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Lithostratigraphy, Depositional Environment and Diagenetic History of Upper Cretaceous-Paleocene Strata of TEC DiIW-1 Deep Well, Polk County, Florida

Ekin Ozakar



FLORIDA STATE UNIVERSITY
COLLEGE OF ARTS AND SCIENCES

LITHOSTRATIGRAPHY, DEPOSITIONAL ENVIRONMENT AND DIAGENETIC
HISTORY OF UPPER CRETACEOUS-PALEOCENE STRATA OF TEC DIW-1 DEEP
WELL, POLK COUNTY, FLORIDA

By
EKIN OZAKAR

A Thesis submitted to the
Department of Earth, Ocean and Atmospheric Sciences
in partial fulfillment of the
requirements for the degree of
Master of Science

2015

Ekin Ozakar defended this thesis on July 13, 2015.

The members of the supervisory committee were:

William Parker
Professor Directing Thesis

Seth Young
Committee Member

Yang Wang
Committee Member

The Graduate School has verified and approved the above-named committee members, and certifies that the thesis has been approved in accordance with university requirements.

To my parents, my brother, my soulmate and my grandfather...

ACKNOWLEDGMENTS

First of all, I want to express my deepest appreciation to my adviser Dr. William Parker for his support, guidance and suggestions during my research. Working with him is a great honor for me. I am deeply grateful to him for recommending the project and providing a great assistance during these two years. I owe special thanks for his productive discussions relating to my research. I absolutely could not have done this without his support. I am also very grateful to my thesis committee members, Dr. Yang Wang and Dr. Seth Young, for their endless support, assistance and critical review of the work. Dr. Seth Young, thank you for being my co-adviser and always encouraging me in every step of this journey.

I would like to thank Florida Geological Survey for their generous help in providing core and rock cutting samples and allowing me to use their equipment. I want to thank to Jesse Hurd at Florida Geological Survey for his assistance through the examination of rock cutting samples. I'd like to thank Dr. Neil Lundberg for his endless support and enjoyable Basin Analysis class where I experienced his great value of teaching about sedimentology. I am also very grateful to Turkish Petroleum Company for providing me a scholarship and wonderful opportunity to get my master degree in US. I will be forever thankful for these generous full financial supports. Without the supports, this study would have been impossible.

I like to give very special thanks to my lovely roommate Sonay Bozkurt for accompanying me through hard and joyful time. She is not only a true friend but also my family in US. She was always there when things weren't always going as well as I thought. She is the one that we share

feelings that nobody can understand. Thank you for being in my life, I am very happy this scholarship brought us together and enabled us to experience a journey that we cannot experience otherwise. Many many thanks to my lovely friend Tugba Sezen. A few years ago, when we were in college in Turkey, we were dreaming about getting our master degrees in US. Even though, we couldn't achieve this at the same time, we made our dreams come true with one year interval and had lots of fun through a year in beautiful Florida. I will be forever thankful to her for being my biggest supporter in all phases of my life. I would like to thank my lovely friend and roommate Yeliz Cengelcik who is such a supportive friend and one of the persons that I can trust without thinking. Thank you being always my supporter, my family in Tallahassee and being sure I had everything I needed. You were the reason of my happiness through the hardest times, which made me a stronger person.

I want to thank all of my colleagues at department of Geology for their friendship and encouragements. I also want to thank my best friends Ceyda Hafizoglu, Irem Ibay, Ceren Yurtsever, Nilay Baskurt Sivel, Hilal Bektas, Zeynep Ataselim, Gamzenur Ozsin for their endless support and friendship. I'm so lucky for having such lovely sisters who make me so strong. I would like to thank my close friends Umit Uzuno and Burak Baykal for supporting me through this journey and being always there whenever I need them.

I will be forever thankful to my boyfriend, Eren Karakus, for his support and patience during these long two years. I am very thankful to him for waiting me to get my master degree while we were far away from each other and living separate lives with 7 hour difference for two years.

I want to express my deepest appreciation to my parents and brother. They have been my biggest supporters. I am very thankful to them for their endless love, trust and sacrifices that they have done so far. I would like to thank my father who has always pushed me to be the best person I can be. I am very thankful to my mother for growing me up such a brave girl who can lead a life thousands of miles away from her home. My brother, my biggest inspiration, always supported me and made me believe that I can achieve all of these things.

TABLE OF CONTENTS

LIST OF FIGURES	ix
ABSTRACT	xi
CHAPTER 1 INTRODUCTION	1
1.1 Study Area.....	3
1.2 Methods and Materials	3
1.3 Objectives of Thesis	6
CHAPTER 2 GEOLOGICAL SETTING	8
2.1 Geologic Overview of Florida through the Upper Cretaceous-Paleocene.....	8
2.2 Stratigraphic Units of This Study.....	13
CHAPTER 3 LITHOSTRATIGRAPHY	27
CHAPTER 4 DEPOSITIONAL ENVIRONMENT	31
4.1 Depositional Environment of Lawson Formation.....	31
4.2 Depositional Environment of Cedar Keys Formation.....	41
CHAPTER 5 DIAGENESIS	49
5.1 Diagenetic Features of Lawson Formation	49
5.2 Diagenetic Features of Cedar Keys Formation	55

CHAPTER 6 DISCUSSION.....	60
6.1 Rudistid Fragments of the Lawson Formation.....	61
6.2 Evaporites of the Cedar Keys Formation	61
6.3 Distribution and Relative Timing of Diagenetic Processes	63
6.4 Petroleum Potential	64
6.5 Changes in Sea Level	65
CHAPTER 7 CONCLUSIONS	69
APPENDICES	73
A. DETAILED LITHOSTRATIGRAPHY	73
B. PLATES	79
C. SEA-LEVEL CYCLES	83
REFERENCES	87
BIOGRAPHICAL SKETCH	93

LIST OF FIGURES

Figure 1.1. Regional location map showing TEC DIW-1 well in Polk County, Florida.	4
Figure 1.2. Selection of samples from drill core material.	5
Figure 2.1. A reconstruction of North American paleogeography during the Late Cretaceous (a), Late Cretaceous-Paleogene (b), and Paleogene (c).	10
Figure 2.2. Structures affecting the Mesozoic and Early Cenozoic sediments in Florida.	12
Figure 2.3. Lithologic units cored by TEC DIW-1 deep well and stratigraphic column of units/formations discussed in this study.	14
Figure 2.4. Location map indicating some key wells drilled for oil exploration in south Florida.	17
Figure 2.5. Cross section through southern Georgia, through Florida, and the Bahamas to north-central Cuba.	18
Figure 2.6. Regional structure of Rebecca Shoal reef.	25
Figure 3.1. Simplified lithostratigraphic column of Upper Cretaceous-Paleocene section of TEC DIW-1 well discussed in this study.	30
Figure 4.1. Standard facies model of Wilson (1975).	32
Figure 4.2. Stratigraphic column of Lawson Formation showing microfacies types, thin section samples, and interpretation of depositional environments [4400-4700 ft (~1341-1433 m)].	32
Figure 4.3. Stratigraphic column of Lawson Formation showing microfacies types, thin section samples, and interpretation of depositional environments [4700-5100 ft (~1433-1554 m)].	33
Figure 4.4. Photomicrograph (XPL-Cross Polarized Light) of dolomitized foraminiferal wackestone facies at a depth of 5070-5080 ft (~1545-1578 m).	34
Figure 4.5. Photomicrograph (XPL) of dolomitized foraminiferal wackestone facies at a depth of 5060-5070 ft (~1542-1545 m).	35
Figure 4.6. Photomicrograph (XPL) of fossiliferous grainstone facies at a depth of 4550-4560 ft (~1387-1390 m).	36
Figure 4.7. Photomicrograph (XPL) of fossiliferous grainstone facies at a depth of 4910-4920 ft (~1496-1499 m).	36
Figure 4.8. Photomicrograph (XPL) of fossiliferous wackestone microfacies at a depth of 4770-4780 ft (~1454-1457 m).	37

Figure 4.9. Photomicrographs (XPL) of peloidal fossiliferous packstone/grainstone microfacies at a depth of 4610-4620 ft (~1405-1408 m).....	39
Figure 4.10. Photomicrographs (XPL) of rudist grainstone/rudstone microfacies at a depth of 4740-4750 ft (~1445-1448 m)..	40
Figure 4.11. Photomicrograph (XPL) of foraminiferal packstone/grainstone microfacies at a depth of 4590-4600 ft (~1399-1402 m).	41
Figure 4.12. Stratigraphic column of Cedar Keys Formation showing microfacies types, thin section samples, and interpretation of depositional environments [3402-3910 ft (~1037-1192 m)].	42
Figure 4.13. Stratigraphic column of Cedar Keys Formation showing microfacies types, thin section samples, and interpretation of depositional environments [3910-4400 ft (~1192-1341 m)].	43
Figure 4.14. Photomicrographs (XPL) of evaporite facies at several depths.	45
Figure 4.15. Photomicrograph (XPL) of dolomitized peloidal packstone at a depth of 4210-20 ft (~1283-1286 m)..	46
Figure 4.16. Photomicrograph (XPL) of dolomitized foraminifera packstone at a depth of 3960-3970 ft (~ 1207-1210 m).....	47
Figure 4.17. Photomicrograph (XPL) of dolomitized foraminiferal packstone at a depth of 3810-3820 ft (1161-1164 m).	48
Figure 5.1. Photomicrograph (XPL) of micritization (micrite envelope) surrounding the skeletal fragment at a depth of 4550-4560 ft (~1387-1390 m).	50
Figure 5.2. Photomicrographs (XPL) of dolomitization in the Lawson Formation.....	53
Figure 5.3. Photomicrographs (XPL) of recrystallization observed in the Lawson Formation...	54
Figure 6.1. Comparison of SFB rocks' organic carbon content and sedimentary basins of the world.	67
Figure 6.2. Photomicrographs (XPL) of pore spaces filled with organics or tar at a depth of 4740-4750 ft (~1445-1448 m).	68

ABSTRACT

The present study deals with the stratigraphy and petrography of the Upper Cretaceous through Paleocene carbonate sequence obtained from a deep well located in Polk County, Florida. Subsurface stratigraphy was measured and described at one locality from a deep well drilled nearly 8,000 ft (~2,438 m). Based on previous studies and lithologic changes that observed under stereo and petrographic microscope, the studied interval is stratigraphically subdivided into three formations. This study spans a 3400-5700 ft (~1,036-2,193 m) interval encompassing Upper Cretaceous Pine Key and Lawson formations and the Paleocene Cedar Keys Formation. Petrographic investigation of the selected sequence led to identification of lithostratigraphy, depositional environment and diagenetic history of Upper Cretaceous-Paleocene rocks. This study revealed that approximately 1,000 ft (~305 m) of a carbonate-evaporite sequence (mainly dolostone and small portions of limestone) are within the Cedar Keys Formation (3,400-4,400 ft [~1,036-1,341 m]), almost 700 ft (~213 m) white to tan limestone that includes dolomitized portions and small amount of anhydrite belongs to the Lawson Formation (4,400-5,100 ft [~1,341- 1,555 m]), and 600 ft (~183 m) white chalky limestone is from the Pine Key Formation (5,100-5,700 ft [~1,555- 1,737 m]). A number of microfacies were recognized in thin sections representing shallow subtidal to intertidal depositional environments of Lawson Formation and shallow subtidal to supratidal depositional environments of Cedar Keys Formation. Thin section analysis revealed that the Lawson and Cedar Keys formations have a complex diagenetic history that is characterized by several diagenetic features such as micritization, cementation, dissolution, dolomitization, and recrystallization. These complex diagenetic features took place

under marine, mixed-marine and fresh water as well as fresh water environments. The Upper Cretaceous Lawson Formation represents a general transgressive to regressive cycle in sea-level while the Cedar Keys Formation indicates more restricted marine environment representing lower sea-levels and multiple transgressive and regressive cycles.

CHAPTER 1

INTRODUCTION

Florida is a part of eastern Gulf of Mexico sedimentary basin that includes two major stratigraphic provinces. The North Florida province is dominated by clastic sedimentary rocks (clay, shale and sandstone), while the South Florida Province is predominantly the non-clastic sedimentary rocks (limestones, marls and evaporates) (Pressler, 1947).

The Florida-Bahamas megabank has been one of the most extensive carbonate platform systems in geologic history that was formed during the Late Mesozoic to Cenozoic (Poag, 1991).

Continental rifting and formation of the North Atlantic Ocean basin in the Triassic led to deposition of Mesozoic sediments on the Florida Platform, beginning a pattern of shallow marine sedimentation that continued throughout the Paleogene (Scott, 1992). Much of the Florida Platform was dominated by carbonate-evaporite deposition during the Paleocene (Miller, 1986). Throughout its geologic history, sedimentation within the Florida Platform, has been notably cyclic with periodic deposition of relatively thick and porous shallow-marine carbonate units. These carbonate units, comprising mostly limestone and dolostone, were deposited in various shallow-water marine depositional environments and are interbedded with evaporite units deposited in sabkhas, mud flats, or restricted lagoon environments (Scott, 1992).

From mid-Mesozoic, onward carbonate sediments dominated the southern and central Florida region. Similarly, carbonate deposition dominated the northern and eastern panhandle Florida from the earliest Cenozoic to the Miocene. Due to the changes in ocean circulation patterns and

eustatic sea-level, evaporites such as anhydrite and gypsum periodically formed, and are very common in Mesozoic and Paleogene sediments (Scott, 1992). In brief, while carbonate and evaporite deposition was predominant towards to the south, siliciclastic deposition was taking place in the northern part of the platform (Randazzo, 1997). According to Pressler (1947), Jurassic through Lower Cretaceous carbonate strata present in south Florida subsurface have potential for producing oil although more detailed studies are needed to be able to fully understand the petroleum potential.

This study is focused on the Upper Cretaceous and Paleocene strata of TEC DIW-1 well, drilling did not reach the Lower Cretaceous oil producing formations. Lithostratigraphy, depositional environment and diagenetic history of this section can shed light on better understanding the stratigraphic units in the study area and provide information on oil explorations for future discoveries. In order to estimate the petroleum potential in Florida Peninsula, sub-surface stratigraphy has been drilled and studied extensively. Among all of these explorations throughout the area, the northern flank of the South Florida Basin and the western continental shelf of the peninsular Florida have shown the greatest oil potential with their Lower Cretaceous carbonates and quartzose sandstones. In addition to this, Paleocene carbonates throughout the northwestern peninsular Florida have production potential (Rainwater, 1970).

Only a few studies have examined the geologic history, lithostratigraphy, depositional environment and diagenetic history of Upper Cretaceous and Lower Paleogene units situated in south-central Florida peninsula. However, extensive studies have been conducted in the nearby South Florida Basin particularly the Lower Cretaceous Sunniland Formation. This area has

recently seen a significant increase in interest for hydrocarbon exploration along with associated scientific studies (Rainwater, 1970; Palacas, 1978; Pollastro, 2001). The Gulf Series, representing Upper Cretaceous strata, comprises four units in the Florida Peninsula. This study focuses on Upper Cretaceous Pine Key and Lawson formations, as well as the Paleocene Cedar Keys Formation and aims to discuss lithostratigraphy, depositional environment and diagenetic history of Upper Cretaceous and Lower Paleogene units.

1.1 Study Area

Polk County is the fourth largest county of Florida and located in the south-central part of the Florida peninsula with about 1,823 square miles (mi^2) ($\sim 4,722$ square kilometers [km^2]) surface area (Purdum et al., 1988). It is delimited on the east by Osceola County, on the west by Hillsborough and Pasco Counties. On the north, the county is bordered by Lake and Sumter Counties and the south by Hardee and Highlands Counties. The TEC DIW-1 well is located in southwestern Polk County, (Figure 1.1) GPS coordinates at N27 43' 13.4'', W81 59' 18.0''. The well penetrates subsurface to almost 8,000 feet (ft) ($\sim 2,438$ meters[m]); This study concerns the units between 3400-5700 ft ($\sim 1,036$ -2,193 m). Data from this well is important because few studies of the Upper Cretaceous-Paleocene section of the Polk County, Florida exist that examine the extent of lithologies present in the area and their depositional environments.

1.2 Methods and Materials

TEC DIW-1 deep well was drilled by Layne Christensen Company in 2011. Core and sample of drill cuttings provided by Florida Geological Survey (FGS) were the primary source of data used in this study.

