Other	INDURATION	FACIES	COMMENTS	

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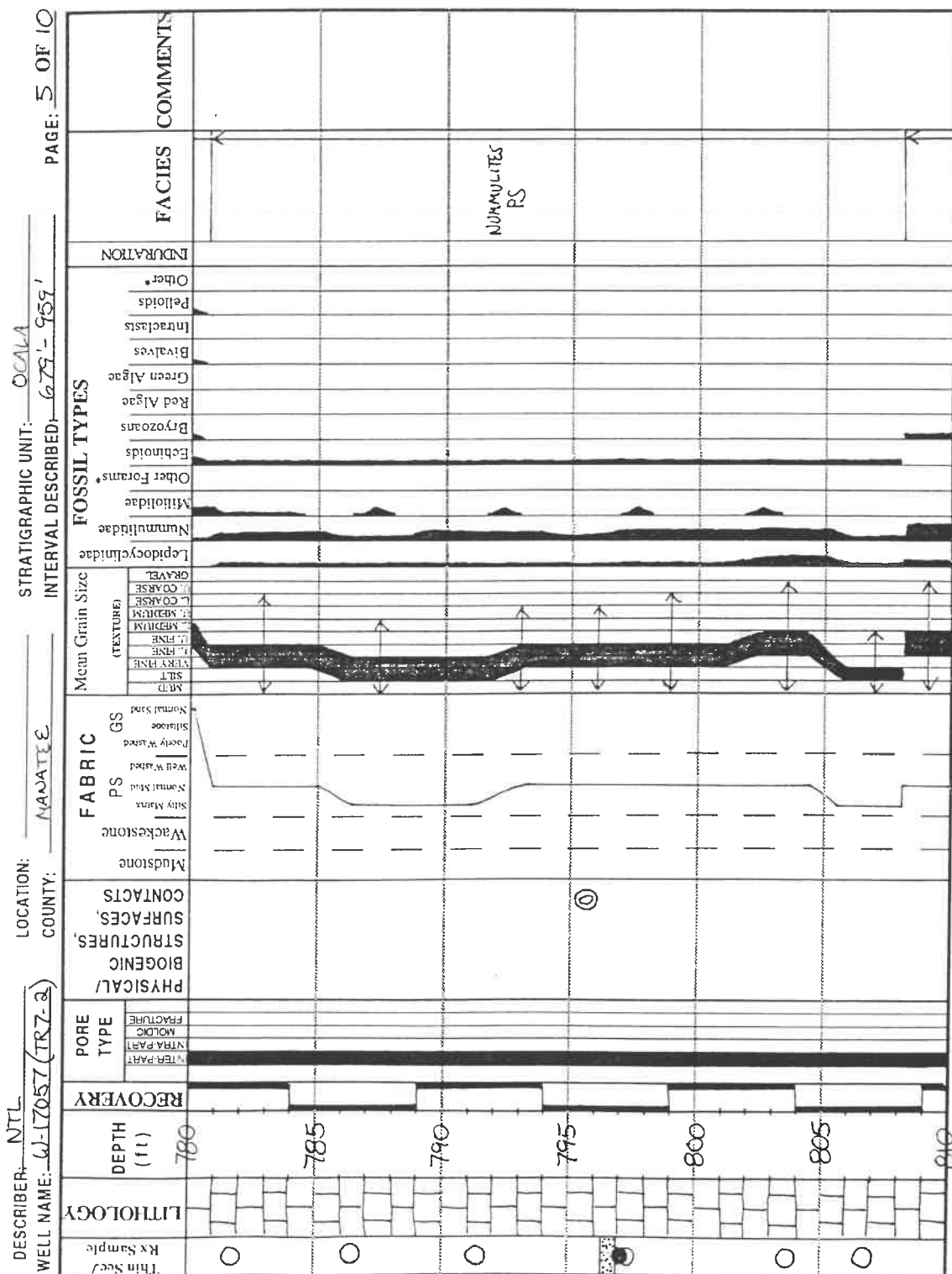
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DESCRIPTOR: NTL		LOCATION: SARASOTA		STRATIGRAPHIC UNIT: Ocala		PAGE: 7 OF 11				
WELL NAME: W-17056 (RWP-9)		COUNTY:		INTERVAL DESCRIBED: 254'-1163'						
LITHOLOGY	DEPTH (ft)	RECOVERY	PORE TYPE	PHYSICAL/ BIOGENIC STRUCTURES, SURFACES, CONTACTS	FABRIC	Mean Grain Size (TEXTURE)	FOSSIL TYPES	INDURATION	FACIES	COMMENTS
[Patterned Lithology]	1020		INTER-PARTIAL, MOLDIC, FRACTURE		Wackestone	Normal Sand	Normal Sand			
	1025				Wackestone	Normal Sand				100% Dolomite Diagenesis
	1030				Wackestone	Normal Sand				
	1035				Wackestone	Normal Sand				NUMULITES/ LEPTODON SILTY PS
	1040				Wackestone	Normal Sand				
	1045				Wackestone	Normal Sand				
	1050				Wackestone	Normal Sand				NUMULITES/ LEPTODON SILTY PS
					Wackestone	Normal Sand				
					Wackestone	Normal Sand				
					Wackestone	Normal Sand				