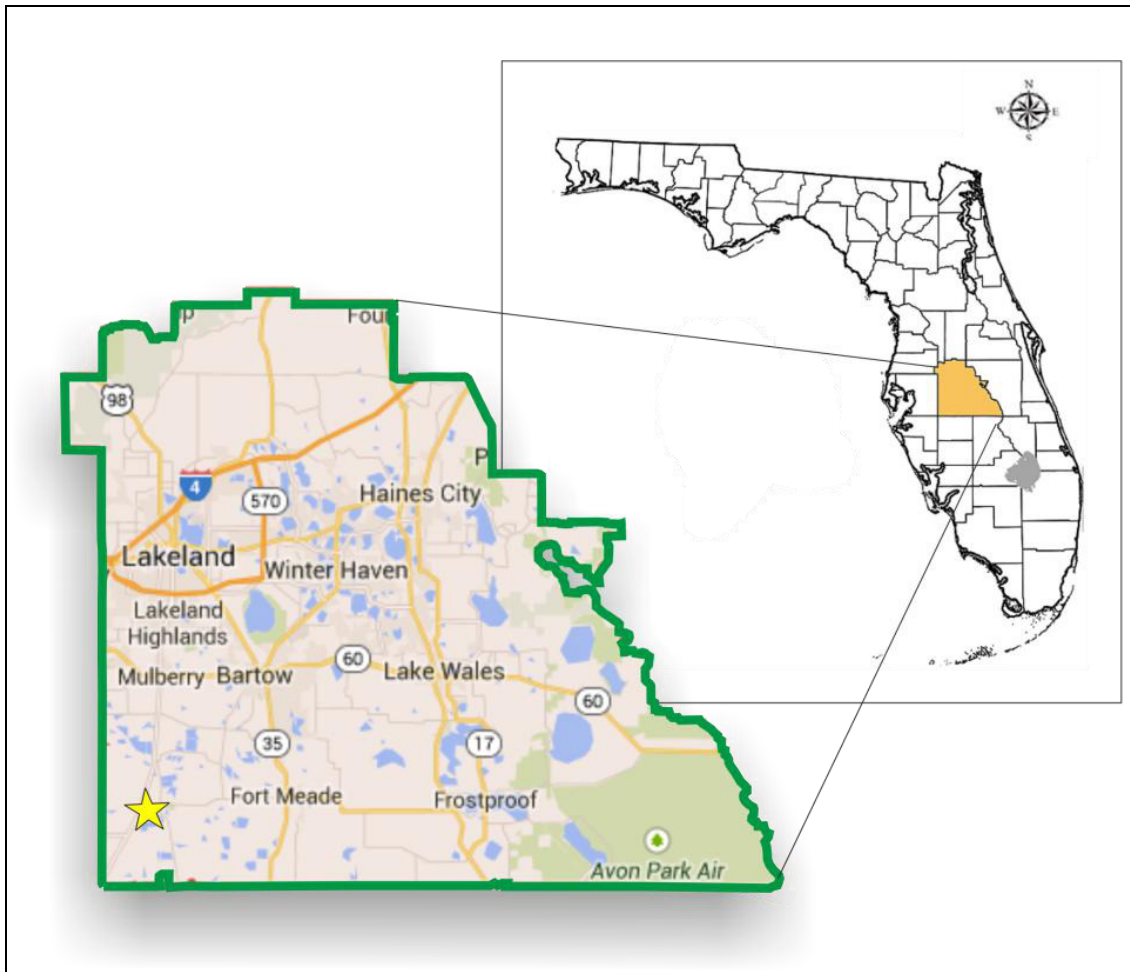


Figure 1.1. Regional location map showing TEC DIW-1 well in Polk County, Florida (county map from Google Earth).

The available interval of drill core for this study is between 3,402 and 3,653 ft (~1,036 and 1,113 m). Suitable samples of this drill core for making petrographic thin sections were selected every 20- 50 cm, based on observed changes in lithology. Between 3400-5700 ft (~1,036 and 1,737 m), only cuttings and not intact core are available. Samples within this section were selected based on observed lithologic changes in order to provide basic representative information for this section of the stratigraphic sequence. In total 64 samples were collected for making petrographic thin sections. For petrographic examination, sample points were selected within the core material

and rock cuttings (Figure 1.2). 64 thin sections prepared from both core and cutting samples were selected to represent lithologic transitions, sedimentary structures and fossil content. Lithologic descriptions were made by examining the rock cuttings under stereo microscope for the rest of the drill core not selected for making petrographic thin sections (every 10 ft [3.48 m]). Thin sections (24 mm x 46 mm) were analyzed quantitatively using a Leitz petrographic microscope to document stratigraphic succession, including texture, composition and sedimentary structures and to determine allochemical constituents including relative percentage of fossil content, peloids, oolites, intraclasts as well as to examine matrix and/or cement. Thin sections were stained with alizarine red to identify calcite in the sample and to distinguish carbonate minerals within the thin sections.



Figure 1.2. Selection of samples from drill core material.

Lithologic classification of thin sections and the rest of the rock cuttings were determined by using Dunham's (1962) carbonate textural terminology for rocks. Examination of detailed petrographic data provided the determination of depositional environment and explanation of lithologic units through the Upper Cretaceous-Paleocene rocks in the study area.

1.3 Objectives of Thesis

The purpose of this study is to gain better understanding of Mesozoic-Cenozoic transition in south-central Florida in terms of lithostratigraphy and depositional environments from subsurface stratigraphy of the TEC DIW-1 deep well. Specifically, I aim to determine lithostratigraphic definition and to describe and discuss the interval of 3,400-5,700 ft (~1,036-1,737 m) of the selected well. Additionally, this study examines the depositional environment and diagenetic history through some part of the Upper Cretaceous Gulf Series and Paleocene section of Cedar Keys Formation. This study also aims to contribute to previous studies concerning the lithostratigraphy, depositional environment and diagenetic history of the study area that will shed new light on the subsurface stratigraphy of the study area providing useful information for potential oil explorations in the future.

In addition to this, a large bolide collided with Earth and left a distinct mark in Cretaceous-Paleogene (K-Pg) boundary sediments in the Gulf of Mexico and Caribbean region (Hildebrand et al., 1991). It is also considered that large-scale tsunamis affected the Gulf of Mexico (Kring, 2000). For instance, along the continental shelves of Texas and northern Mexico, tsunami deposits present decimeter-size rip-up clasts (Bourgeois et al., 1988). In an effort to develop better understanding of Chixulub impact through the Florida Platform, several discussions and investigations have been made with a number of geologists and it is thought that the platform should have been influenced by these events. Thus far no evidence or sign of tsunamis and/or impact breccia within the Florida platform has been discovered. One reason could be because of the lack of the drill cores, a limited number of wells and poor quality of drill cuttings across the

K-Pg boundary that make it difficult to search for evidence of the bolide impact throughout the Florida platform (Scott, 1992).

CHAPTER 2

GEOLOGICAL SETTING

2.1 Geologic Overview of Florida through the Upper Cretaceous-Paleocene

The Florida Platform is an ancient carbonate platform that extends from the southern edge of the North America continent into the northeastern Gulf of Mexico (Figure 2.1). The platform has an east-west dimension of almost 310 mi (~500 kilometers [km]) and extends approximately 400 mi (~645 km) north to south (Hine et al., 2001; Scott, 1992). The western edge of the platform is marked by the Florida Escarpment that plunges into the Gulf of Mexico to a depth of nearly 5900 ft (~ 1,800 m). The eastern boundary of this ancient carbonate platform extends to the shelf break of east coast of Florida (Hine et al., 2001).

Crystalline basement rocks of Florida are older than Early Jurassic (>200 mya) and known to underlie deeply buried strata. These basement rocks were a part of the African Plate of paleocontinent of Gondwana, that collided with Laurentia during the formation of the supercontinent Pangea and provide basement for carbonate platforms such as Bahama and Florida Platforms (Smith, 1982). From the Mid-Cretaceous to the Late Paleogene, the Florida carbonate platform became separated by Suwannee Strait, also known as Gulf Trough, which is considered to be a structural low (Hull, 1962; Popenoe et al., 1987; Sheridan et al., 1981). A distinctive facies boundary was created by a strong oceanic current associated with the Suwannee Strait that separated siliciclastics of the north originating from the southern Appalachians and carbonates of south Florida platform (Scott, 1992). Because of the restriction of circulation in the depositional environments of carbonates, evaporites such as gypsum and

anhydrite periodically developed (Scott, 1992). As a result of rifting of the Atlantic Basins in the Early Triassic, shallow marine sedimentation was pervasive on the Florida Platform through the Mesozoic (Scott, 1992). Due to the fact that the main carbonate deposition area was rimmed by a barrier reef system, a substantial restricted sub-environment developed and favored evaporite deposition in Paleocene (Winston, 1991). More than 2200 ft (~670 m) thick, the Paleocene Cedar Keys Formation covers the Florida Platform and is represented by interbedded thick anhydrite layers (Miller, 1986; Scott, 1992).

Paleogeographic maps of North America show that sea level rise and tectonic activity led to a shallow sea that covered much of the North America during the Mesozoic. This shallow ocean is known as Western Interior Sea and connected the Arctic Ocean with the Gulf of Mexico. The landmass that existed on the western side of this seaway is known as Laramidia and the landmass that existed on the eastern side of this seaway is known as Appalachia (Mitrovica et al., 1989). At the very end of Cretaceous, due to the mountain building and other plate movements, the interior seaway shrunk, which can be illustrated in the maps (Figure 2.1). During the Upper Cretaceous (75 Ma) a shallow ocean covered the Florida, which created a perfect environment for carbonate deposition (Means, 2010) (Figure 2.1). Throughout the Florida Peninsula, open marine carbonate accumulation was developed due to transgression and warming climatic conditions during the Late Cretaceous. During the Early Paleogene (60 Ma) sea level decreased, however shallow marine seas continued to cover the Florida until the Late Oligocene (Lane, 1994). Thus, the open marine conditions generating carbonates continued through the Paleocene and as a result of sea-level fluctuations, carbonate and evaporates accumulated together. By the early Cenozoic the eastern part of the Florida Platform remained submerged while the western

portion became subaerially exposed (Schlager, 1981; Mullins et al., 1988 a, b). The Cretaceous/Paleogene transition was a time of decreasing sea-level that can be observed from North America Paleogeographic maps (Figure 2.1).

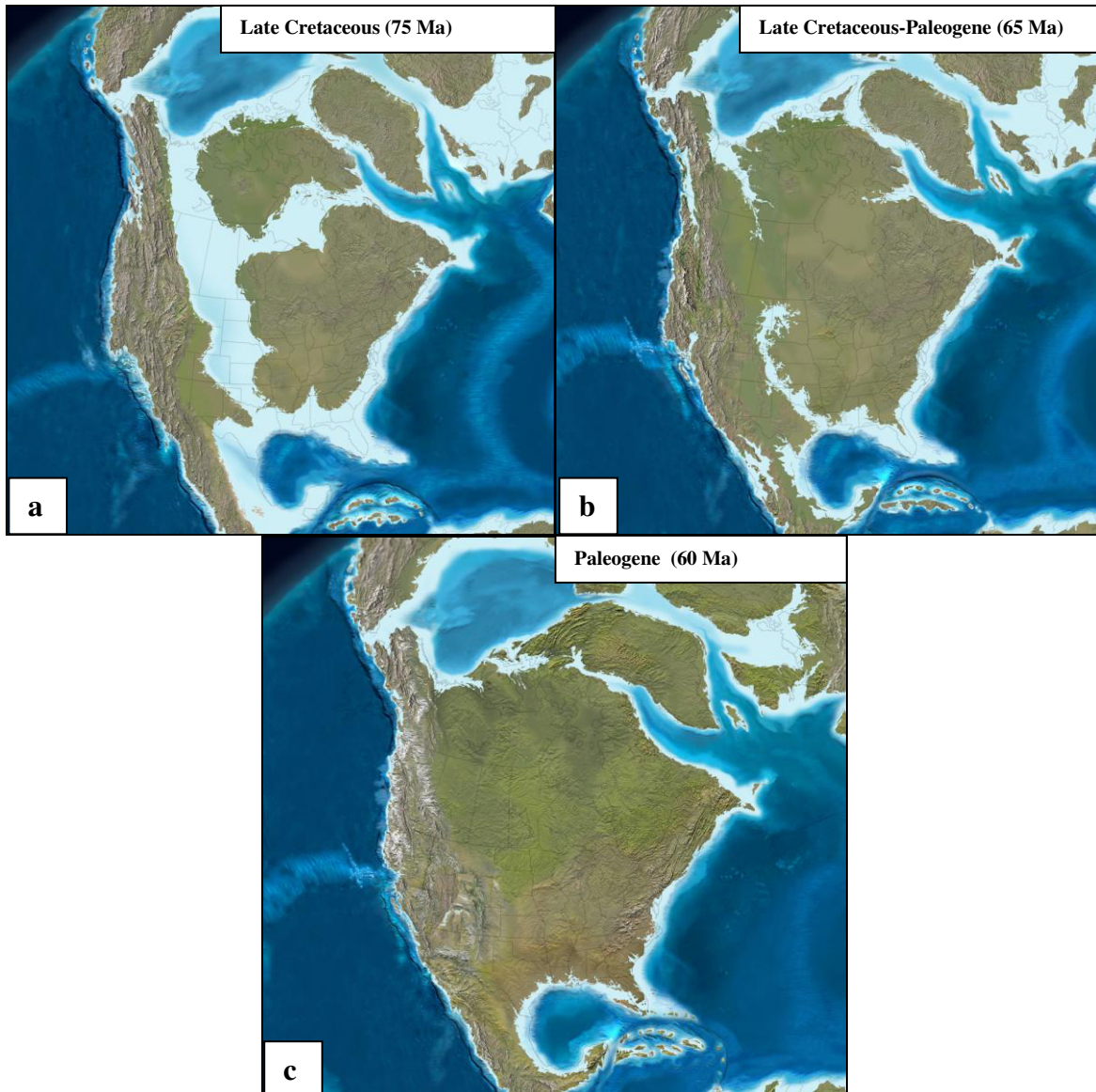


Figure 2.1. A reconstruction of North American paleogeography during the Late Cretaceous (a), Late Cretaceous-Paleogene (b), and Paleogene (c) (derived from Ron Blakey, Colorado Plateau Geosystems, Arizona USA). Note that relative oceanic water depths are indicated by light vs. dark blue colors.

Sea level fluctuations caused the deposition of siliciclastic, carbonate and evaporite facies throughout the Florida Platform (Randazzo, 1997). In the Jurassic, the carbonate platform started as a rimmed shelf and became a carbonate ramp sequence by the early Cenozoic. As a result of fluctuating sea level and carbonate/siliciclastic interaction with climatic changes, a complex depositional environment resulted (Scott, 1988).

2.1.1 Major Structural Features of Florida Platform Affecting Upper Cretaceous and Paleocene Sediment Deposition

The major structures that affect the Mesozoic and early Cenozoic geology of Florida are shown in Figure 2.2. Eventually, the western portion of Florida Platform was submerged during the mid-Cretaceous due to sedimentation rates that fell behind the tectonic subsidence (Hine et al., 2001). Florida-Bahama Platform was continually subsiding during the Mesozoic and Cenozoic (Winston, 1991), and structural highs or arches throughout Florida were generated by slow rates of subsidence rather than flanking basins. Therefore, it is thought that tectonic uplift/compression was not an efficient factor triggering the formation of structural features (Winston, 1991).

The Peninsular Arch, a north-north west to south-south east trending arch, played an important role in deposition of sediments from the Jurassic through the Cretaceous (Applin, 1951; Toulmin, 1955; Puri and Vernon, 1964; Maher, 1965). It is also known as dominant subsurface structural feature of Florida that is approximately 275 mi (~443 km) long anticlinal fold, or topographic high (Applin and Applin, 1965; Duncan et al., 1994; Klopp, 1975; Puri and Banks, 1959).

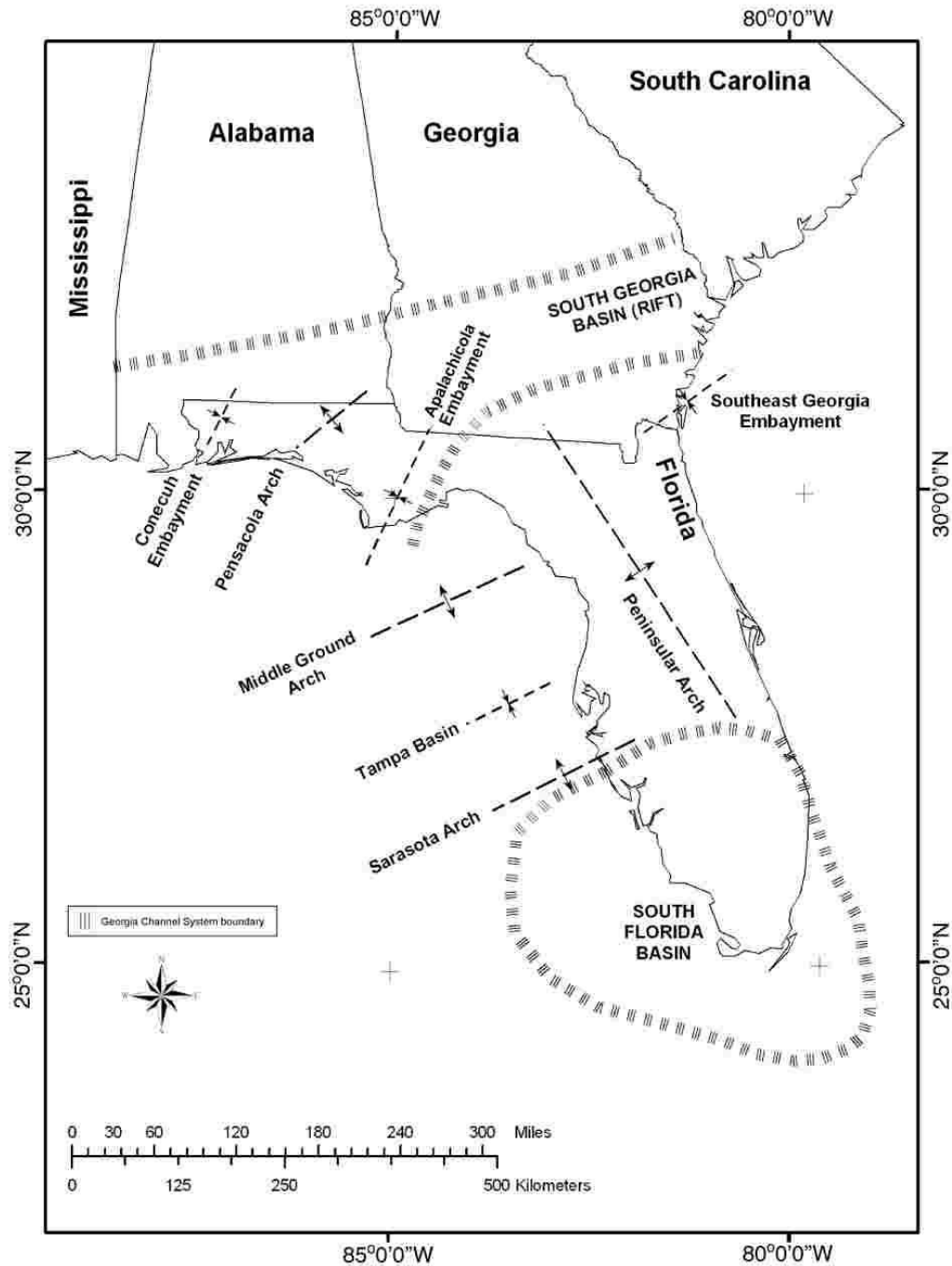


Figure 2.2. Structures affecting the Mesozoic and Early Cenozoic sediments in Florida (modified from Lloyd, 1991).

Duncan et al. (1994) stated that the Peninsular Arch consists of Paleozoic stratigraphic units that overly Precambrian basement rocks and also acts as a positive basement structure. Deposition of

sediments from Jurassic into the Early Cenozoic was affected by pre-Mesozoic rocks of the Arch (Klopp, 1975). According to Toulmin (1955), because the Peninsular Arch was topographically high and subaerially exposed in Early Cretaceous, sediments were not deposited on the arch, rather deposited around it. However, by the Late Cretaceous sediments were deposited on the arch. Pressler (1947) emphasized that there are two major provinces in Florida, Alabama, Southern Georgia, Bahama Islands and Cuba (land areas of eastern part of Gulf of Mexico), north Florida and southern Florida, that comprise clastic sediments and non-clastic sediments (carbonates and evaporites) respectively. From the Mid-Cretaceous to the Late Paleogene, the Florida carbonate platform is separated by Suwannee Strait (also known as Gulf Trough), a structural low (Hull, 1962; Popenoe et al., 1987; Sheridan et al., 1981) and an important structural feature (Scott, 1992). According to Scott (1992), after Huddlestun's (1993) study, the name Georgia Channel System was applied to the entire structure in the area including Suwannee Strait or Gulf Trough. This feature played an important role from Late Cretaceous to the Paleocene representing a boundary that separated siliciclastics of north and carbonates of south (Scott, 1992).

2.2 Stratigraphic Units of This Study

Almost continuous limestone deposition was the predominant form of sedimentation over most of the Florida peninsula, from Lower Cretaceous to the top of the Oligocene. In the Lower Cretaceous and Paleocene, and late-middle Eocene, alternation of limestone, anhydrite and gypsum are documented, however in the Upper Cretaceous formations neither gypsum nor anhydrite are present (Applin and Applin, 1944). Scott (1986) reports, limestone and dolomite with some evaporites are the predominant lithology in the Paleogene strata of peninsular Florida

with clastic sediments being < 1%. Dolostone is the most common form of carbonate, with variable portions of limestones, in the Paleocene through middle Eocene in peninsular Florida. In northern Florida limestone and clastic facies grade into each other, within the clastic facies. Foraminiferal microfaunas are similar to those in western Gulf Coast. However, from the Lower Cretaceous to early-middle Eocene, limestone facies in peninsular Florida contain similar microfauna to Cuba, the West Indies, Mexico and Europe (Applin and Applin, 1944).

ERA	SYSTEM		SERIES	PREVIOUS STRATIGRAPHIC TERMS (Applin and Applin, 1944; Puri and Vernon, 1964; Faulkner and Applegate, 1986; Winston, 1991; Pollastro et al., 2001)	FORMATIONS
CENOZOIC	TERITARY	PALEOGENE	PALEOCENE	MIDWAY	CEDAR KEYS FORMATION
MESOZOIC	CRETACEOUS		UPPER	NAVARRO	LAWSON FORMATION
				TAYLOR	PINE KEY FORMATION
				AUSTIN	
				TUSCALOOSA	ATKINSON FORMATION
			LOWER	WASHITA	CORKSCREW SWAMP FM.
					ROOKERY BAY FM.
					PANTHER CAMP FM.
				FREDERICKSBURG	DOLLAR BAY FORMATION

Figure 2.3. Lithologic units cored by TEC DIW-1 deep well and stratigraphic column of units/formations discussed in this study (modified after Maher and Applin, 1968).

By comparing the stratigraphic characteristics of the studied section with the original description of rock units established in Floridan stratigraphy for the same stratigraphic interval, the Upper Cretaceous-Paleocene sequence in the study area is stratigraphically subdivided into 3 formations. Figure 2.3 shows units penetrated by TEC DIW-1 well and stratigraphic column of formations discussed in this study. Moreover, numerous wells have been drilled in Florida on the basis of oil exploration. These exploratory wells enabled researchers to identify lithology and the thickness of the subsurface formations throughout Florida. Some of the key wells drilled in Florida and location of the studied well are shown in Figure 2.4.

Different units represent the Upper Cretaceous (Gulf Series) strata of the Florida Peninsula, specifically, the Lawson Formation (Navarro Age), Pine Key Formation (Taylor age), and Atkinson Formation (Woodbine and Eagle Ford Age) (Puri and Vernon, 1964). The Upper Cretaceous section of this study comprises of Pine Key Formation (Taylor age), and Lawson Formation (Navarro Age).

In an effort to develop a better understanding of the lithology, depositional environment and diagenetic history through the Upper Cretaceous-Paleocene carbonate rocks, this thesis presents a detailed study of Upper Cretaceous Pine Key and Lawson formations, as well as the Cedar Keys Formation deposited during the Paleocene. Table 2.1 shows the correlation of Cedar Keys Formation, Lawson Formation and Pine Key Formation of Florida peninsular with Southern Georgia, Texas and clastic facies of Florida. It shows distinctive foraminiferas and bivalves of studied formations. In addition, Figure 2.5 represents the cross section from southern Georgia to north-central Cuba including the approximate thickness and the depth of the Upper Cretaceous

and Paleocene strata examined in this study. It also shows the thickening of formations from north to south through the Florida Peninsula.

Table 2.1. Correlation of Cedar Keys Formation, Lawson Formation and Pine Key Formation of Florida Peninsula with Southern Georgia, Texas and clastic facies of Florida (modified after Applin and Applin, 1944).

Subsurface rocks of Florida and Southern Georgia						Texas	
		Limestone Facies	Key Fossils	Clastic Facies	Key Fossils		
Paleocene		Cedar Keys Fm.	<i>Borelis gunteri</i>	Beds of Upper Midway Age		Midway Group	Wills Point Fm.
				Beds with Tamesi Fauna	<i>Globorotalia velascoensis</i>		Kincaid Fm.
Upper Cretaceous		Lawson Fm.	Upper	Beds of Navarro Age	Various Typical Species	Navarro Group	
			Lower				
			<i>Vaughanina</i> ? sp. Rotalid <i>Sulcoperculina cosdina</i> <i>Lepidorbitoides</i> several sp.				
		Pine Key Fm.	<i>Stensioina americana</i> Inceramus Fragments	Beds of Taylor Age	<i>Stensioina americana</i> Inceramus Fragments	Taylor Marl	

2.2.1 Pine Key Formation

Applin and Applin (1944) described these rocks as hard, white or cream colored, chalky limestone, that underlie the Lawson Formation (Navarro Age) over the most of the Peninsula and used the term beds of Taylor Age for these rocks. Applin and Applin (1967) and Miller (1986) described the Upper Cretaceous units consisting of carbonates in most of peninsular Florida and clastics in north-central and panhandle of Florida and. They report that the

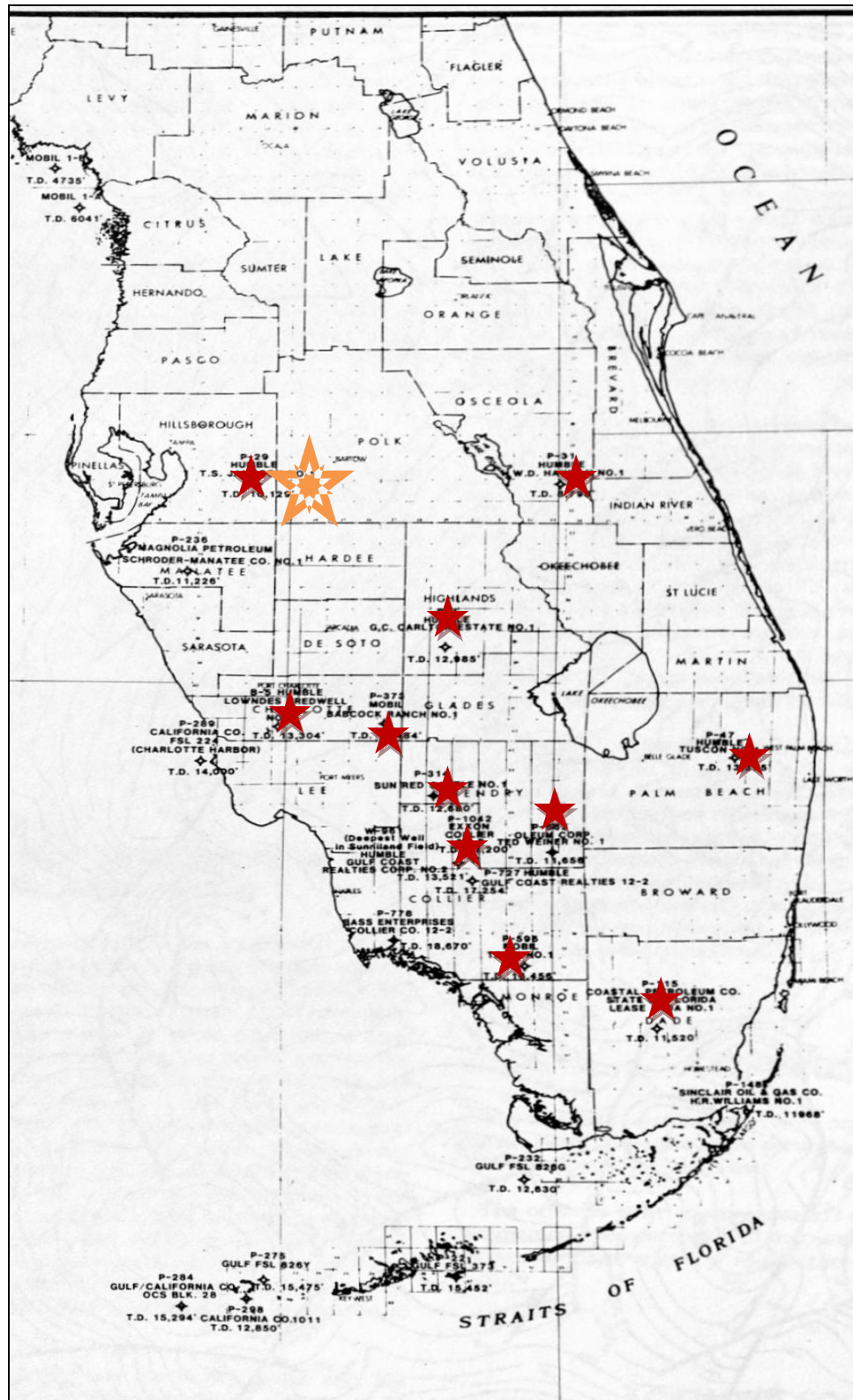


Figure 2.4. Location map indicating some key wells drilled for oil exploration in south Florida (Faulkner and Applegate, 1986). Note that orange star indicates the location of the studied well.

carbonate facies are composed of chalk or argillaceous-chalk that underlie the lower member of the Lawson Formation. In south-central and southern Florida hard white or cream colored, chalky limestones containing low porosity and permeability, which are separated by thin dolomite lenses, dolomitic chalk, and anhydrite make up the carbonate facies (Applin and Applin, 1944; Applin and Applin, 1967).

In South Florida Basin, The Upper Cretaceous Pine Key Formation is composed of chalky limestone and dolomite (Winston, 1978 and 1987, Faulkner and Applegate, 1986). According to Winston (1991), white chalk and chalky limestone deposited in shallow water environment form the Pine Key Formation in both central and southern Florida. The Taylor Age rocks in this study fit the description of Pine Key Formation and are in the right relative stratigraphic position, I assign the term of Pine Key Formation for these chalky limestone units.

In central peninsular Florida this unit is approximately 400 ft (~122 m) increasing markedly in the south to 1,200 ft (~366 m) or more (Applin and Applin, 1967). Miller (1986) and Applin and Applin (1967) stated that microfauna assemblages are the only way to distinguish thick sequence of limestone facies in peninsular Florida. Miller (1986) assigned, middle to outer marine conditions for the depositional environment of these rocks. This chalky limestone facies is indicated by *Inoceramus* fragments, abundant in the upper parts of the unit, and contains several distinct foraminifera such as: *Stensiöina americano* Cushman, *Bolivinoidea decorate*, *Anomalina rubiginosa* Cushman. These are the most characteristic foraminifera that distinguish the chalks of Pine Key Formation and the lower member of the Lawson Formation (Applin and Applin, 1944, 1967). According to Applin and Applin (1944): *Planulina texana* Cushman, *Robulus münsteri*

Roemer, *Globotruncana arca* Cushman, *Globigerina cretacea* d'Orbigny specimens are typical of lower part of Pine Key Formation in peninsular Florida (Applin and Applin, 1944).

2.2.2 Lawson Formation

The youngest units, Cretaceous age, are represented by the Lawson Formation in peninsular Florida (Applin and Jordan, 1945). According to Applin and Applin (1944), the Lawson Formation underlies the Cedar Keys Formation and overlies the Pine Key Formation. The depositional environment of Lawson Formation during the Upper Cretaceous was in a partly restricted shallow marine shelf (Applin and Applin, 1967). Applin and Applin (1944) stated that the Lawson Formation is about 900 ft (~274 m) thick and can be seen as a limestone facies in the northeastern and peninsular Florida. The maximum thickness is also recorded as approximately 600 ft (~183 m) in southern Florida (Miller, 1986). The Lawson Formation is divided into a lower and upper member with distinctive fossil assemblages and characteristic features. The upper member is rarely fossiliferous having poorly preserved marine faunas. On the contrary, the lower member is easily recognizable with a distinctive marine fauna (Applin and Jordan, 1945).

The clastic equivalents of the Lawson Formation (Navarro age) are common in western Florida, Alabama, Mississippi and southern Georgia. In this lithofacies, fossil assemblages are similar to those in Navarro Group in Texas (Maher and Applin, 1968). Miller (1986) stated that the Lawson Formation can be easily distinguished by rudistid pelecypod fauna and were deposited in middle to outer shelf conditions. In the most general sense the lower member is observed as hard, white and cream-colored chalky limestone and contains abundant microfossils. The lower member of the Lawson Formation also contains small amounts of gypsum observed in a few

wells (Applin and Applin, 1944). Applin and Applin (1967) described the unit predominantly as a white chalk consisting of interbedded chalky dolomite and dolomitic chalk at several levels. There is a gradational boundary between upper and lower members represented by soft, white chalk situated at the top of the lower member which grades into dolomitic chalk at the basal portion of the upper member (Applin and Applin, 1967). In general, this member is nearly 300-400 ft (~91-122 m) thick except in Levy County (700 ft [~213 m]). Similar to upper member, the unit gets deeper from north Florida (2,000 ft [~610 m]) to south Florida with a depth of almost 5,900 ft (~1798 m) (Applin and Applin, 1944). In western Florida and some parts in southern Georgia, Mississippi and Alabama, Upper Cretaceous rocks occur as a mixed carbonate and clastic facies in which the fauna closely resembles to those in Navarro Group in Texas (Applin and Applin, 1944).