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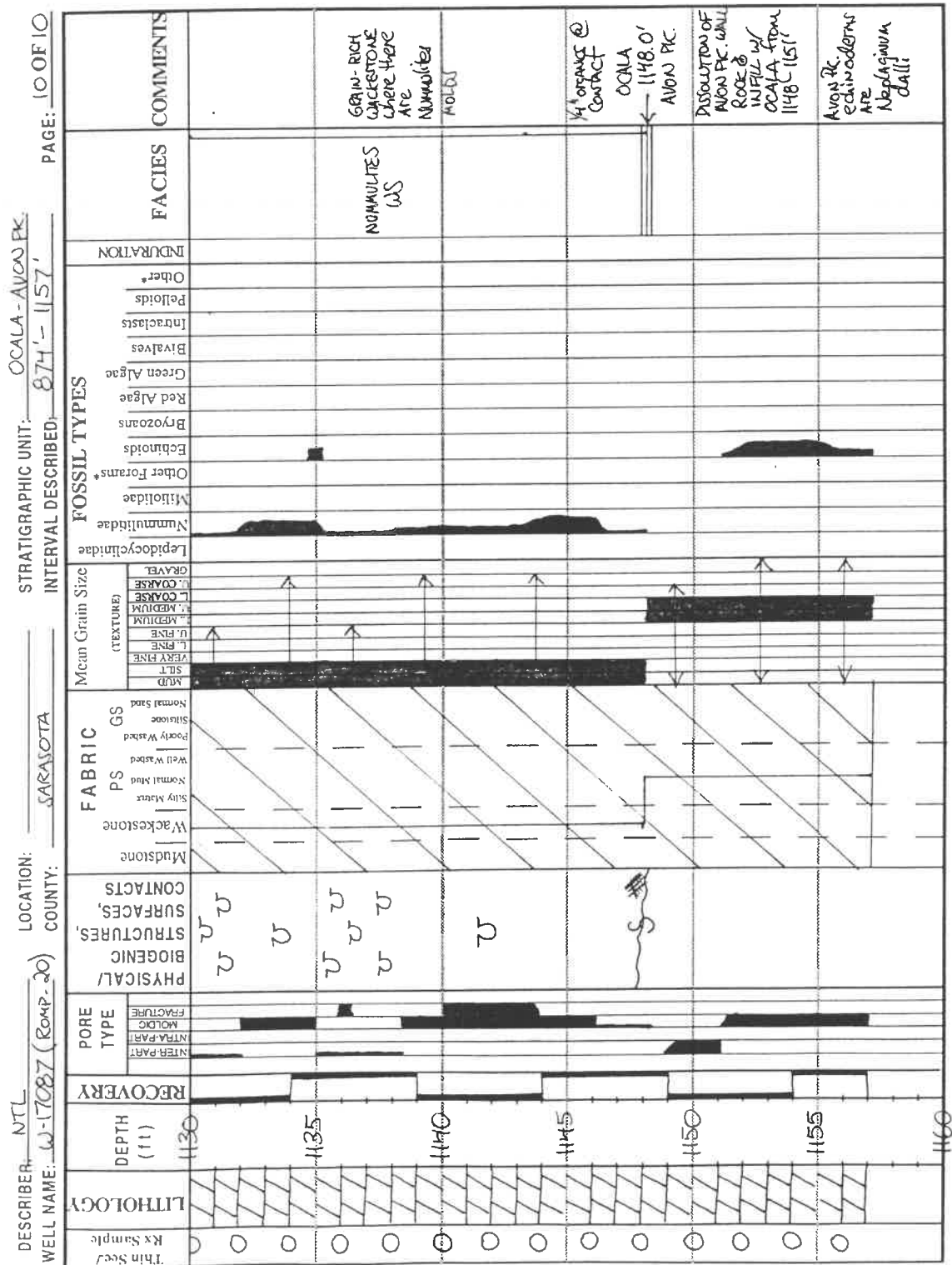
DESCRIBER: N.T.L. LOCATION: OCALA-AVON PK. PAGE: 10 OF 10
 WELL NAME: W-17057 (TR-2) COUNTY: MANATEE STRATIGRAPHIC UNIT: 679' - 959'
 INTERVAL DESCRIBED:

LITHOLOGY	DEPTH (ft)	RECOVERY	PORE TYPE	PHYSICAL/ BIOGENIC SURFACES, CONTACTS	FABRIC			Mean Grain Size (TEXTURE)	FOSSIL TYPES										FACIES	COMMENTS													
					Mudstone	Wackestone	PS		GS	Silt	Very Fine	Fine	Med	Coarse	Gravel	Lepidocyclus	Nummulitidae	Miliolidae			Other Forams	Echinoids	Bryozoans	Red Algae	Green Algae	Bivalves	Intraclasts	Peloids	Other				
Hatched pattern	930		INTERPART	PS	Well Sorted	Normal	Well Sorted	Normal	Silt																								
	935			PS	Well Sorted	Normal	Well Sorted	Normal	Silt																								
	940			PS	Well Sorted	Normal	Well Sorted	Normal	Silt																								
	945			PS	Well Sorted	Normal	Well Sorted	Normal	Silt																								
	950			PS	Well Sorted	Normal	Well Sorted	Normal	Silt																								
	955			PS	Well Sorted	Normal	Well Sorted	Normal	Silt																								
	960			PS	Well Sorted	Normal	Well Sorted	Normal	Silt																								

Ocala, 946.0', AVON PK.
 OPEN BORINGS filled w/ Ocala sand.
 AVON PK. echinoids are Neohamulus calli.

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APPENDIX B

SEDIMENTARY FACIES OF THE OCALA

Miliolid and Mixed Skeletal Facies:

Miliolid Grainstone: The miliolid grainstones are characterized as being very well-rounded grainstones dominated by a diverse assemblage of the foraminiferal family Miliolidae (Loeblich and Tappan 1964). Other allochems found in this facies include peloids, echinoids, bryozoans, bivalves, gastropods, solitary corals, intraclasts, rotaliid and biserial foraminifera, red and green algae, and occasional nummulites and lepidocyclina foraminifera. A minimum of 25% of the allochems had to be Miliolidae to differentiate this facies from the mixed skeletal grainstone. Sedimentary structures found include occasional cross-bedding, burrowing, and walled burrows with geopetal infill. The porosity is dominated by primary intergranular with minor amounts of intraparticle and secondary moldic where the facies is indurated. This facies is interpreted as occupying relatively shallow shoal and/or sand sheet environments on the upper ramp. This interpretation is based partially on the common occurrences of Miliolidae in shallow-water deposits of the Oligocene Suwannee Formation (Hammes 1992). In addition, the lack of significant amounts of mud in the matrix suggests active reworking, and not a lagoonal environment, which can also be rich in Miliolidae foraminifera.

Mixed Skeletal Grainstone: The mixed skeletal grainstones are characterized by a diverse assemblage of skeletal grains, intraclasts, and peloids. Common skeletal grains include echinoderms, bryozoans, miliolids, bivalves, and gastropods. Less common skeletal constituents include rotaliid and biserial foraminifera, red and green algae, solitary corals and nummulites and lepidocyclina foraminifera. Sedimentary structures found include occasional cross-bedding, burrowing, and walled burrows with geopetal infill. The porosity is dominated by primary intergranular with minor amounts of intraparticle and secondary moldic the facies is indurated. This facies is interpreted as occupying relatively shallow shoal and/or sand sheet environments on the upper ramp. This is based on a similar facies occurrence and interpretation in the Oligocene Suwannee Formation (Hammes 1992). Like the miliolid grainstones, the lack of significant amounts of mud in the matrix suggests active reworking.

Mixed Skeletal Packstone: The mixed skeletal packstones are characterized by much of the same biota as the mixed skeletal grainstones, the primary difference being the amount of admixed carbonate mud. Common allochem constituents include peloids, echinoderms, bryozoans, miliolids, bivalves, and gastropods. Less common constituents include rotaliid and biserial forams and occasional nummulites and lepidocyclina foraminifera. Sedimentary structures include occasional walled burrows and bioturbation by burrowers. Porosity types are mostly primary interparticle and micro-interparticle (i.e. chalky porosity or micro-intercrystalline pores between interparticle micrite crystals) with minor amounts of intraparticle and secondary moldic if the facies is indurated. This facies is interpreted as occupying relatively shallow upper to middle ramp environments. This interpretation is based on its stratigraphic occurrence in the Ocala Formation and the recognition of similar facies by Hammes (1992). The highly diverse, open-marine fauna indicates open-marine, subtidal deposition adjacent to the grainstone shoals (Hammes, 1992). The packstone texture of this facies suggests only periodic reworking by storms (incomplete winnowing).

Nummulites and Lepidocyclina Facies:

Before discussing the various sedimentary facies delineated on the basis of large foraminifera, a discussion must precede it regarding the paleoecology of these biota. There are two families of macro-foraminifera that are very common in the Ocala Formation, the Nummulitidae and the Lepidocyclinidae (Loeblich and Tappan 1964). Eva (1976) worked in the Eocene of the Caribbean and documented a high co-occurrence of these two forams and suggested adjacent (and overlapping) ecological niches. Eva (1976) places the lepidocyclina forams high on the seaward slope of a carbonate bank and the nummulites forams immediately downslope toward the basin. This may agree with observations made on the west Florida ramp within the study area. The first of the two foraminifera families to appear following the Middle/Late Eocene sea-level regression is the nummulites (see the downdip wells W-17057, W-17087, W-16784, W-16783, W-17056, W-17000, W-30026, and W-17001) suggesting they first colonized the deeper water sections of the ramp. Once relative water depth had been reduced by sediment accumulation, the two species occur together, often in dense coquinas (see the same wells). The lepidocyclina forams also form facies of their own and could be interpreted as a shallow ramp facies (*sensu* Eva, 1976), as evidenced by the common updip occurrences of these facies (see the upper sequences of wells W-16609, W-10254, and W-16304).

Buxton and Pedley (1989) present an alternative model in which the paleoecological positions of these two foraminifera are reversed. Based on foraminifera test morphology they place the nummulites higher on the bank and the larger 'orbitoid' foraminifera further out on the ramp. This model could also fit the observed facies patterns in west-central Florida. The initial occurrences of nummulites facies in the downdip wells (W-17057, W-17087, W-16784, W-16783, W-17056, W-17000, W-30026, and W-17001) might actually represent the transgressive deposit with the furthest transgression (maximum flooding surface) marked by the appearance of the deeper water lepidocyclina.

As this thesis is primarily a sedimentologic and hydrologic one, the exact paleoecology of the two macro-foraminifera will not be addressed. In either paleoecological model (Eva 1976; Buxton and Pedley 1989) they are placed in adjoining facies belts from the inner to outer ramp margins, so they are similarly lumped here. This facilitates an easier construction of facies architecture on the ramp and avoids a detailed paleontologic investigation.

Because it is widely recognized that the larger foraminifera maintained symbiotic relationships with algae, one can infer that their environmental distributions were limited to the photic zone (Chaproniere 1975; Hallock 1981; Hallock 1982). The maximum depth of the photic zone is contested in the literature, but it is unlikely to be greater than 200 m (Eva 1976). In this study area, the sedimentary sections are presumed to have been deposited concurrently within each of the three third-order sequences identified. Therefore, if one assumes a maximum paleo-water depth of 2 meters (6 ft.) for the updip grainstone shoals (Hammes, 1992) and the thickest downdip sequence sections are slightly less than 40m thick (W-17001, sequence #1, 124 feet) then one can presume that the paleo-water depths for the foraminiferal facies ranged from a few meters to 42 meters within the study area. This is compatible with Cheetham's (1963) estimate of paleowater depths of < 45m (150') based on Ocala bryozoan fauna. However, these simple calculations fail to take into account compaction which may be on the order of 30% (assuming an average initial depositional porosity of $\approx 50\%$, an observed present mean porosity of $\approx 35\%$ and all porosity loss due to compaction). This expands the potential lower depositional depth limit of the Ocala Formation to 55 meters. Because of the uncertainties involved, exact paleo water depths are avoided in paleoenvironmental interpretations. Relative ramp

positions (i.e. upper, middle, and lower or inner, middle, and outer) are proposed instead.

It has often been postulated that the larger Tertiary foraminifera formed banks or bioherms on ramp surfaces (or fore-reef slopes) (see the literature review of Aigner, 1982 and 1985) similar to the fusulinid dominated bioherms described in the Pennsylvanian of North America (Wilson 1975, p. 209). Comparable dense foraminiferal coquinas are commonly found on the west Florida ramp during the Late Eocene (this study) and might suggest bank-like deposits. Aigner (1982; 1985), however, has presented an alternative hypothesis to the bank deposits, and that is hydrodynamic forces winnowing out the finer grained muds and concentrating the foraminifera. Evidence for this theory rests in the lack of "appreciable encrustation" on nummulites tests (bank deposited tests often become highly encrusted upon death) and documented "high-energy" sedimentary structures indicative of episodic physical processes (Aigner 1985).

The later hypothesis is more likely applicable to this thesis based on the lack of encrustations on the Ocala's macro-foraminifera and presence of abraded tests in non-coquina fabrics. It is speculated that the foraminiferal tests were concentrated into bank-like deposits in-situ by current velocities as low as 20 cm/sec (Aigner 1982), reworking the tests and moving much of the finer mud and silt constituents downslope. Due to the frequent occurrence of fragmented and abraded foraminiferal tests in non-coquina fabrics, it is believed that surface wave forces actively impinged on the west-Florida ramp and may even have been responsible for the persistence of subtidal cycles that failed to aggrade to base-level (sensu Osleger, 1991).

Nummulites/Lepidocyclina Packstone: This facies is characterized by a packstone texture with the dominant allochems being macro-foraminifera of the families Nummulitidae and Lepidocyclinidae. Other less common biotic constituents include echinoderms, bivalves, bryozoans, and roaliid and biserial foraminifera. The criterion distinguishing this facies from either the nummulites packstone or the lepidocyclina packstone was the presence of both foraminifera in near equal abundance. If one or the other of the two macro-foraminifera was present in a ratio greater than 4:1 (80% / 20%) the rock was assigned to that foraminiferal packstone. As an example, if a core section contained 25% nummulites and 75% lepidocyclina it would be classified as a nummulites/lepidocyclina packstone, but if the percentages were 15% and 85%, respectively, the facies would be a lepidocyclina packstone.

Sedimentary structures found in the nummulites/lepidocyclina packstone included occasional walled burrows and bioturbation by burrowers. Porosity types are mostly primary interparticle and micro-interparticle (i.e., in micrite matrix). Intraparticle porosity is also common in dense foraminiferal coquinas. Where this facies is dolomitized the most abundant porosity is intercrystalline and moldic. The facies was often distinguished by the shapes of the molds in heavily dolomitized intervals. The Lepidocyclinidae family has a characteristic thin saucer shape while the Nummulitidae family has a characteristic fat diamond shape. This facies is interpreted as occupying a broad environment from the seaward side of grainstone shoals (shallow ramp) to deeper ramp settings.