According to Applin and Applin (1944), various species of *Lepidorbitoides* which also can be observed in Maestrichtian of Europe, the Madruga chalk of Cuba and the Cardenas beds of Mexico, characterize the lower member of the Lawson formation. The ‘Monroe gas rock’ of Louisiana and the ‘Jackson gas rock’ of Mississippi also include these fossils, and they are reported in Florida units as well. Other important fossils present in this lower member are brachiopods, bryozoan fragments, echinoid spines, *Saccocoma* spp., *Sulc operculina* cosdeni and disk- and ball-shaped algae. Although the member has distinctive features, identification of fossils is not easy due to dolomitization and recrystallization (Applin and Applin, 1967). Applin and Jordan (1945) and Maher and Applin (1968) described the common foraminifera species that belongs to the unit as: *Epidorbitoides (Asterorbis) aguayoi* D. K. Palmer, *Lepidorbitoides (Lepidorbitoides) minima* H. Douville, *Lepidorbitoides (Lepidorbitoides) nortoni* Vaughan,

Lepidorbitoides (Lepidorbitoides) planasi M. G. Rutten, *Loxostoma clavatum* Cushman, *Lenticulina (Robulus) minsteri* Roemer, *Sulcoperculina cosdeni*, n. sp, and large specimens of *Cibicides harperi* Sandidge.

Applin and Applin (1944) observed that the upper member is lithologically white and cream colored, calcitic, porous limestone which includes gypsum in most wells studied in the area. Maher and Applin (1968) stated in their study that differential erosion happened at the end of the Cretaceous time resulted in different thickness of the unit in different wells. According to Maher and Applin (1968), light-colored chalky limestones form the facies of the upper member that are interbedded with irregular dolomite layers and anhydrite lenses that formed secondarily. They also emphasized indicative faunas such as rudist bivalves and rudist fragments as characteristic of the upper member of Lawson Formation in Florida Peninsula. Winston (1994) stated that upper member of the Lawson formation is cream or light to tan colored, coarsely crystalline dolomite with gypsum and anhydrite lenses. Furthermore, the unit, an algal and rudistid biostrome, has been highly altered due to the diagenesis but still some relic grains can still be observed (Applin and Applin, 1944; Applin and Applin, 1967; Miller, 1986; Winston, 1994). Alteration of skeletal grains and sediment types in the upper member is most probably caused by wave-action indicating shallow-water marine environment (before lithification started). This can be observed on material as abrasion or partial destruction (Applin and Applin, 1967). In north Florida the unit lies approximately at 2,000 ft (~610 m) and deepens from north to south reaching as deep as 5,600 ft (~1,707 m) (Applin and Applin, 1944). The upper member of Lawson formation is generally 200 to 300 ft (~61 to 914 m) thick (Applin and Applin, 1944).

In the Upper member of Lawson Formation includes rotalids affected by alteration as well (Maher and Applin, 1968). It also includes specimens of *Vaughanina* sp., *Orbitoides* sp., and *Pseudorbitoides?* sp., (Applin and Applin, 1944). Large foraminifera such as *Vaughanina cubensis* Palmer and *Orbitoides brownie* Ellis can also be seen in the Upper member of the formation. In addition to this, *Meandropsina* packed limestone lenses were observed in the southern Florida wells (Maher and Applin, 1968). Applin and Applin (1944) stated that the upper member of the Lawson formation lying below the Cedar Keys contains microfossils which are recrystallized. Therefore, specific and generic determination of these microfossils is difficult.

2.2.3 Cedar Keys Formation

Throughout the Florida Peninsula, Paleocene units underlie the Lower Eocene and conformably overlie Gulfian series strata of Cretaceous age (Applin and Applin, 1944; Cole, 1944). The Paleogene stratigraphic unit discussed in this paper is the Cedar Keys Formation which is described by Applin and Applin (1944) as gray and cream colored white limestone that shows a characteristic spotted appearance. This unit characteristically contains many gypsum and anhydrite beds in most wells throughout the peninsula and contains one or more oolitic lenses. In central and southern Florida the anhydrite content increases remarkably (Applin and Jordan, 1945). The Paleocene section in Panhandle and west Florida consists of mostly siliciclastics rather than carbonates (Cooke, 1945; Chen, 1965; Miller, 1986). This clastic facies is also known as beds of Midway age including Tamasei fauna similar to those in Valesco Formation in Mexico (Applin and Applin, 1944). Chen (1965) stated that carbonate sediments of the Paleocene section in Florida Peninsula consist mainly of dolostone interbedded with anhydrite and gypsum with minor amounts of limestone as can be observed in Midway age Cedar Keys

Formation. The Cedar Keys Formation is described by Winston (1991) and (1995) as a sequence of thick anhydrite and euhedral dolomite which is interpreted as deposited behind the Rebecca Shoal Barrier reef (Figure 2.6). According to Winston's (1994) description, anhydrite is assumed to be a replacement of limestone and dolomite is also considered to be secondary replacement of limestone due to the oolite, pellet or relic skeletal grains in dolomite beds. Due to the restriction of marine circulation (by presence of Rebecca Shoal barrier reef), an increase in salinity triggered this replacement. According to Cole (1944), Chen (1965), Winston (1978), Miller (1986), in most wells studied throughout the Florida Peninsula, this unit is partially or entirely dolomitized and contains intergranular gypsum located in the pore spaces of dolomite.

A Borealis fauna characterizes the Cedar Keys formation in most of peninsular Florida. However, it is not easy to distinguish this fauna in the upper section because of the high dolomitization (Miller, 1986). In addition to this, the upper part consists mainly of tan to gray, coarsely crystalline dolomite interbedded with anhydrite and presents moderate to high porosity. The lower part of the unit consists of microcrystalline dolomite interbedded with chicken-wire textured, white anhydrite. This texture and high amounts of anhydrite indicates the unit was deposited in a tidal flat environment and then, more extensively, in a sabhka environment (Miller, 1986). In general, it can be said that an evaporite-carbonate sequence characterizes the Cedar Keys formation. According to Applin and Applin (1944), the unit becomes thicker from north to south reaching a thickness of almost 1,670 ft (~510 m) in Polk County and almost 2,120 ft (~646 m) at the south end of the peninsula. While the unit thickens southward, the amount of gypsum and anhydrite increases.

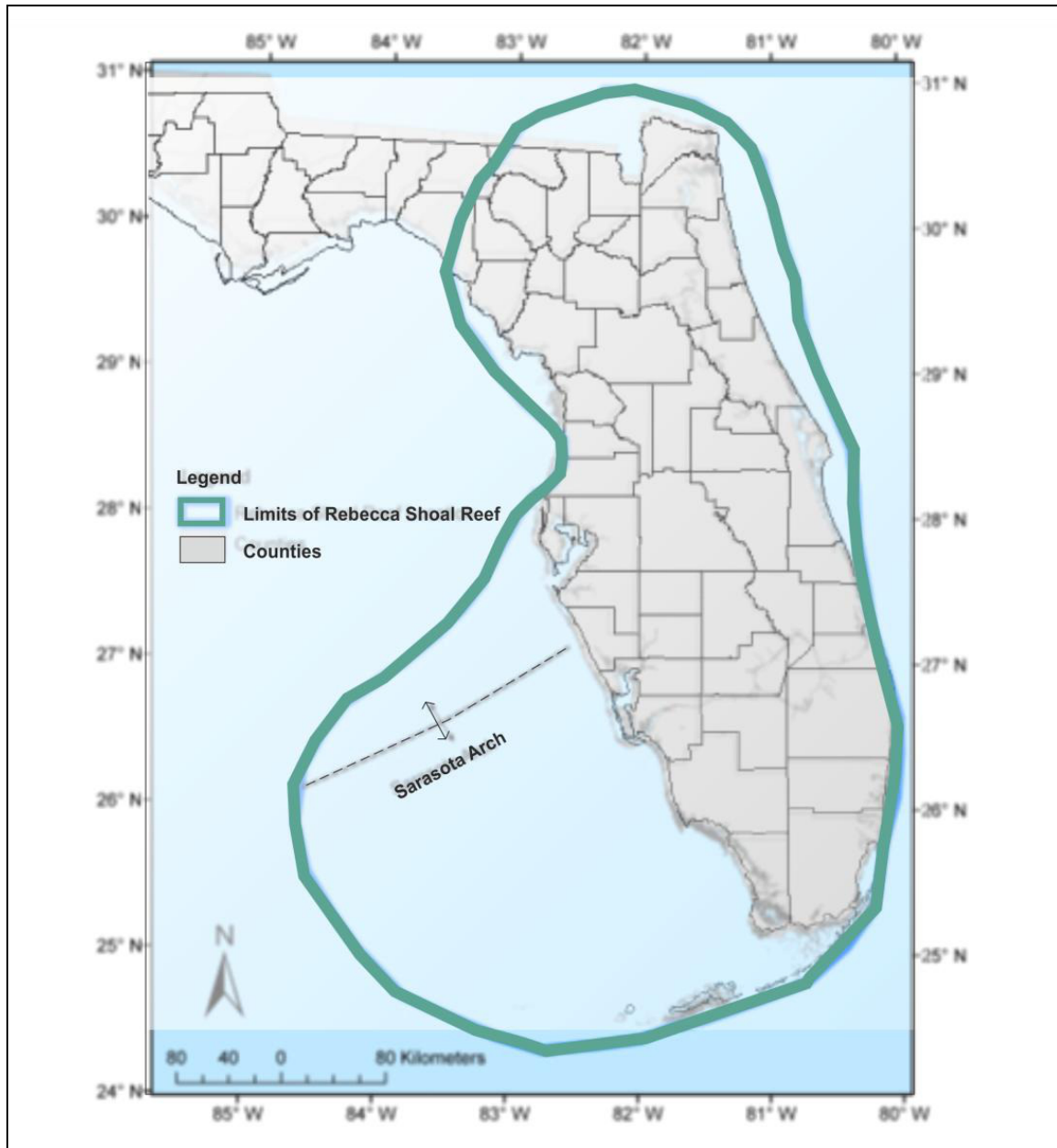


Figure 2.6. Regional structure of Rebecca Shoal reef (adapted from Winston, 1994).

The Cedar Keys Formation is divided into six subunits by Winston (1994) all containing different amounts of anhydrite layers. Unit A and B which include some oolites and pellets, are porous dolomites accompanied by thin lenses of anhydrite. Porosity in these two subunits appears to be mainly granular and intercrystalline. Unit C represents mostly anhydrite beds with

a thickness of almost 600 ft (~183 m) or more in some wells. Unit D is mainly dolomite including relic grains such as oolites and pelloids as well as thin beds of anhydrite in south-central and south Florida. Unit E is similar to Unit D but contains fewer relic grains and thick beds of porous dolomite represent Unit F which includes fewer or rarely anhydrite nodules. Unit E and F can be observed only in South Florida Basin (Winston 1994). Depositional conditions of Cedar Keys Formation are thought to be a back reef environment that caused a lagoonal facies and this back reef environment is represented by the Rebecca Shoal barrier reef (almost 1000 ft [~305 m] thick) that resembles a giant atoll formed during the Upper Cretaceous and Paleocene (Winston, 1994). The reef which is known as the Plantation Tongue of the Rebecca Shoal barrier reef grew during the Upper Cretaceous and almost encircled the Peninsula forming the units of E and F which only can be observed in South Florida Basin. It completely encircled the peninsula in the beginning of the Paleocene. This part of the reef is known as the Tavernier Tongue which is thought to have caused the deposition of anhydrite-dolomite sequence indicated by units A through D. Together the Plantation Tongue and the Tavernier Tongue formed the giant atoll (Winston, 1994).

The Cedar Keys formation can be recognized by the first appearance of the *Borelis* fauna which is a key to distinguish the formation from Upper Cretaceous Lawson Formation. *Borelis gunteri* Cole and *Borelis floridanus* Cole, *Cribospira? bushnellensis* Applin and Jordan, *Fisherina kissengenensis* Applin and Jordan, *Valvulammia nassauensis* Applin and Jordan. These specimens accompany the main foraminifera (*Borelis gunteri* Cole and *Borelis floridanus* Cole) throughout the peninsula.

CHAPTER 3

LITHOSTRATIGRAPHY

The comparison of the stratigraphic characteristics of the studied section with the original descriptions of strato-types of rock units that established in the Florida Peninsula stratigraphy for the same stratigraphic interval enabled me to subdivide the Upper Cretaceous-Paleocene section stratigraphically into three formations in the study area which include Upper Cretaceous Pine Key Formation, Lawson Formation and Paleocene age Cedar Keys Formation. The stratigraphic concepts discussed and expressed by Cole (1944), Applin and Applin (1944), Chen (1965), Applin and Applin (1967), Winston (1994) provide the basic background information within which lithostratigraphy of sediments from the Polk County TEC DIW-1 well is interpreted. Total thickness of the section studied is almost 2,300 ft (~701 m) of which approximately 1,000 ft (~305 m) is from Cedar Keys Formation (3,400-4,400 ft [~1,036-1,341 m]) almost 700 ft (~213 m) is from Lawson Formation (4,400-5,100 ft [~1,341- 1,555 m]), and 600 ft (~183 m) is from Pine Key Formation (5,100-5,700 ft [~1,555- 1,737 m]). Figure 3.1 shows the simplified lithostratigraphic column of Upper Cretaceous-Paleocene section of TEC DIW-1 well, which is examined between the depths of 3,400 and 5,700 ft (~1,036 and 1,737 m). The detailed stratigraphy with detailed descriptions for each depth can be seen in Appendix A. The Upper Cretaceous section is subdivided here into two formations including, from base to top: Pine Key Formation and Lawson Formation. Lawson formation is subdivided into a lower and upper member as suggested by Applin and Jordan (1945). The Paleocene section is represented by Cedar Keys Formation in this study.

The Pine Key Formation is directly below the Upper Cretaceous strata of Lawson Formation in the studied well. Rock cuttings indicated that the sediments from the bottom of the selected depth to the base of Lawson formation are mostly white, tan and light gray to gray chalky limestone with few fragments of dolomite lenses and small amounts of pure white anhydrite (1 to 8 %). In addition to this, some of the limestone fragments observed in this section are dark gray spotted. Small amount of dark gray shale (1-2 %) also exists in various levels of the formation. Limestone fragments contain varying proportions of fossil fragments. Applin and Applin (1967) stated that the thickness of the unit is increasing markedly in the south to almost 1,200 ft (~366 m) or more. Pine Key formation is identified from 5,100 to 5,700 ft (~1,555 to 1,737 m) in this study, which is judged to be upper part of the Pine Key Formation. Previous studies indicates that low porosity and permeability are typical of the carbonate facies (Applin and Applin, 1944; Applin and Applin, 1967) which can also be observed in this study that the carbonate rocks are less porous compared to overlying units.

The Lawson formation, directly below the Paleocene Cedar Keys Formation and above the Pine Key Formation, is subdivided into two members as Upper and Lower members. The Lower member is represented by white to tan limestone that recrystallized from time to time including 2 to 10 percent anhydrite and thick dolomite layer at the base of the Lower member. This dolomitized portion includes abundant fragments of fossils and intraclasts. It is also thought that the Lower member is almost 400 ft (~122 m) thick in this study, which is considered to be almost 300-400 ft (~91-121 m) in the study area by Applin and Applin (1967). The Limestone section includes abundant fossil fragments such as mollusk, rudist, shell and orbitoid forams. The Upper member is represented by white, tan to gray, recrystallized and highly porous limestone

interbedded with light to dark brown crystalline dolomite and includes small amounts of anhydrite layers and lenses. It includes miliolid, orbitoid and other types of forams. Although it is fossiliferous, its fossil abundance is not as high as the Lower member. The Upper member is also sparsely oolitic. The transition between Upper and Lower member is distinguished by the abundance of fossil fragments of Lower member and high porosity feature of the Upper Member. The Upper member of Lawson formation is generally 200 to 300 ft (~61 to 91 m) thick (Applin and Applin, 1944). The thickness of Upper member is approximately 300 ft (~91 m) thick in this study.

The Cedar Keys Formation, which overlies the Lawson Formation, is mostly tan to gray, highly porous, crystalline dolomite interbedded with thick anhydrite and minor amounts of limestone in the studied interval. Although the unit is approximately 2,000 ft (~610 m) thick in the southern peninsula, in this study almost 1000 ft (~305 m) of the lower section is available for study. This unit includes foraminiferal fragments at various levels. Some samples contain large benthic forams, mollusk and other shell fragments, making this unit fossiliferous in general. In addition to this, it is clear that the carbonate-evaporite sequence characterizes the Cedar Keys Formation. As indicated in Figure 3.1, I was able to distinguish Cedar Keys Formation from Lawson formation with the increase of thick anhydrite lenses as well as the dolomitization. A Detailed stratigraphic column of Upper Cretaceous-Paleocene section of TEC DIW-1 well and a detailed description of rock units are given in Appendix A.