Nummulites Packstone: This facies is characterized by a packstone texture with the dominant allochems being macro-foraminifera of the family Nummulitidae. Other less common allochems include lepidocyclina, echinoderms, bivalves, bryozoans, and roaliid and biserial foraminifera. Sedimentary structures found in this facies include occasional walled burrows and bioturbation by burrowers. Porosity types are mostly primary interparticle and micro-interparticle (i.e., in micrite matrix). Intraparticle porosity is also common in dense nummulites coquinas. Where this facies is dolomitized the most abundant porosity is intercrystalline and moldic. The facies was

often distinguished by the shape of the nummulites tests in heavily dolomitized intervals. This facies is interpreted as occupying a broad environment from the seaward side of grainstone shoals (shallow ramp) to deeper ramp. Based on Eva's (1976) observations it may have been ecologically dominant in the middle to deeper sections of the ramp.

Lepidocyclus Packstone: This facies is characterized by a packstone texture with the dominant allochems being macro-foraminifera of the family Lepidocyclinidae. Other less common allochems include nummulites, echinoderms, bivalves, bryozoans, rotaliid and biserial foraminifera. Sedimentary structures found in this facies include occasional walled burrows and bioturbation by burrowers. Porosity types are mostly primary interparticle and micro-interparticle (i.e., in micrite matrix). Intraparticle porosity was also common in dense nummulites coquinas. Where this facies is dolomitized the most abundant porosity is intercrystalline and moldic. The facies was often distinguished by the shape of the lepidocyclus tests in heavily dolomitized intervals. This facies is interpreted as occupying a broad environment from the seaward side of grainstone shoals (shallow ramp) to deeper ramp. Based on Eva's (1976) observations it may have been ecologically dominant in the upper to middle sections of the ramp.

Nummulites/Lepidocyclus Wackestone: This facies is characterized by a wackestone texture with the dominant large allochems being foraminifera of the families Nummulitidae and Lepidocyclinidae. The most common constituent by weight in this facies, as it is in most wackestones, is mud (i.e. depositional components < 31 μm in size). Other less common large constituents include echinoderms, bivalves, bryozoans, pellets, and rotaliid foraminifera. The criteria for distinguishing between this facies and the nummulites wackestone and lepidocyclus wackestone is the same used for the foraminiferal packstones (see Nummulites/Lepidocyclus Packstone above). Sedimentary structures found in this facies include bioturbation by burrowers, and this is extensive in the basal sections of the Ocala Formation. The dominant porosity type is micro-interparticle (i.e., in micrite matrix). Where this facies is dolomitized the most abundant porosity is intercrystalline and moldic. The facies was often distinguished by the shape of the nummulites and lepidocyclus tests in heavily dolomitized intervals. This facies is interpreted as occupying low energy environs on the ramp. The nummulites/ lepidocyclus wackestone was most likely deposited at the far end of the depth spectrum, in the deeper ramp settings. The presence of wackestones directly overlying packstones and grainstones was often the criteria used in distinguishing sequence and cycle boundaries.

Nummulites Wackestone: This facies is characterized by a wackestone texture with the dominant large allochems being foraminifera of the family Nummulitidae. The most common constituent by weight in this facies, as it is in most wackestones, is mud (i.e. depositional components < 31 μm in size). Other less common large constituents include lepidocyclus, echinoderms, bivalves, pellets, and rotaliid foraminifera. Sedimentary structures found in this facies include bioturbation by burrowers, and this is extensive in the basal sections of the Ocala Formation. The dominant porosity type is micro-interparticle (i.e., in micrite matrix). Where this facies is dolomitized the most abundant porosity is intercrystalline and moldic. The facies was often distinguished by the shape of the nummulites tests in heavily dolomitized intervals. This facies is interpreted as occupying low energy environs on the ramp. The nummulites wackestone was most likely deposited at the far end of the depth spectrum, in the deeper ramp settings. The presence of wackestones directly overlying packstones and grainstones was often the criterion used in distinguishing sequence and cycle boundaries.

Lepidocyclina Wackestone: This facies is characterized by a wackestone texture with the dominant large allochems being foraminifera of the family Lepidocyclinidae. The most common constituent by weight in this facies, as it is in most wackestones, is mud (i.e. depositional components < 31 μm in size). Other less common large constituents include nummulites, echinoderms, bivalves, pellets, and rotaliid foraminifera. Sedimentary structures found in this facies include bioturbation by burrowers, and this is extensive in the basal sections of the Ocala Formation. The dominant porosity type is micro-interparticle (i.e., in micrite matrix). Where this facies is dolomitized the most abundant porosity is intercrystalline and moldic. The facies was often distinguished by the shape of the lepidocyclina tests in heavily dolomitized intervals. This facies is interpreted as occupying low energy environs on the ramp. The lepidocyclina wackestone was most likely deposited at the far end of the depth spectrum, in the deeper ramp settings. The presence of wackestones directly overlying packstones and grainstones was often the criteria used in distinguishing sequence and cycle boundaries.

Mixed Skeletal Wackestone: This facies is characterized by a wackestone texture with dominant large allochems being bivalves and echinoderms. The most common constituent by weight in this facies, as it is in most wackestones, is mud (i.e. depositional components < 31 μm in size). Other less common constituents include bryozoans, pellets, rotaliid foraminifera, and occasional nummulites and lepidocyclina. Sedimentary structures found in this facies include bioturbation by burrowers, which is extensive in the basal sections of the Ocala Formation. The dominant porosity type is micro-interparticle (i.e., in micrite matrix). Where this facies is dolomitized the most abundant porosity is intercrystalline with occasional molds of larger biota. This facies is interpreted as occupying low energy environs on the ramp, and most typically occurs at the base of sequences and cycles. The mixed skeletal wackestone was most likely deposited at the far end of the depth spectrum, in deeper ramp settings. The presence of wackestones directly overlying packstones and grainstones was often the criteria used in distinguishing sequence and cycle boundaries.

Pelagic Foraminiferal Facies:

Bioturbated Pelagic Wackestone: This facies is characterized by a wackestone texture with few recognized (or identified) large allochems. Trace echinoderms and bivalves were found. The most common constituent by weight in this facies, as it is in most wackestones, is mud (i.e. depositional components < 31 μm in size). Petrographic observation of this facies shows numerous small, frail foraminiferal tests that are interpreted as being pelagic, open-marine biota. Bioturbation in this facies is pervasive throughout. The dominant porosity type is micro-interparticle (i.e., in micrite matrix). This facies is interpreted as occupying the deepest portions of the ramp within the study area, as evidenced by its only appearances in three wells at the extreme south of the study area. The bioturbated pelagic wackestone was most likely deposited at the furthest end of the depth spectrum, in very low-energy, deep ramp settings. The extensive bioturbation may be indicative of low sedimentation rates combined with well oxygenated waters (Pedley 1992).