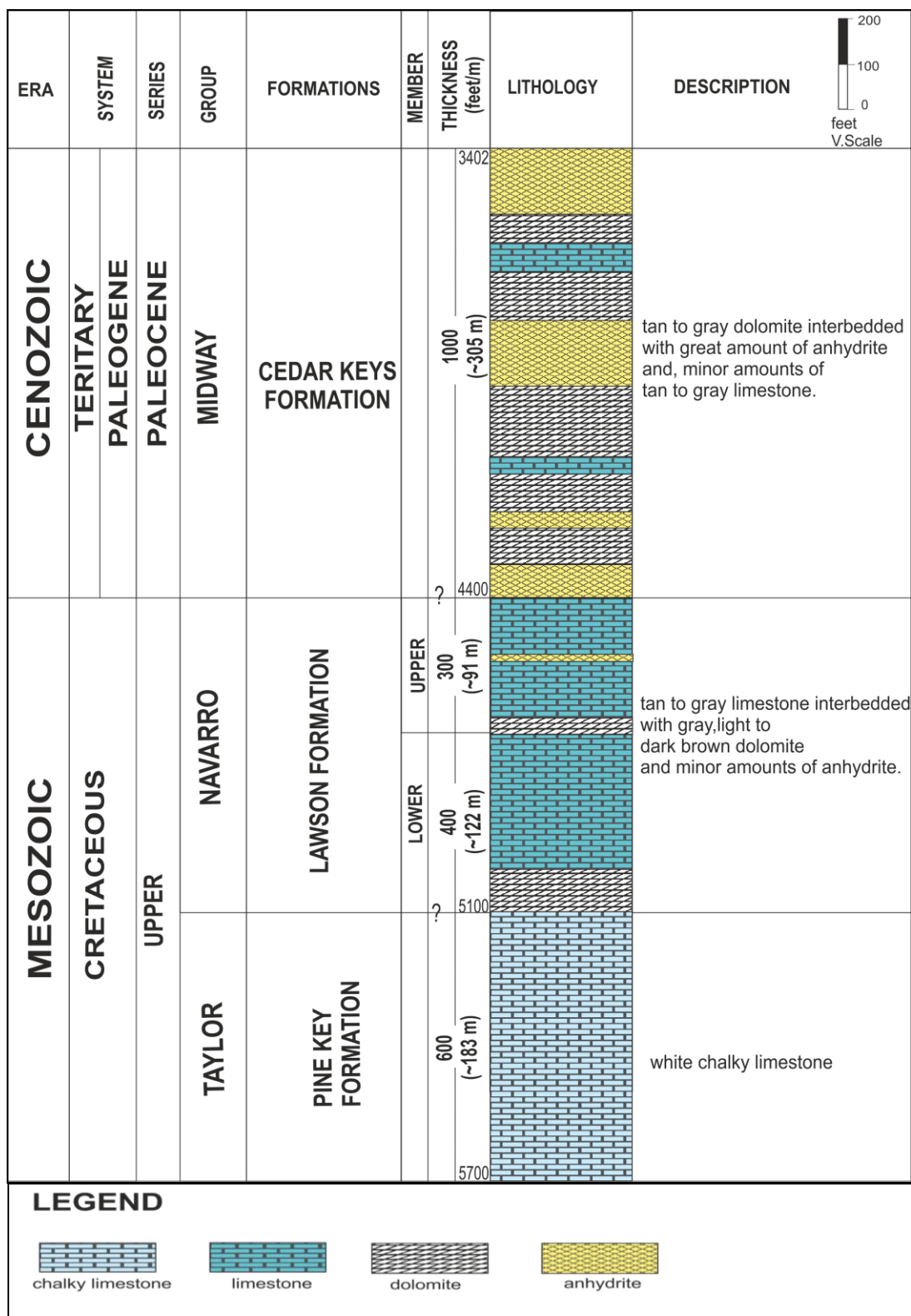


Figure 3.1. Simplified lithostratigraphic column of Upper Cretaceous-Paleocene section of TEC DIW-1 well discussed in this study.

CHAPTER 4

DEPOSITIONAL ENVIRONMENT

The detailed microfacies studies for the Upper Cretaceous-Paleocene sedimentary rock units in the study area have enabled determination of the different depositional environments involved in the evolution of each rock unit. Carbonate and evaporate facies were identified through microscopic descriptions. Thin section analyses showed six microfacies in the Lawson Formation and four microfacies in the Cedar Keys Formation from petrographic studies of 64 thin sections. Due to the lack of the core and rock cutting samples that represent Pine Key Formation, only depositional environments of Lawson Formation and Cedar Keys Formation are interpreted.

Microfacies are named according to Dunham (1962) classification and interpretation of depositional environment is determined according to facies belts (FZ) of Wilson (1975) (Figure 4.1) and Standart Microfacies (SMF) of Flugel (2004). Descriptions of the each microfacies and interpretations of their environments are presented below.

4.1 Depositional Environment of Lawson Formation

The Lawson Formation shows six petrographic microfacies types with respect to description of eighteen thin sections. The microfacies of the Lawson Formation are dolomitized foraminiferal wackestone, fossiliferous grainstone, fossiliferous wackestone, peloidal fossiliferous packstone/grainstone, and foraminiferal packstone/grainstone. The interpretation of depositional environments and microfacies types are shown in Figure 4.2 and Figure 4.3.

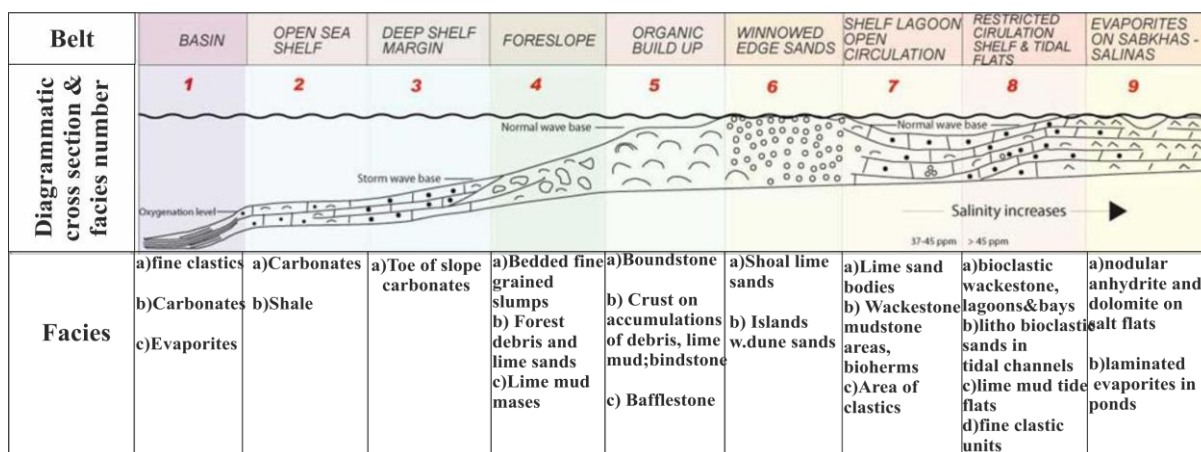


Figure 4.1. Standard facies model of Wilson (1975) (modified after Alnaji, 2002).

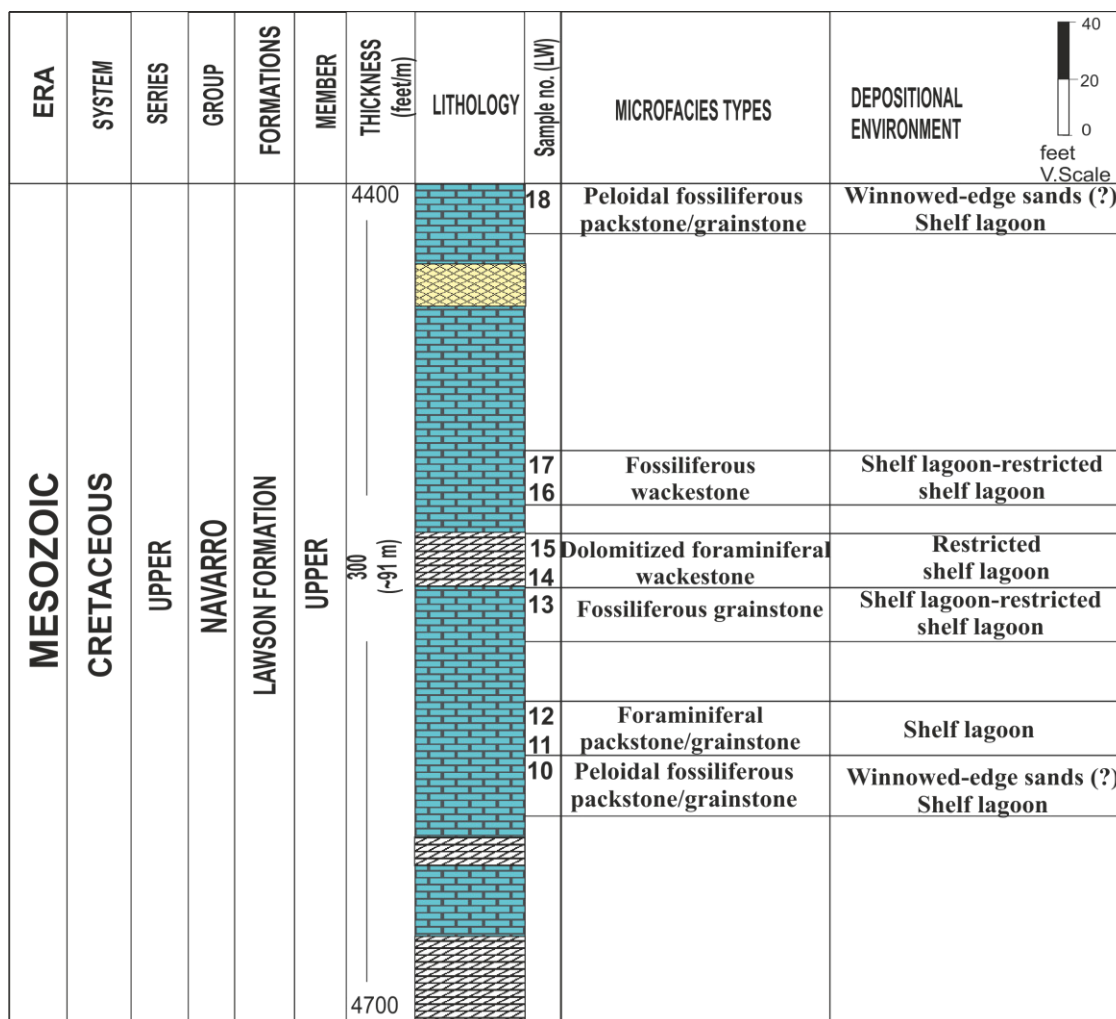


Figure 4.2. Stratigraphic column of Lawson Formation showing microfacies types, thin section samples, and interpretation of depositional environments [4400-4700 ft (~1341-1433 m)].

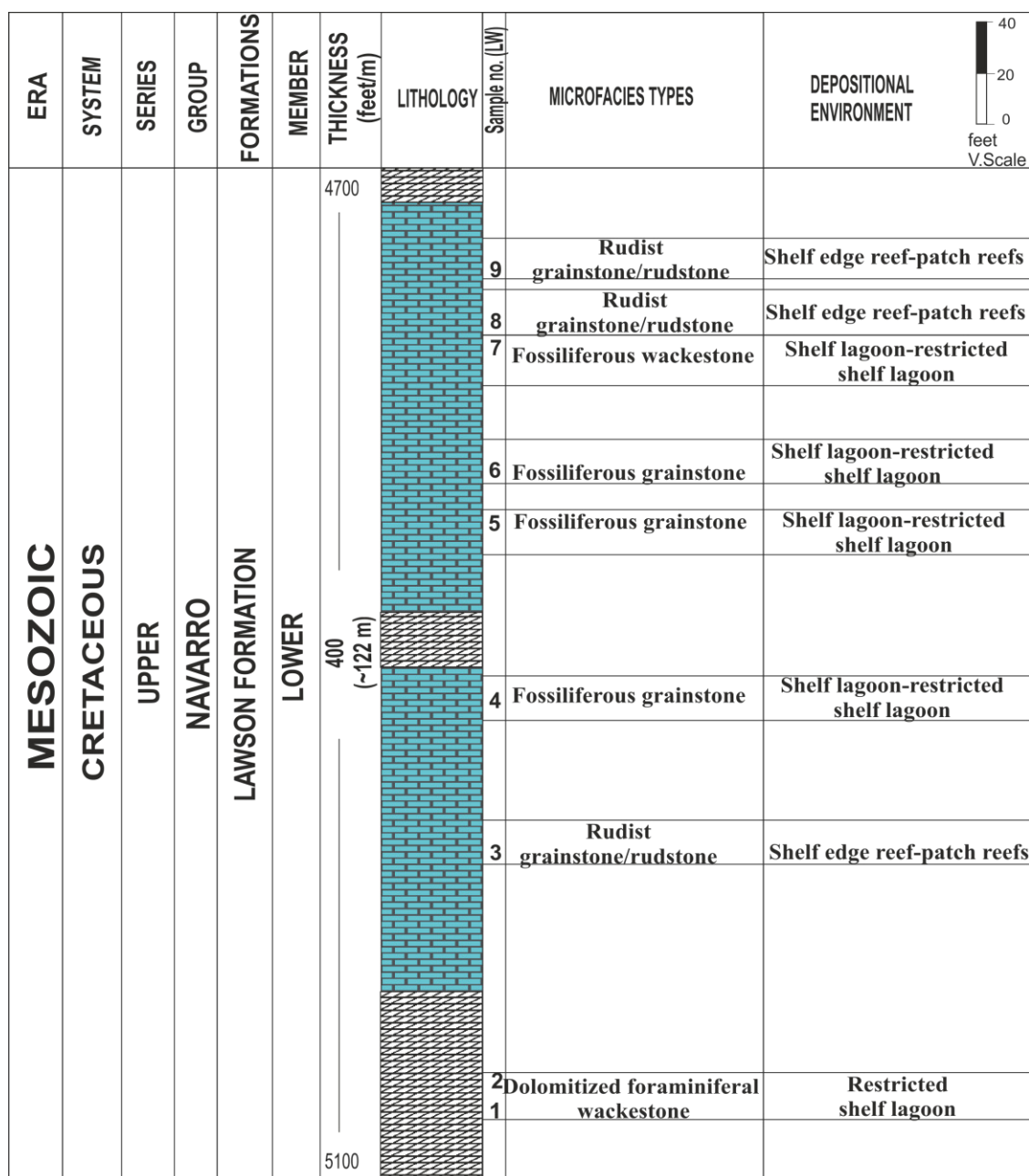


Figure 4.3. Stratigraphic column of Lawson Formation showing microfacies types, thin section samples, and interpretation of depositional environments [4700-5100 ft (~1433-1554 m)].

4.1.1 Dolomitized Foraminiferal Wackestone

This facies is encountered at the basal and upper parts of the Lawson formation and represented by several thin section samples (LW-1, LW-2, LW-14, LW-15). The textural type recognized in

this facies is wackestone fabric according to Dunham (1962) and observed twice vertically within the formation. This microfacies is characterized by the presence of whole and large benthic foraminifera with micrite that recrystallized to coarser material (Figure 4.4 and Figure 4.5). A possible bryzoan is also observed in the lower part of the formation as indicated by previous researchers discussed in previous chapters. Very fine crystalline dolomite rhombs that are scattered into the micrite matrix suggests that Mg-rich marine water invaded the original composition of micrite in this microfacies. Dolomitization is the main process affecting the matrix as well as the allochems and may indicate deposition in the restricted, intertidal environment. This microfacies type is comparable to FZ 7 and 8 of Wilson (1975) and SMF (18, 19, 22) of Flugel (2004) indicating deposition in restricted marine shelf lagoon environment. Deposition in the intertidal environment is suggested for this facies, which is also supported by presence of whole benthic foraminifera.

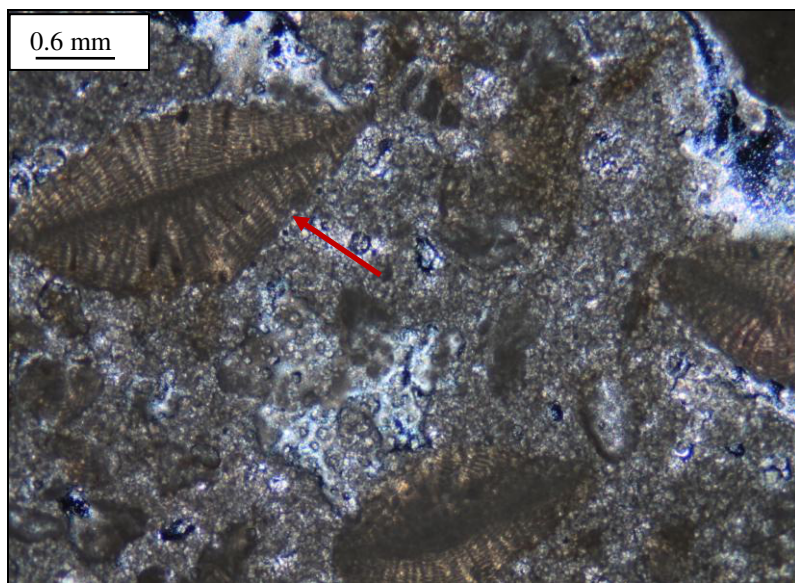


Figure 4.4. Photomicrograph (XPL-Cross Polarized Light) of dolomitized foraminiferal wackestone facies at a depth of 5070-5080 ft (~1545-4578 m). The microfacies is characterized by large benthic foraminifera.

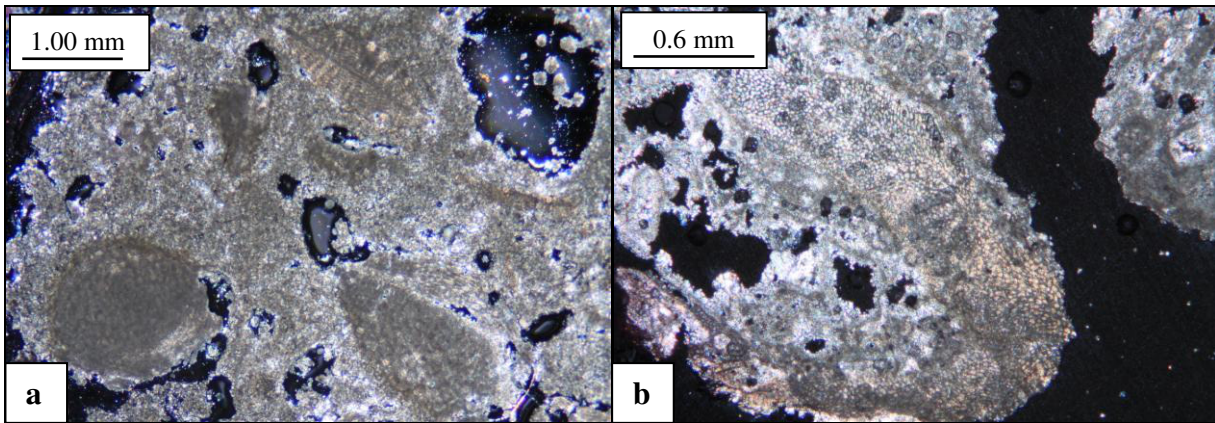


Figure 4.5. Photomicrograph (XPL) of dolomitized foraminiferal wackestone facies at a depth of 5060-5070 ft (~1542-1545 m). The matrix is dominated by micrite that recrystallized to coarser material (a). Photomicrograph (XPL) of a bryzanan fragment at a depth of 4970-4980 ft (~1515-1518 m) (b).

4.1.2 Fossiliferous Grainstone

This microfacies comprises mainly white to tan colored limestone and is repeated four times vertically within the Lawson Formation. It is represented by four thin sections, LW-4, LW-5, LW-6 and LW-13. The textural type encountered in this facies is mainly grainstone fabric according to Dunham (1962). This microfacies is characterized by the presence of a diverse faunal assemblage and shell fragments, which indicates shallow subtidal environment and limited wave energy. Bioclasts of this microfacies belong to echinoderms and benthic foraminifera with milioids and rotalids observed extensively in this facies (Figure 4.6).

Several rotalid appearances through the upper part of the formation are also reported by previous researchers as described in previous chapters. In addition, abundance of well developed micrite envelopes (Figure 4.6) shows a shallow-water, restricted environment (Golubic et al., 1975).

This microfacies also exhibits selective dolomitization, with euhedral dolomite rhombs in micrite

matrix developed as a result of dolomitization (Figure 4.7). This microfacies is similar to FZ 7 and 8 of Wilson (1975) and SMF (8, 9, 10, 16, 18, 19) of Flugel (2004). It represents deposition in a lagoonal setting, which may represent both open to restricted wave energy conditions. It also indicates depositional environments of shallow subtidal to intertidal.

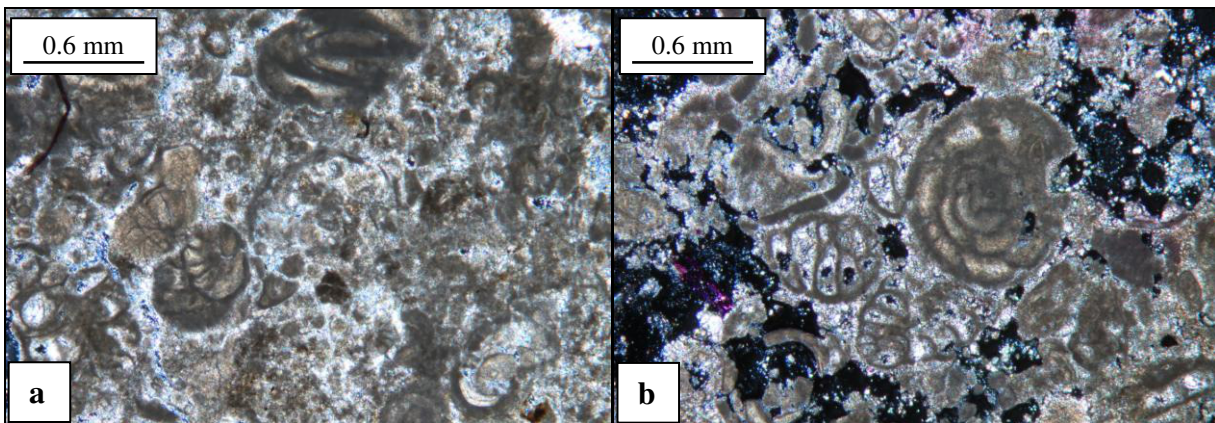


Figure 4.6. Photomicrograph (XPL) of fossiliferous grainstone facies at a depth of 4550-4560 ft (~1387-1390 m). Note that well developed micrite envelopes around the skeletal allochem and miliolid (top); rotalids left of center (a). Possible *Eponides* or other rotalid in right-center. Possible *Lituola* to the lower left and unknown-*Bulimina*? to left (b).

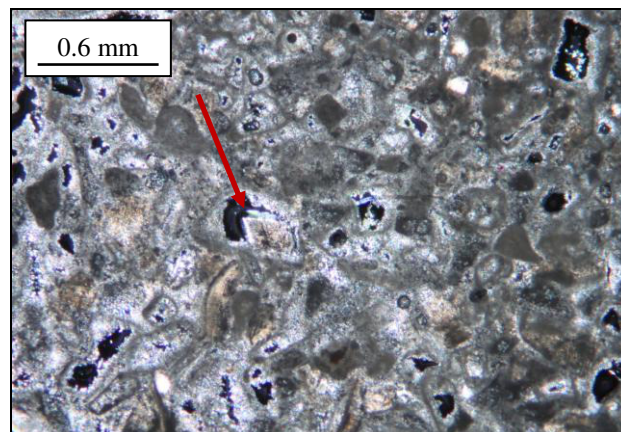


Figure 4.7. Photomicrograph (XPL) of fossiliferous grainstone facies at a depth of 4910-4920 ft (~1496-1499 m). Note that dolomite rhombs in the matrix.

4.1.3 Fossiliferous Wackestone

The fossiliferous wackestone microfacies is a tan to light brown limestone and represented by thin section samples of LW-7, LW-16 and LW-17 from the lower and upper parts of the Lawson Formation. Because of the recrystallization of some samples, especially in the upper part of the formation, identification of species of benthic foraminifera was not possible. The textural type recognized in this microfacies is wackestone fabric according to Dunham (1962). Microscopic investigation of this facies showed that abundant allochems are bioclastic particles, mollusk fragments (Figure 4.8) as well as benthic foraminifera. Molluscan species may indicate a depositional environment of shallow sub-tidal (Illing et al., 1965). It is also dominated by lime-mud (micrite) as a major constituent (Figure 4.8).

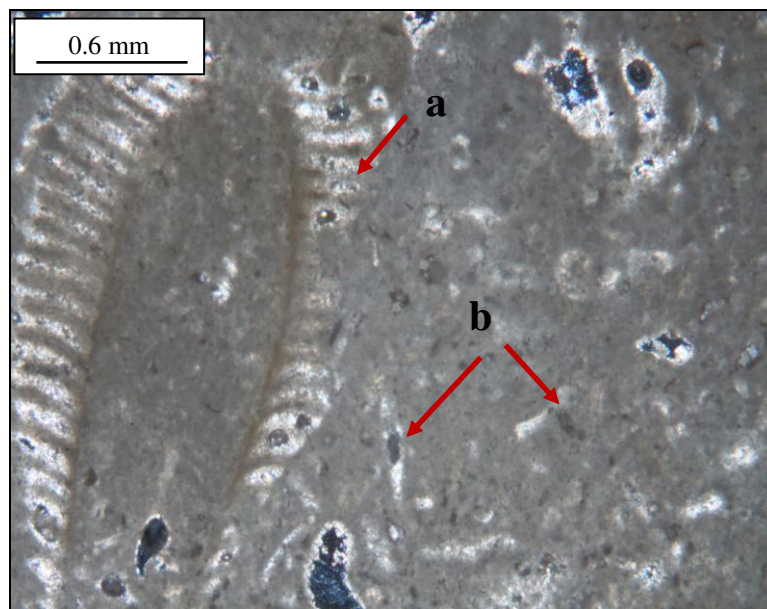


Figure 4.8. Photomicrograph (XPL) of fossiliferous wackestone microfacies at a depth of 4770-4780 ft (~1454-1457 m). The microfacies consists of mollusk fragments (a) together with bioclastic debris (b).

This microfacies is characterized by the presence of lime mud as a matrix, with sparry calcite cement in some parts of the facies. Shell fragments that show a wide range of sizes are also predominant in the facies. Therefore, this microfacies is comparable to FZ 7 and 8 of Wilson (1975) and SMF (8, 9, 10, 16, 18, 19) of Flugel (2004). It represents deposition in shelf lagoons. The predominance of bioclastic shell fragments in this microfacies reflects the conditions of limited wave energy, shallow subtidal environment. In some parts of the facies, sparry calcite cement filling original pore space is observed as an indicator of moderate to high energy environment affected by tidal currents near shoal.

4.1.4 Peloidal Fossiliferous Packstone/Grainstone

The peloidal grainstone microfacies is comprised mainly of light-creamy brown limestone. Thin section of LW-10 and LW-18 represent this microfacies which was observed twice in the upper parts of the formation at different depths. The allochemical constituents are pellets displaying packstone/grainstone depositional fabric according to Dunham (1962). Petrographically, these limestones are composed of closely packed pellets represented by variable sizes (Figure 4.9). Peloidal grains, disarticulation of body fossils as well as the lack of abundant fossils reflect that the peloidal fossiliferous packstone/grainstone was deposited above fair weather wave base and in an environment that represents high to moderate energy conditions.

Due to the reworking process (by wave or tidal processes) in a relatively shallow-water environment, bioclasts may subject to fragmentation (Heckel, 1972) (Figure 4.9). This microfacies is similar to 7 (6?) of Wilson (1975) and interpreted to represent deposition around shallow subtidal or winnowed edge sands.

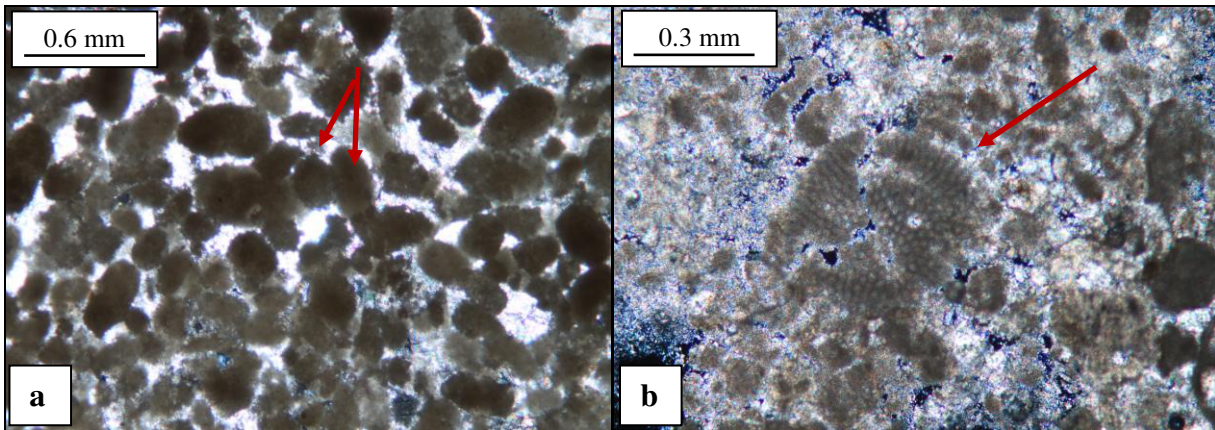


Figure 4.9. Photomicrographs (XPL) of peloidal fossiliferous packstone/grainstone microfacies at a depth of 4610-4620 ft (~1405-1408 m). The microfacies contains closely packed pellets (a). The microfacies includes fragmentation of fossil particles (b).

4.1.5 Rudist Grainstone/Rudstone

This microfacies is characterized by the grainstone to rudstone texture and consists of large fragments of fossils such as rudists. The major constituent of this microfacies is rudist fragments associated with undifferentiated benthic foraminifera, bioclasts and echinoderms, which are observed in some parts of this microfacies (Figure 4.10). Rudistid texture is repeated three times vertically within the formation (LW-3, LW-8 and LW-9) and observed especially in the lower part of the Lawson Formation. Pore spaces are filled with mud and walls of rudist fragments are protected (Figure 4.10). Rudist bivalves indicate different life habitats that range from protected to open platforms and they were prone to build organic mounds. However, not all of them were reef builders, and they rarely reflected true reefs (Flügel, 2004). The faunal component, textural features of some rudist fragments and cementation through some parts of the rudist fragments may indicate normal marine, upper subtidal depositional environments that were influenced by low to moderate water energy conditions. The presence of some unbroken shells shows that water currents were not sufficient to destroy all of the shells. This microfacies may reflect FZ 7

of Wilson (1975) and SMF 24 of Flugel (2004) indicating the shelf edge reef which is also known as patch reefs. Depositional environment of this microfacies may be shallow water, shelf lagoon environment representing the open circulation conditions.

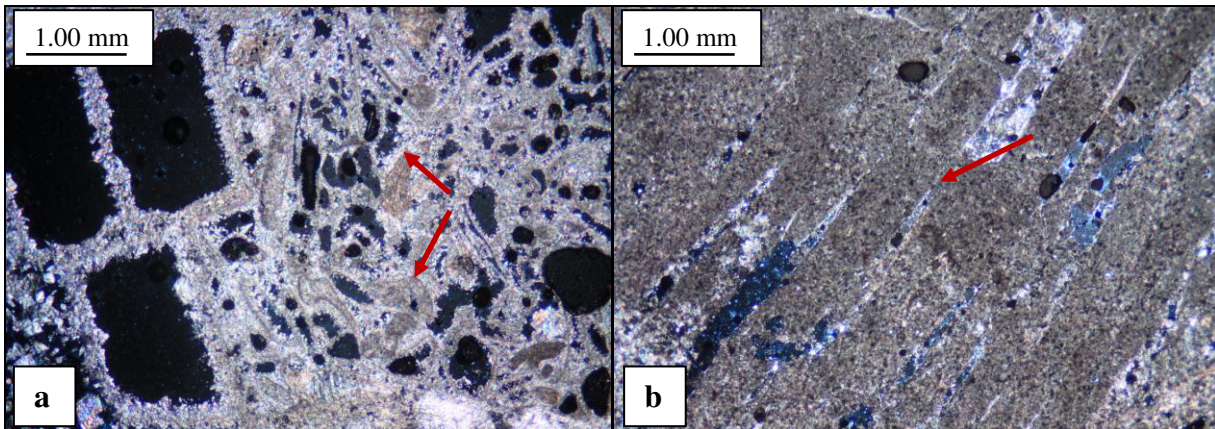


Figure 4.10. Photomicrographs (XPL) of rudist grainstone/rudstone microfacies at a depth of 4740-4750 ft (~1445-1448 m). The microfacies includes several fossil particles (a). The microfacies includes walls of rudists and pore spaces filled with mud (b).

4.1.6 Foraminiferal Packstone/Grainstone

This microfacies is observed at the upper parts of the Lawson Formation and lithologically characterized as tan to gray limestone, which is indicated by thin sections of LW-11 and LW-12. The textural type in this study is packstone/grainstone according to Dunham (1962). Abundant benthic forams form a major constituent, however, because of the high recrystallization of samples, they couldn't be identified. The internal structures of benthic foraminifera are entirely recrystallized into coarse crystalline mosaic calcite (Figure 4.11). The texture of packstone to grainstone facies and presence of cement in some parts show that the deposition took place above fair-weather wave base in shallow water environment influenced by medium to high

energy conditions (Flügel, 2010). Therefore, this microfacies indicates FZ 7 of Wilson (1975) and SMF (8, 10, 16, 18) of Flügel (2004).