Laminated Pelagic Wackestone: This facies is characterized by a wackestone texture with no large allochems and a unique finely laminated sedimentary structure. Lamina vary in color and grain size (muds and silts), but are typically 1-3 mm in thickness. Petrographic observation of this facies shows numerous small, frail foraminiferal tests that are interpreted as being pelagic, open-marine biota. There are occasional burrows cutting across the lamina, but the laminated nature of this facies remains largely intact in a 2" diameter core. The dominant porosity type is micro-interparticle (i.e., in micrite

matrix). This facies is interpreted as occupying the deepest portions of the ramp within the study area, as evidenced by its only appearances in two wells at the extreme south of the study area. The facies underlies the bioturbated pelagic wackestone and therefore represents an even deeper, lower-energy deposit on the outer ramp.

Appendix C: Results of Falling Head Permeameter Tests

FGS Well#	SWFWMD Well #	Core Depth	K (cm/sec)				RUN#5	RUN#4	AVG. K (cm/sec)	AVG. K (ft/day)	Sedimentary Facies *	Comments
			RUN #1	RUN #2	RUN #3	RUN#5						
W-15826	TR8-1	689'-690'	4.04E-05	3.92E-05	3.78E-05				3.91E-05	1.11E-01	Mx. Sk. PS	
W-15826	TR8-1	741'-742'	4.45E-06	4.64E-06	4.62E-06				4.57E-06	1.30E-02	Numm. PS	
W-15826	TR8-1	809'-810'	4.76E-06	4.16E-06	5.11E-06				4.68E-06	1.33E-02	N/L PS	
W-15826	TR8-1	869'-870'	1.79E-06	1.88E-06	2.00E-06				1.89E-06	5.35E-03	Numm. PS	
W-16181	TR13-1X	574.5'-574.9'	4.87E-06	5.56E-06	6.30E-06				5.57E-06	1.58E-02	Mx. Sk. PS	
W-16181	TR13-1X	642.0'-642.4'	3.31E-05	3.10E-05	3.21E-05				3.21E-05	9.09E-02	Mx. Sk. GS	
W-16181	TR13-1X	683.0'-683.4'	3.79E-05	4.33E-05	4.76E-05				4.29E-05	1.22E-01	Mll. GS	
W-16304	Romp-99	113.0'-113.4'	1.65E-05	1.59E-05	1.55E-05				1.60E-05	4.53E-02	Numm. PS	
W-16304	Romp-99	164.5'-164.9'	2.57E-04	2.85E-04	2.86E-04				2.76E-04	7.82E-01	Mx. Sk. GS	
W-16304	Romp-99	209.1'-209.5'	1.61E-04	1.52E-04	1.17E-04				1.43E-04	4.06E-01	Mll. GS	
W-16307	Romp-58	179.0'-179.5'	4.25E-05	3.39E-05	4.09E-05				3.91E-05	1.11E-01	Mx. Sk. PS	
W-16307	Romp-58	212.0'-212.5'	7.04E-06	7.36E-06	8.54E-06				7.65E-06	2.17E-02	Lep. PS	
W-16307	Romp-58	314.5'-315.0'	1.06E-07	1.17E-07	1.22E-07				1.15E-07	3.26E-04	N/L PS	
W-16576	Dover Elem-1	365.0'-365.4'	6.82E-06	5.89E-06	5.83E-06				6.18E-06	1.75E-02	Mx. Sk. PS	
W-16576	Dover Elem-1	441.0'-441.4'	5.44E-06	5.21E-06	4.94E-06				5.20E-06	1.47E-02	N/L PS	
W-16576	Dover Elem-1	512.0'-512.3'	1.00E-05	1.03E-05	1.06E-05				1.03E-05	2.92E-02	Mx. Sk. GS	
W-16618	TR9-2	483'-484'	1.97E-05	2.43E-05	4.03E-05	5.69E-05			3.53E-05	1.00E-01	Mx. Sk. PS	No Flow after 60 days - max. K possible reported
W-16618	TR9-2	549.2'-550.2'	1.14E-09						1.14E-09	3.24E-06	Numm. PS	
W-16618	TR9-2	624.5'-625.5'	3.43E-05	3.35E-05	3.36E-05				3.38E-05	9.58E-02	Mx. Sk. GS	
W-16618	TR9-2	682.5'-683.5'	2.36E-07	2.64E-07	2.88E-07	3.06E-07	3.07E-07		2.80E-07	7.95E-04	Numm. PS	
W-16740	Romp-39	796.7'-797'	2.40E-06	2.50E-06	4.12E-06				3.01E-06	5.83E-03	Mx. Sk. PS	
W-16740	Romp-39	840.7'-841'	3.83E-09						3.83E-09	1.09E-05	N/L PS	No Flow after 32 days - max. K possible reported
W-16740	Romp-39	911.7'-912	1.90E-06	2.04E-06	2.11E-06				2.02E-06	5.71E-02	Numm. PS	
W-16783	Romp-22	641'-641.5'	1.64E-08						1.64E-08	4.66E-05	Mx. Sk. GS	No Flow after 30 days - max. K possible reported
W-16783	Romp-22	818.5'-819'	1.74E-06	1.80E-06	1.96E-06				1.83E-06	5.19E-03	N/L PS	
W-16783	Romp-22	909'	4.69E-07	6.52E-07	7.19E-07				6.13E-07	1.74E-03	Lep. WS	
W-16784	Romp-33	805'	3.69E-06	3.97E-06	4.83E-06				4.16E-06	1.18E-02	Lep. PS	
W-16784	Romp-33	854'	8.23E-07	1.02E-06	1.28E-06				1.04E-06	2.95E-03	N/L PS	
W-16784	Romp-33	895'	2.07E-06	2.20E-06	2.49E-06				2.25E-06	6.38E-03	N/L PS	