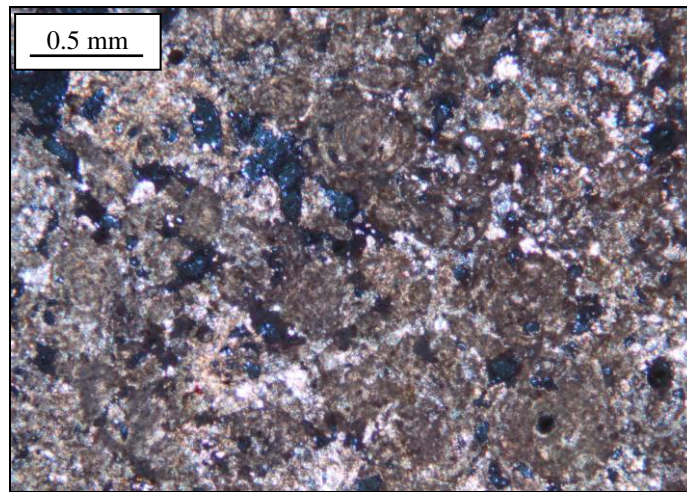


Figure 4.11. Photomicrograph (XPL) of foraminiferal packstone/grainstone microfacies at a depth of 4590-4600 ft (~1399-1402 m).

4.2 Depositional Environment of Cedar Keys Formation

The Cedar Keys Formation contains four petrographic microfacies types observed in twenty one thin sections (Figure 4.12). The four microfacies for the Cedar Keys Formation are (1) evaporites, (2) dolomitized peloidal packstone, (3) dolomitized foraminiferal wackestone, and (4) dolomitized foraminiferal wackestone/packstone facies. The microfacies names, number of thin section samples, and depositional environments of these microfacies are shown in Figure 4.12 and Figure 4.13. Because of the abundant evaporite sequences causing dissolution and high recrystallization of samples, most of the thin sections indicating this formation could not represent different microfacies at several depths.

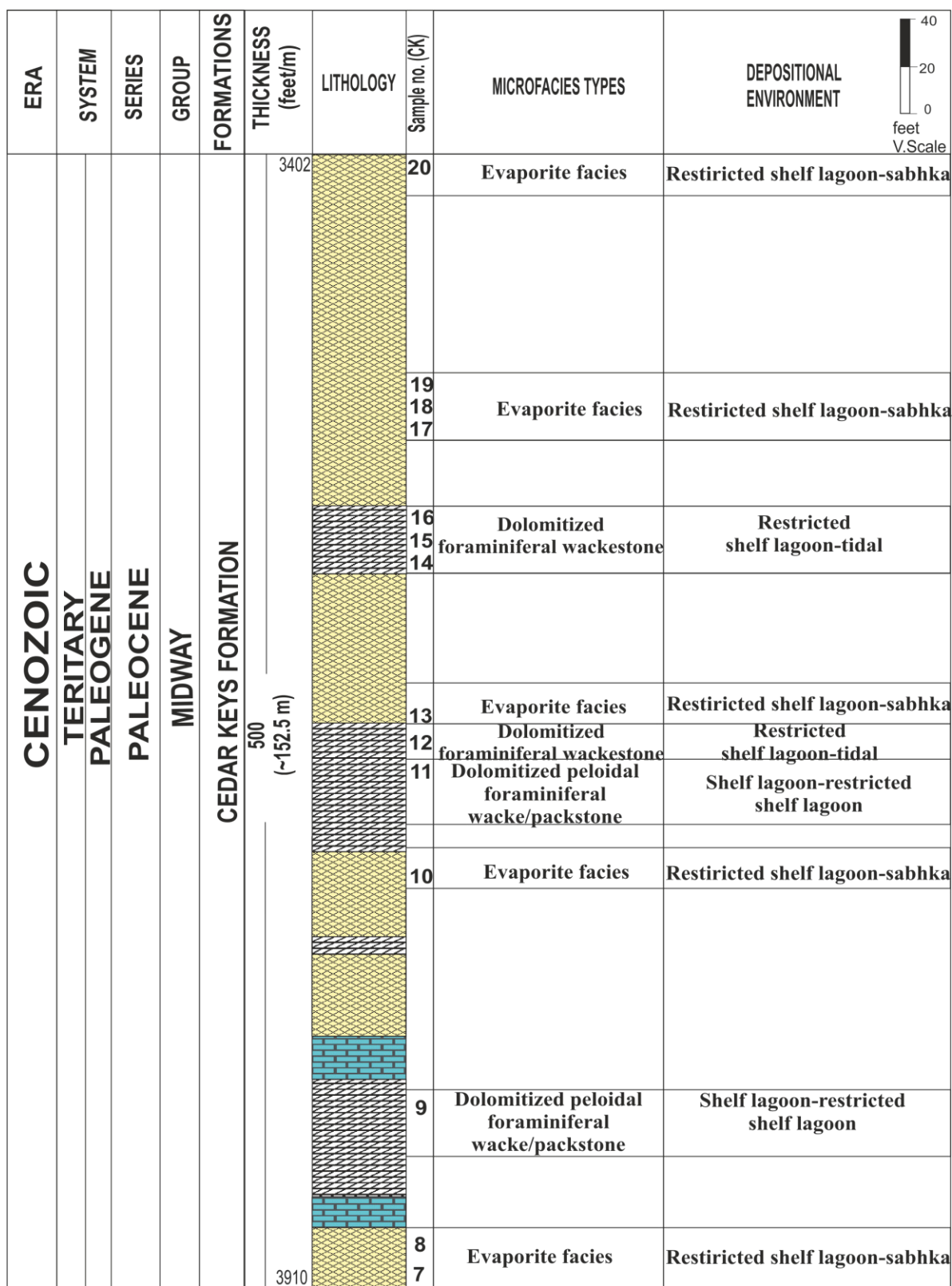


Figure 4.12. Stratigraphic column of Cedar Keys Formation showing microfacies types, thin section samples, and interpretation of depositional environments [3402-3910 ft (~1037-1192 m)].

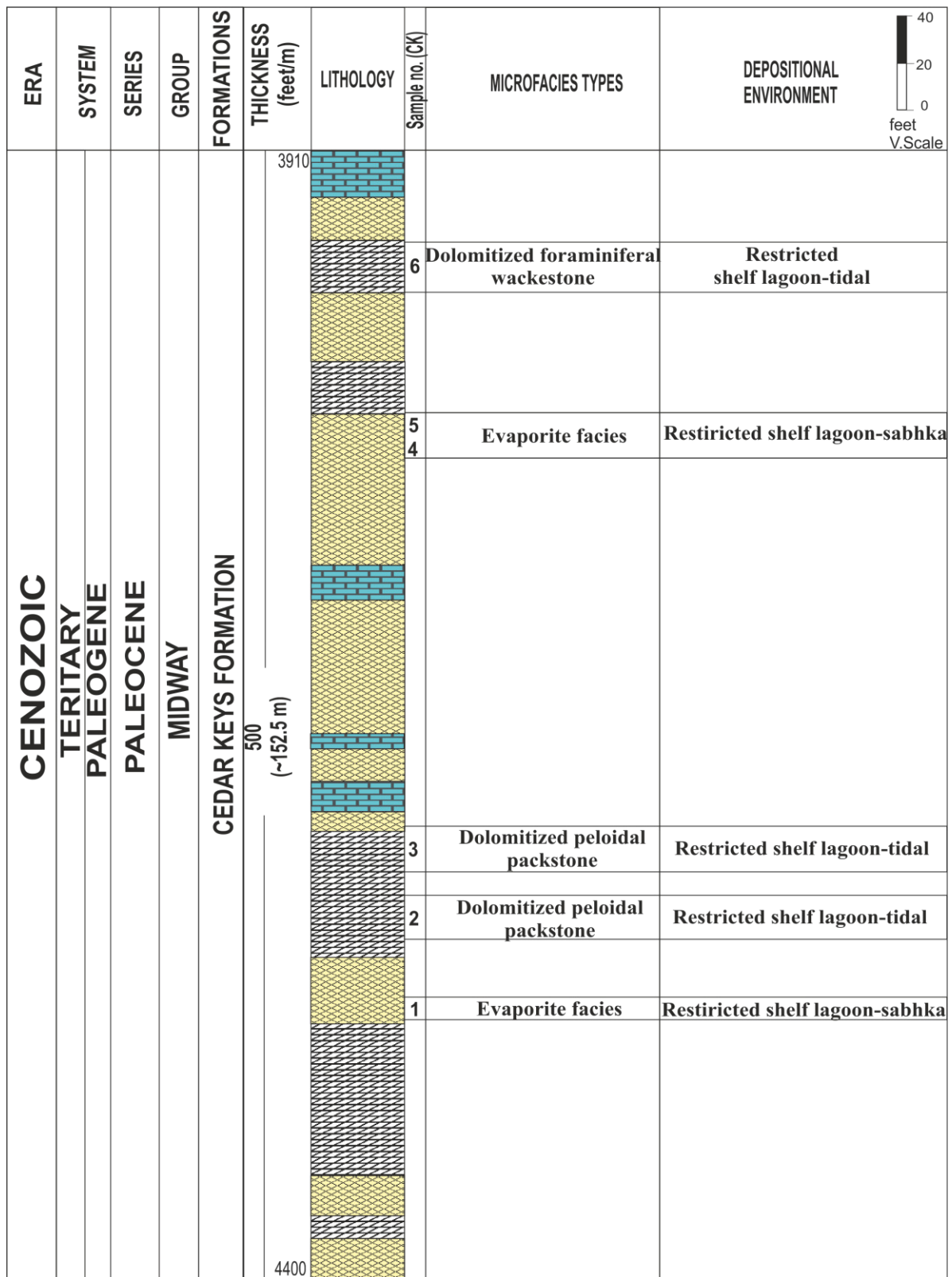


Figure 4.13. Stratigraphic column of Cedar Keys Formation showing microfacies types, thin section samples, and interpretation of depositional environments [3910-4400 ft (~1192-1341 m)].

4.2.1 Evaporite Facies

This facies is the most common facies in the Cedar Keys Formation. It is observed at several depths and represented by thin sections CK-1, CK-4, CK-5, CK-7, CK-8, CK-10, CK-13, CK-17, CK-18, CK-19, and CK-20. The facies consists mainly of anhydrite that is formed as a relic mineral, which replaced gypsum during diagenesis. Due to the sea level fluctuations and periodic precipitation, gypsum assumed a nodular structure (Ogniben, 1955). Nodular texture is widely observed through the examination of thin section (Figure 4.14). The Cedar Keys Formation evaporites are interbedded regularly with marine carbonates showing initial deposition of gypsum in restricted shallow marine-sabkha environment. However, thick sequences of evaporites indicate that these conditions were temporary from time to time. According to Murray (1964), the recrystallization process of gypsum, which had resulted from the displacement of host sediment in supratidal environment, may cause formation of anhydrite. The anhydrite observed in this facies is interpreted to reflect post burial alteration of the gypsum, as described above. In some parts of the thin sections, it is observed that gypsum started to push sediment away that indicates gypsum growth and beginning of nodular gypsum (Figure 4.14). Gypsum is disseminated through the sediment and isolated in small patches, which represents gypsum growth through the formation. In addition to the nodular texture of gypsum, fibrous texture is also observed at several depths of the formation, which is interbedded with carbonates of the Cedar Keys Formation (Figure 4.14). This texture is believed to form through the rehydration process of anhydrite to gypsum (Testa and Lugli, 2000). The depositional environment was intertidal to supratidal after the Facies Zones (FZ) classification of Wilson (1975) and SMF classification of Flugel (2004). Facies classifications indicates environment of FZ 8 reflecting restricted circulation shelf and tidal flats and sabkhas-salinas represented by FZ 9. According to

Flugel (2004), SMF 20, SMF 23 and SMF 24 may indicate the facies with evidence of dolomitized rocks interbedded with evaporites.

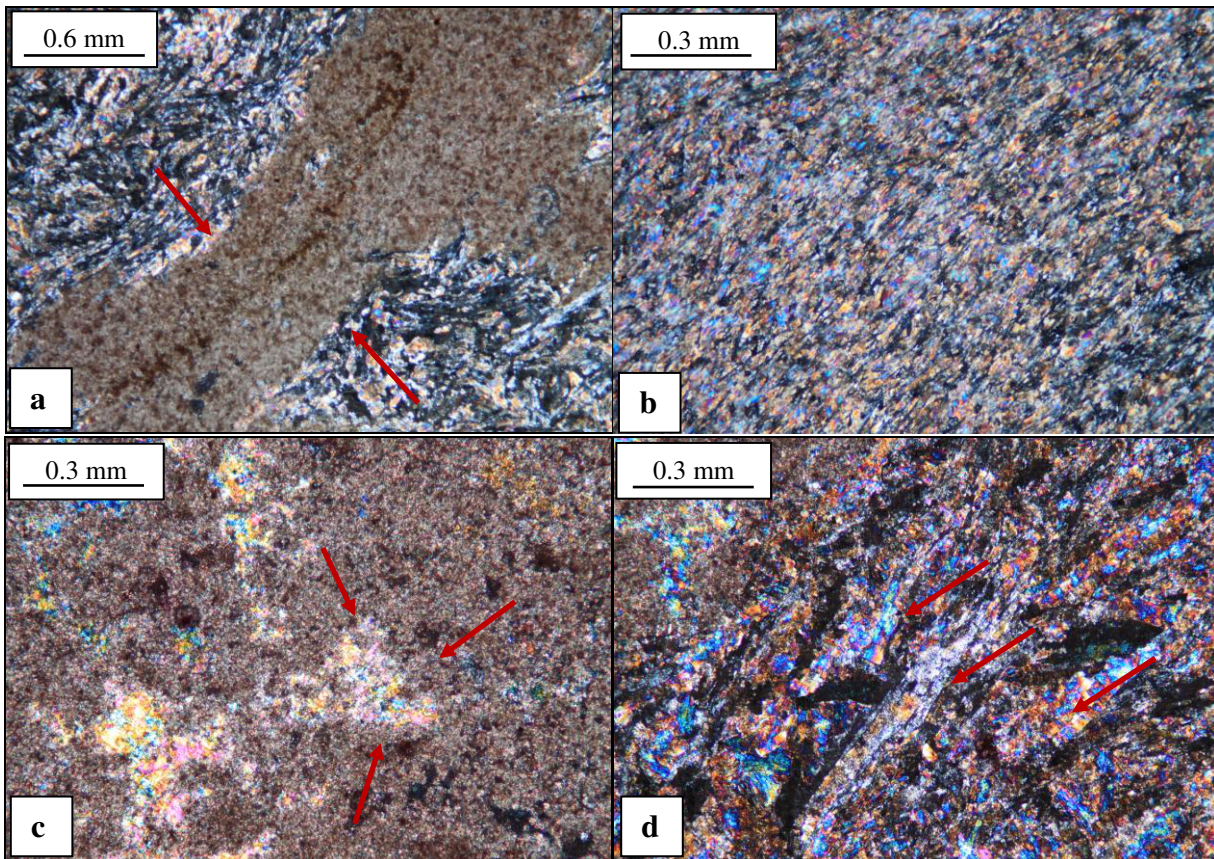


Figure 4.14. Photomicrographs (XPL) of evaporite facies at several depths. Take into consideration that the gypsum pushing the sediment away at a depth of 3570 ft (~1088 m) (a). An example of nodular texture at a depth of 3568 ft (~1088 m) (b). Facies includes gypsum that isolated in small patches (c) and note that radiated gypsum veins scattered within the Cedar Keys Formation at a depth of 3646.5 ft (~1111 m) (d).

4.2.2 Dolomitized Peloidal Packstone

This microfacies has been identified at the lower part of the formation and represented by thin section CK-2 and CK-3. This microfacies is characterized by the packstone texture according to

Dunham (1962). Peloids are the dominant nonskeletal grains of this microfacies (Figure 4.15).

Petrographically, micritic peloids and radiating patterns of gypsum that filled secondary porosity are observed (Figure 4.15). Very fine crystalline dolomite in the micrite matrix indicates that the original composition of micrite was altered by Mg-rich marine water.

The peloidal facies is generally common in shallow marine, protected, lagoonal environments representing low energy environment (Tucker and Wright, 1990). Therefore, this microfacies is represented by FZ 8 of Wilson (1975) and SMF (16, 17, 18) of Flugel (2004) as evidenced by peloidal grains and dolomitization. FZ 9 of Wilson (1975) can also be considered for this microfacies due to the gypsum that filled secondary porosity. This microfacies is interpreted to represent deposition mainly around restricted shelf lagoon environment.