Appendix C (cont'd): Results of Falling Head Permeameter Tests

FGS Well#	SWFWMD Well#	Core Depth	K (cm/sec)				AVG. K (cm/sec)	AVG. K (ft/day)	Sedimentary Facies *	Comments
			RUN #1	RUN #2	RUN #3	RUN #4	RUN #5			
W-17000	Romp-28	630'	1.24E-05	1.28E-05	1.32E-05			1.28E-05	3.63E-02	Mx. Sk. PS
W-17000	Romp-28	713'	1.80E-06	2.30E-06	2.17E-06			2.09E-06	5.93E-03	N/L PS
W-17000	Romp-28	771.5'	4.07E-06	4.11E-06	4.26E-06			4.15E-06	1.18E-02	Lep. PS
W-17000	Romp-28	849'	4.89E-06	4.90E-06	5.10E-06			4.96E-06	1.41E-02	Numm. WS
W-17001	Romp-14	693'	8.77E-05	1.19E-04	1.49E-04			1.19E-04	3.37E-01	Mx. Sk. GS
W-17056	Romp-9	921.4' - 921.9'	7.90E-06	8.00E-06	8.26E-06			8.05E-06	2.28E-02	Numm. PS
W-17056	Romp-9	1002.5'-1002.9'	2.33E-06	2.44E-06	2.68E-06			2.48E-06	7.04E-03	N/L PS
W-17056	Romp-9	1102.5'-1102.9'	5.74E-06	6.99E-06	8.08E-06			6.95E-06	1.97E-02	Numm. WS
W-17057	TR7-2	740'	8.88E-06	8.56E-06	8.99E-06			8.81E-06	2.50E-02	Numm. PS
W-17057	TR7-2	797'	7.17E-06	7.44E-06	7.77E-06			7.46E-06	2.12E-02	Numm. PS
W-17057	TR7-2	887'	8.31E-05	9.52E-05	9.52E-03			9.11E-05	2.58E-01	N/L WS
W-17087	Romp-20	939.6'-940'	4.02E-06	4.44E-06	4.70E-06			4.38E-06	1.24E-02	Numm. PS
W-17087	Romp-20	1064.0'-1064.4'	1.31E-08					1.31E-08	3.71E-05	N/L PS
W-30026	Romp-13	860.5'-861'	3.04E-06	3.17E-06	3.04E-06			3.08E-06	8.74E-03	Lep. PS
W-30026	Romp-13	1019.5'-1020'	2.22E-06	2.27E-06	2.24E-06			2.25E-06	6.37E-03	Numm. WS

Top of core slightly fractured

Sample did not saturate in 3 weeks

* =

Numm. WS = Nummulites Wackestone
 Lep. WS = Lepidocyclina Wackestone
 N/L WS = Nummulites/Lepidocyclina Wackestone
 Numm. PS = Nummulites Packstone
 Lep. PS = Lepidocyclina Packstone
 N/L PS = Nummulites/Lepidocyclina Packstone
 Mx. Sk. PS = Mixed Skeletal Packstone
 Mx. Sk. GS = Mixed Skeletal Grainstone
 Mili. GS = Miliolid Grainstone

Appendix D: Ocala Porosity Data.

FGS Well # (1)	Depth (1)	Mass of		Total Volume (cm ³)	Volume of Rock (g/cm ³)	Mass of Wax (g)	Volume of Wax (cm ³)	Volume of Pores (cm ³)	Sedimentary		Comments
		Oven-Dried Sample (g)	Wax and Sample (g)						% Ø	Facies (2)	
W-15826	690.0'	23.216	24.414	16.18	8.567	1.198	1.346	6.27	38.7	Mx. Sk. PS	
W-15826	742.0'	18.515	19.325	12.01	6.832	0.810	0.910	4.27	35.5	Numm. PS	
W-15826	810.0'	19.979	21.254	13.87	7.372	1.275	1.433	5.07	36.5	N/L PS	
W-15826	870.0'	16.610	17.313	9.74	5.918	0.703	0.790	3.03	31.1	Numm. PS	70%Dol, 30%Cal
W-16181	575.0'	23.381	24.529	14.70	8.628	1.148	1.290	4.78	32.5	Mx. Sk. PS	
W-16181	642.4'	20.906	22.102	13.94	7.714	1.196	1.344	4.88	35.0	Mx. Sk. GS	
W-16181	683.4'	25.734	27.040	16.08	9.496	1.306	1.467	5.12	31.8	Mil. GS	
W-16304	113.4'	16.615	18.918	13.73	6.131	2.303	2.588	5.01	36.5	Numm. PS	
W-16304	164.9'	22.643	25.698	16.07	8.355	3.055	3.432	4.28	26.6	Mx. Sk. GS	
W-16304	209.0'	16.999	19.299	13.20	6.273	2.300	2.584	4.34	32.9	Mil. GS	
W-16307	179.5'	11.899	13.399	10.18	4.391	1.500	1.685	4.10	40.3	Mx. Sk. PS	
W-16307	212.8'	15.320	16.839	11.63	5.653	1.519	1.707	4.27	36.7	Lep. PS	
W-16307	314.8'	22.854	23.959	12.58	8.433	1.105	1.242	2.91	23.1	N/L PS	
W-16576	365.4'	21.350	23.391	15.46	7.878	2.041	2.293	5.29	34.2	Ms. Sk. PS	
W-16576	441.4'	18.736	20.288	13.42	6.914	1.552	1.744	4.76	35.5	N/L PS	
W-16576	512.3'	14.986	16.273	10.41	5.530	1.287	1.446	3.43	33.0	Mx. Sk. GS	

Appendix D (cont'd): Ocala Porosity Data.

FGS Well # (1)	Depth (1)	Mass of		Total Volume (cm ³)	Volume of Rock (g/cm ³)	Mass of Wax (g)	Volume of Wax (cm ³)	Volume of Pores (cm ³)	% Ø	Sedimentary Facies (2)		Comments
		Oven-Dried Sample (g)	Mass of Wax and Sample (g)									
W-16618	482.8'	16.950	18.041	11.41	6.255	1.091	1.226	3.93	34.4	Mx. Sk. PS		
W-16618	552.3'	48.514	51.993	34.40	17.902	3.479	3.908	12.59	36.6	Numm. PS		
W-16618	624.3'	10.544	11.495	7.27	3.891	0.951	1.069	2.31	31.8	Mx. Sk. GS		
W-16618D	624.3'D	9.738	10.971	7.56	3.593	1.233	1.386	2.58	34.1	Mx. Sk. GS		
W-16618	681.3'	61.437	63.530	33.21	22.670	2.093	2.352	8.19	24.7	Numm. PS		
W-16740	797.0'	18.003	18.950	12.15	6.643	0.947	1.064	4.44	36.6	Mx. Sk. PS		
W-16740	840.5'	28.287	29.292	15.01	10.438	1.005	1.129	3.44	22.9	N/L PS		
W-16740D	840.5'D	27.571	29.502	15.78	10.174	1.931	2.170	3.44	21.8	N/L PS		
W-16740	912.0'	21.040	21.945	12.44	7.764	0.905	1.017	3.66	29.4	Numm. PS		
W-16783	640.9'	5.513	6.000	3.79	2.034	0.487	0.547	1.21	31.9	Mx. Sk. GS		
W-16783	817.7'	61.239	63.139	34.42	22.153	1.900	2.135	10.13	29.4	N/L PS		40%Dol, 60%Cal
W-16783D	817.7'D	59.029	62.837	35.70	21.354	3.808	4.278	10.07	28.2	N/L PS		40%Dol, 60%Cal
W-16783	909.5'	26.107	27.299	14.43	9.302	1.192	1.339	3.79	26.3	Lep. WS		70%Dol, 30%Cal
W-16784	805.0'	22.728	23.887	15.95	8.387	1.159	1.302	6.26	39.3	Lep. PS		
W-16784	853.5'	25.055	26.035	14.18	9.245	0.980	1.101	3.83	27.0	N/L PS		
W-16784	896.0'	24.982	26.020	11.90	9.218	1.038	1.166	1.52	12.7	N/L PS		

Appendix D (cont'd): Ocala Porosity Data.

FGS Well # (1)	Depth (1)	Mass of		Total Volume (cm ³)	Volume of Rock (g/cm ³)	Mass of Wax (g)	Volume of Wax (cm ³)	Volume of Pores (cm ³)	% Ø	Sedimentary Facies (2)		Comments
		Oven-Dried Sample (g)	Mass of Wax and Sample (g)									
W-17000	630.5'	14.358	15.344	10.83	5.298	0.986	1.108	4.42	40.8	Mx. Sk. PS		
W-17000	712.4'	24.822	26.033	16.56	9.159	1.211	1.361	6.04	36.5	N/L PS		
W-17000	772.0'	44.717	46.526	27.03	16.501	1.809	2.033	8.50	31.4	Lep. PS		
W-17000D	772.0'D	43.165	46.950	29.57	15.928	3.784	4.252	9.39	31.8	Lep. PS		
W-17000	849.5'	17.918	18.770	11.33	6.612	0.852	0.957	3.76	33.2	Numm. WS		
W-17001	693.4'	53.516	55.596	29.30	19.748	2.080	2.337	7.22	24.6	Mx. Sk. GS		
W-17056	920.9'	21.111	22.623	14.98	7.790	1.512	1.699	5.49	36.7	Numm. PS		
W-17056	1002.9'	30.424	32.191	19.10	11.171	1.767	1.985	5.94	31.1	N/L PS		10%Dol, 90%Cal
W-17056	1102.4'	27.687	29.086	15.55	9.715	1.399	1.572	4.26	27.4	Numm. WS		100% Dolomite
W-17056D	1102.4'D	27.637	30.598	17.63	9.697	2.961	3.327	4.61	26.1	Numm. WS		100% Dolomite
W-17057	740.1'	44.883	46.840	31.27	16.562	1.957	2.199	12.51	40.0	Numm. PS		
W-17057	797.0'	24.089	25.407	16.19	8.889	1.318	1.481	5.82	35.9	Numm. PS		
W-17057	887.0'	56.989	59.047	30.35	19.996	2.058	2.312	8.04	26.5	N/L WS		100% Dolomite
W-17087	940.0'	27.692	30.274	18.71	10.219	2.582	2.901	5.59	29.9	Numm. PS		
W-17087	1064.4'	23.725	25.058	11.15	8.325	1.333	1.498	1.33	11.9	N/L PS		100% Dolomite

Appendix D (cont'd): Ocala Porosity Data.

FGS Well # (1)	Depth (1)	Mass of		Total Volume (cm ³)	Volume of Rock (g/cm ³)	Mass of Wax (g)	Volume of Wax (cm ³)	Volume of Pores (cm ³)	% Ø	Sedimentary Facies (2)		Comments
		Oven-Dried Sample (g)	Wax and Sample (g)									
Romp-13	860.3'	40.850	43.241	29.12	15.074	2.391	2.687	11.36	39.0	Lep. PS		
Romp-13D	860.3'D	39.406	42.371	30.03	14.541	2.965	3.332	12.16	40.5	Lep. PS		
Romp-13	1019.4'	34.345	36.248	21.54	12.673	1.903	2.138	6.73	31.2	Numm. WS		
Romp-13D	1019.4'D	33.384	35.915	22.37	12.319	2.531	2.843	7.21	32.2	Numm. WS		

1 = Duplicate samples indicated by a "D" following the FGS Well # and depth. Average difference between the seven initial and duplicate samples was 1.26% (re-runs are listed, but the original values were used in all cross plots and calculations)

2 = Numm.WS = Nummulites Wackestone
 Lep.WS = Lepidocyclina Wackestone
 N/L WS = Nummulites/Lepidocyclina Wackestone
 Numm.PS = Nummulites Packstone
 Lep.PS = Lepidocyclina Packstone
 N/L PS = Nummulites/Lepidocyclina Packstone
 Mx.Sk.PS = Mixed Skeletal Packstone
 Mx.Sk.GS = Mixed Skeletal Grainstone
 Mil.GS = Miliolid Grainstone

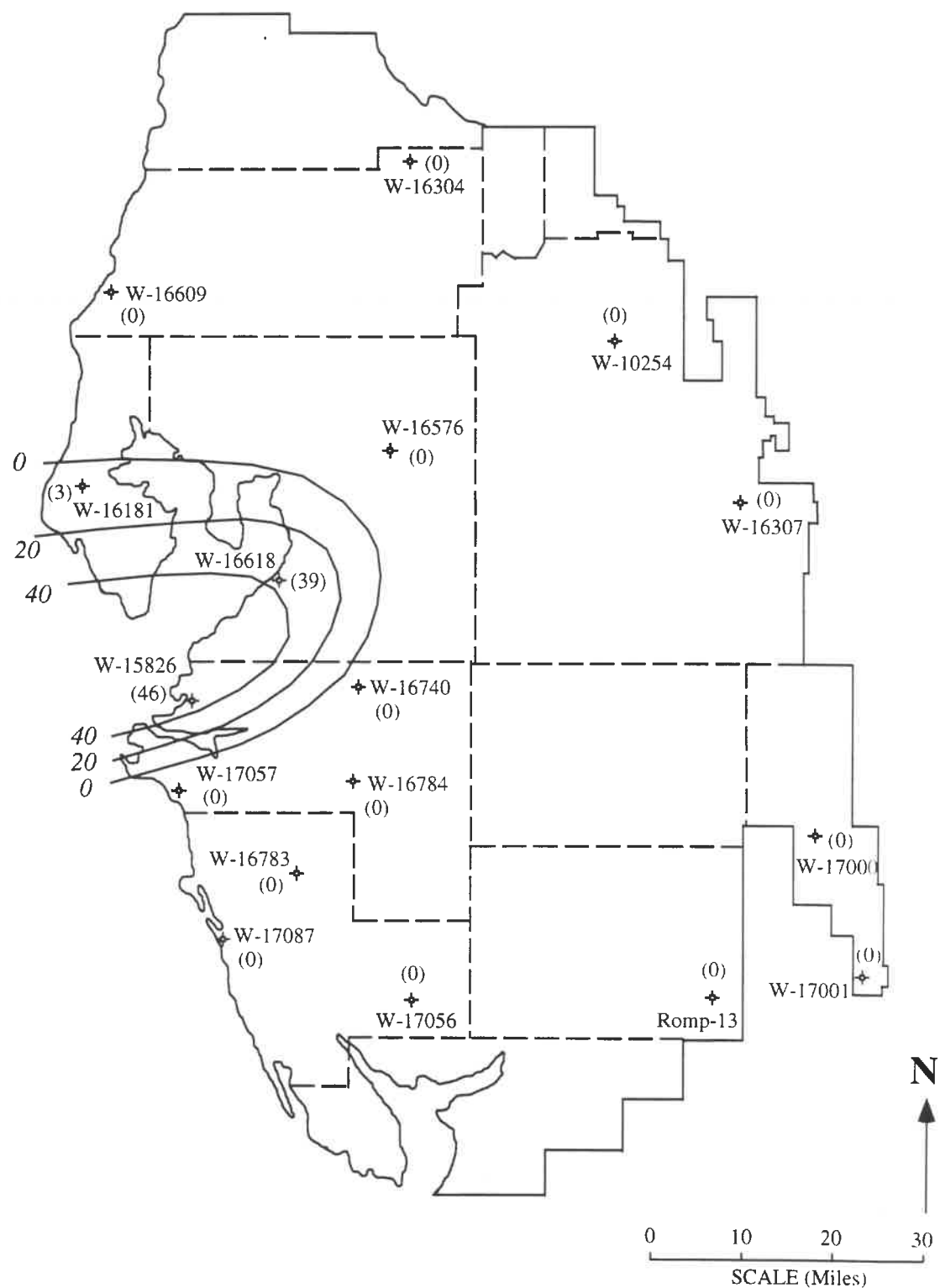


Figure E-1: Isopach map of the mixed skeletal grainstones found in sequence #1. Contour interval is in 20% increments of the total thickness of the sedimentary package.

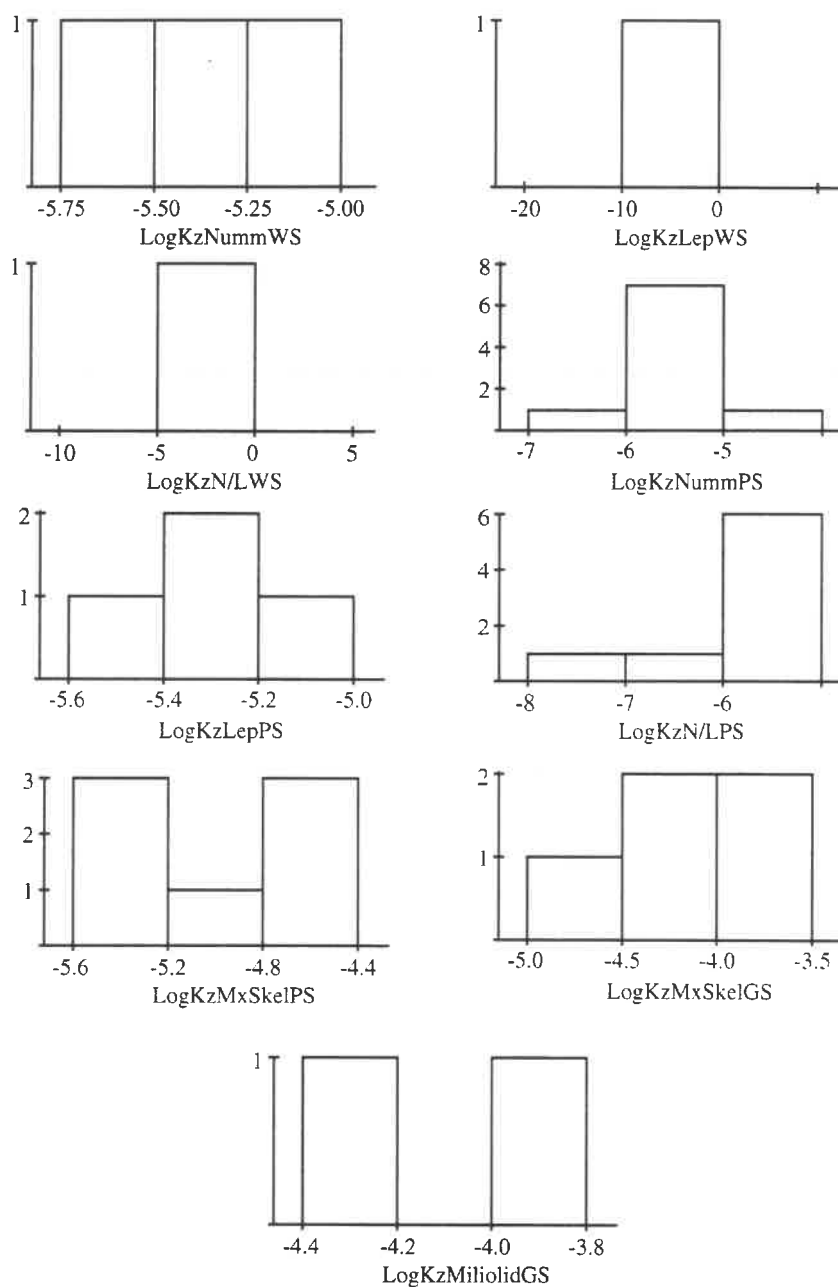


Figure E-2: Histograms of hydraulic conductivity within each sedimentary facies. The low sample sizes make assumptions of normality questionable. The nearly log normal distribution of all the samples (Figure 30) may indicate that these facies subsets are also normally distributed, as permeability data is commonly normalized by log transformation.

Appendix E-3: Summary results of point counting.

PACKSTONES

	W-16618@ 681.3'	W-17056@ 1002.9'	W-15826@ 742.0'	W-17057@ 740.0'
Grains:				
Sand Sized ($> 62 \mu\text{m}$)	20	26	43	62
Coarse Silt ($> 31 \mu\text{m}$)	26	42	17	36
Silt and Mud ($< 31 \mu\text{m}$)	184	158	148	89
Pores:				
Intragranular	0	4	12	12
Macro-intergranular ($> 31 \mu\text{m}$)	2	0	6	35
Micro-intergranular ($< 31 \mu\text{m}$)	68	70	74	63
Cement	0	0	0	3
Total Points Counted	300	300	300	300

GRAINSTONES

	W-16304@ 164.9'	W-16181@ 683.4	W-16181@ 642.4
Grains:			
Med.-Coarse Sand Sized ($> 250 \mu\text{m}$)	116	132	78
Fine Sand Sized ($> 62 \mu\text{m}$)	54	20	34
Coarse Silt ($> 31 \mu\text{m}$)	4	6	18
Silt and Mud ($< 31 \mu\text{m}$)	6	0	24
Pores:			
Intragranular	4	15	26
Macro-intergranular ($> 31 \mu\text{m}$)	52	56	56
Micro-intergranular ($< 31 \mu\text{m}$)	0	0	14
Cement	64	71	50
Total Points Counted	300	300	300
Average Grain-to-Grain Contacts:	2.98	2.25	4.19