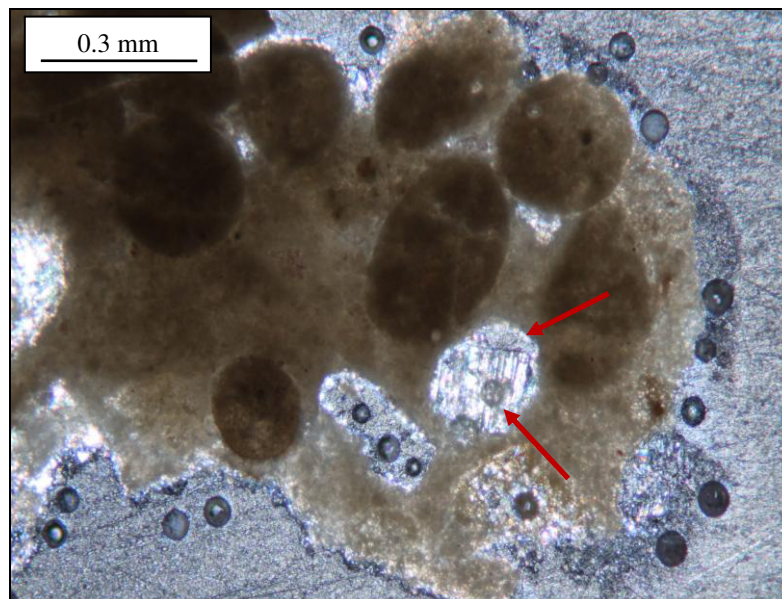


Figure 4.15. Photomicrograph (XPL) of dolomitized peloidal packstone at a depth of 4210-20 ft (~1283-1286 m). Note that the radiated gypsum filled into secondary pore space.

4.2.3 Dolomitized Foraminiferal Wackestone

This facies is observed in the upper and lower parts of the Lawson formation and represented by four thin sections, which are CK-6, CK-12, CK-14, CK-15, and CK-16. According to Dunham (1962), the textural type of this facies is wackestone, which is partially dolomitized. The presence of the unidentified foraminifera and sparite cement are the main constituents of the facies. Micrite is partly recrystallized into sparry calcite and sparite. The fine to medium grained dolomite rhombs that are scattered in the sparry calcite with skeletal grains may reflect mixing of the ground water with marine water. The facies occasionally includes possible peripheral sections of *Planulina* or *Ammodiscus* (Figure 4.16). The presence of allochems in sparry calcite cement points to deposition that took place in shallow water environment. However, because of the recrystallization of micritic matrix, medium to low energy conditions represent this microfacies rather than high energy conditions. According to Wilson (1975), it is possible to assign this microfacies to FZ 8, which indicates deposition around restricted, shelf lagoon environment indicating deposition through the intertidal environment.

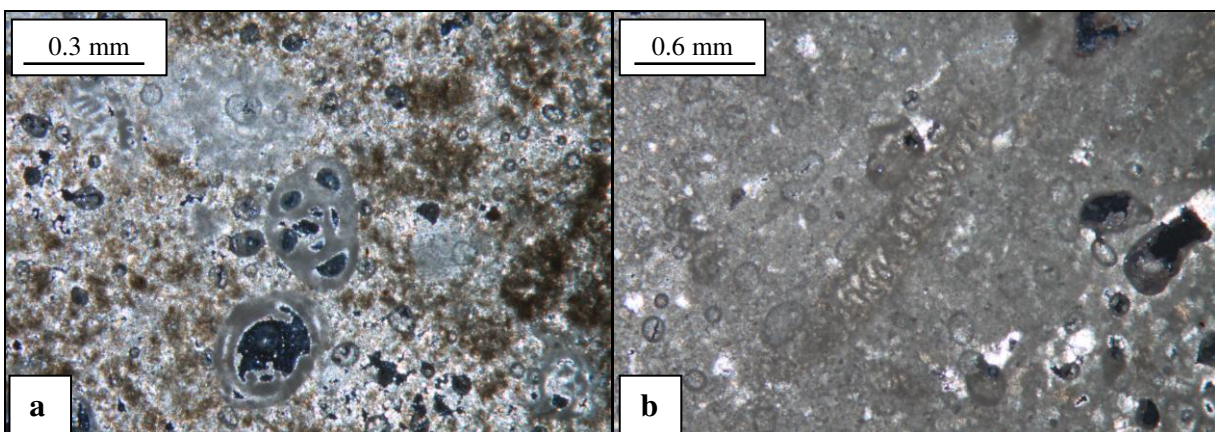


Figure 4.16. Photomicrograph (XPL) of dolomitized foraminifera packstone at a depth of 3960-3970 ft (~ 1207-1210 m) (a). Possible peripheral section of *Planulina* or *Ammodiscus*? at 3960-3970 ft (~ 1207-1210 m) (b).

4.2.4 Dolomitized Peloidal Foraminiferal Wackestone/Packstone

This facies is mainly composed of peloids that scattered in several parts of this microfacies and unidentified benthic foraminiferal debris (Figure 4.17). Thin sections CK-9 and CK-11 represent this microfacies in the upper parts of the Cedar Keys Formation. The textural type of this microfacies is wackestone to packstone fabric according to Dunham (1962). The allochems are cemented with recrystallized micrite matrix. Dolomitization took place as described for the dolomitized foraminiferal wackestone microfacies. The peloidal facies usually reflects common shallow marine, protected, lagoonal environments representing low energy conditions (Tucker and Wright, 1990). This microfacies is similar to FZ 7 and 8 of Wilson (1975) and SMF (8, 9, 10, 16, 17 18, 19) of Flugel (2004) and indicates deposition in shelf lagoon environment reflecting shallow subtidal to intertidal depositional environment.

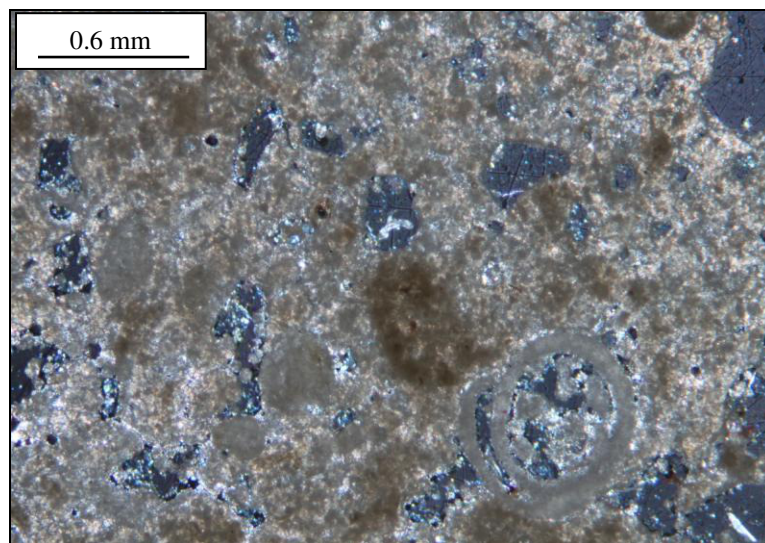


Figure 4.17. Photomicrograph (XPL) of dolomitized foraminiferal packstone at a depth of 3810-3820 ft (1161-1164 m).

CHAPTER 5

DIAGENESIS

Diagenesis reflects the chemical and physical process that performs on rocks after their initial deposition, before pressure and temperature reach values causing real metamorphism. Rock-water interaction is the primary driving force in the carbonate diagenesis. Over time carbonates interact with different fluids after the deposition resulting in different diagenetic features (Longman, 1980). Each diagenetic environment is represented by different diagenetic textures. Petrographic studies show that the Lawson Formation and Cedar Keys Formation reflect a complex diagenetic history, which is described below. The goal of this section is to summarize the diagenetic history of the formations studied by determining the types, textures and sequence of diagenetic processes. Due to the lack of the core and rock cutting samples that represent Pine Key Formation, only diagenesis of Cedar Keys and Lawson formations have been interpreted.

5.1 Diagenetic Features of Lawson Formation

The diagenetic process that affected the Lawson Formation carbonates from original deposition marine to the final burial at significant depth is complex. The Lawson Formation shows different diagenetic phases and events such as micritization, cementation, dissolution, recrystallization and dolomitization as seen in the thin sections representing this formation.

5.1.1 Micritization

Micritization is a dark alteration rim of micrite-size crystals on allochems, which is also known as degrading neomorphism. The term micritization represents boring activity of endolithic algae

resulted from conversion of allochems into micrite, which is also known as lime mud (Flügel, 1982). Petrographic investigations show that mostly the skeletal grains are bored around the margins. Micritic envelopes surround some skeletal fragments and some benthic foraminifera (Figure 5.1). The micritization of carbonates is a slow process and therefore, indicates low energy, restricted environments. According to Wilson and Evans (2002), shallow marine, or meteoric to shallow marine environments support the micritization process. Micritization identified here is an early diagenetic process and most probably represents marine phreatic environment.

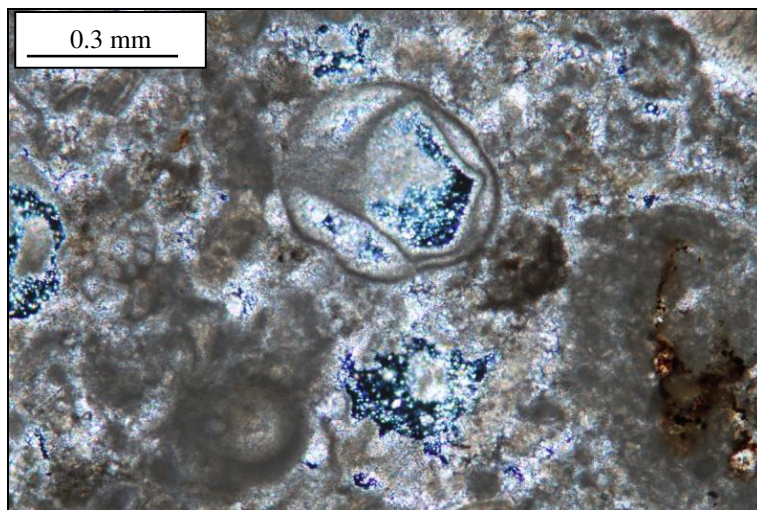


Figure 5.1. Photomicrograph (XPL) of micritization (micrite envelope) surrounding the skeletal fragment at a depth of 4550-4560 ft (~1387-1390 m).

5.1.2 Cementation

Cementation is the fundamental diagenetic process whereby sediments become lithified or consolidated through precipitation of a material in the pore spaces between the grains (Flügel, 1982). Additionally, the cement belonging to carbonate sediments may be intergranular or

intragranular. Different types of calcite cement types have been recognized in the Lawson Formation. These are isopachous rim calcite cement, fibrous calcite cement, bladed calcite cement, granular and drusy calcite cement. A submarine and equal-sized isopachous rim calcite cement occurs along the margin of many bioclasts (Appendix B, Plate1). In this kind of cementation crystals have equal sizes coating around the grains. According to Longman (1980), bladed and equant calcite rim cement generally indicates freshwater phreatic environment. However, the fibrous calcite rim cement is precipitated in shallow marine diagenetic environment (Longman, 1980). Isopachous rim cementation features represent early cementation stage of diagenesis under marine phreatic environment. In this study, the fibrous calcite cement can be considered as the first generation. Some bladed crystals within the grains may represent the late stage of cementation showing meteoric phreatic environment (Appendix B, Plate1). Thin sections have also shown drusy and granular cement (Appendix B, Plate1), which are suggestive of late cementation. This type of cement fills the free spaces remaining after cementation that took place in shallow marine environment. As a result, diagenesis under fresh water phreatic environment is indicated by late cementation.

5.1.3 Dissolution

Dissolution is one of the most important diagenetic processes that affects the porosity in the Lawson Formation especially where grain-supported texture is observed. Carbonate sediments and cements may undergo dissolution. During dissolution the unstable constituents such as aragonitic or high magnesium bioclastic shells dissolve and result in secondary porosity (Tucker and Wright, 1990). This process shows diagenesis took place under fresh water phreatic environment. Several types of fabric selective and non-fabric selective porosity have been observed as a result of dissolution in the Lawson Formation such as moldic, vuggy, intraparticle,

and intercrystalline (Appendix B, Plate2). Primary porosity is of lesser importance and generally includes intraparticle porosity. The porosity related with the dolomite is intercrystalline (Appendix B, Plate2). This kind of porosity suggests that porosity evolution is resulted from dolomitization. The reduction of volume from calcite to dolomite is responsible for creating the intercrystalline porosity (Weyl, 1960). This kind of porosity is found frequently in the lower part of the formation and interpreted as secondary fabric selective porosity. Moldic porosity, mostly in the form of shell fragments occurs in minor amounts and indicates fabric selective porosity (Appendix B, Plate2). Additionally, filling of bioclastic fragments by the growth of calcite cement reflects infilling of moldic pores. These pores are created by dissolution of fragments originally composed of aragonite and high Mg-calcite and filled up by drusy growth, sparry calcite cement (Appendix B, Plate 2). This feature is interpreted to be the result of late diagenesis. Therefore, dissolution may represent fresh water-phreatic, mixed marine-fresh water phreatic and also burial diagenetic environments (Bathurst, 1975). Other types of porosity determined in the Lawson formation such as vuggy porosity (non-fabric selective) can be seen in (Appendix B, Plate2).

5.1.4 Dolomitization

Dolomitization occurs when magnesium-rich calcite or aragonite minerals are transformed to dolomite (Land, 1982). Dolomitization process is important to development of reservoir due to the reduction of almost 13 percent volume through calcite to dolomite transition. For this reason, dolomitization has been widely studied through the formations having petroleum potential. There are three types of dolomitization. First one is related with evaporites and formed by direct precipitation of evaporites that is formed in environments such as sabhkas (McKenzie, 1981).

Second one is related with diagenesis under mixing zone of marine and meteoric phreatic environments which is also observed in the Lawson Formation. Third one is related with deep burial (subsurface) dolomitization that is evidenced by baroque (saddle) dolomites. This kind of dolomitization occurs due to the increasing temperature and depth causing reduction of hydrated Mg^{+2} (Illing, 1959). My petrographic studies show that dolomite occurred as a replacement mineral of calcite showing dolomite is not primary precipitate. This interpretation is based on euhedral to subhedral crystals that disseminated within the skeletal allochems (Figure 5.2).

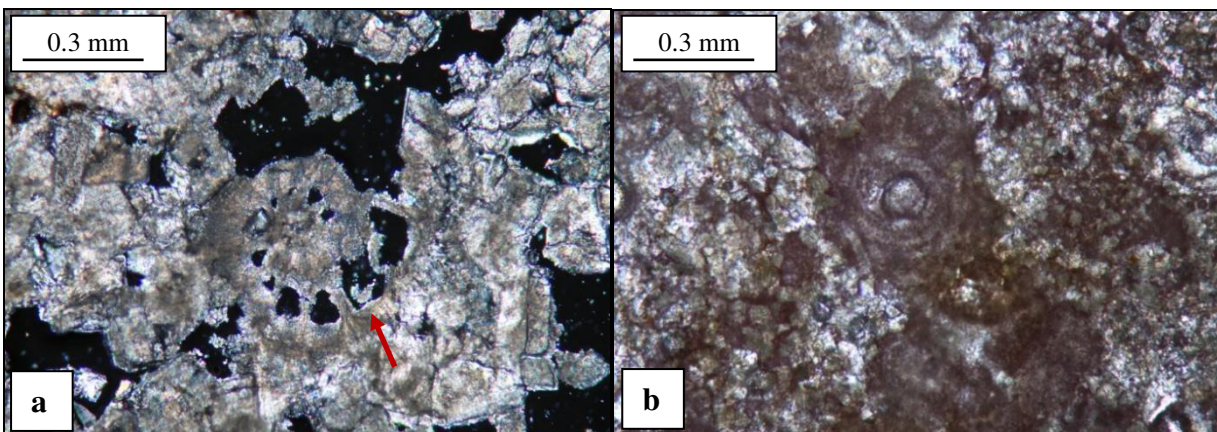


Figure 5.2. Photomicrographs (XPL) of dolomitization in the Lawson Formation. Euhedral to subhedral crystals together with skeletal allochem indicating dolomitizaion at 4880-4890 ft (~1487-1490 m) (a). Note that greenish cloudy textue of dolomite crystals surrounding skeletal allochems at a depth of 4540-4550 ft (~1384-1387 m) (b).

Medium to coarse crystalline dolomites may indicate replacement of limestone during late diagenesis (Machel and Anderson, 1989). The medium to coarse crystal size observed within the Lawson Formation probably indicates a mixing zone, dolomitization event. Even though, dolomitization is observed frequently along the Lawson Formation, the rate of the dolomitization increases downward where micro to coarse-crystalline size dolomite facies have been observed.

Dolomite is known to form in diagenetic environments where fresh and marine waters mix (Badiozamani, 1973). This is a proposed mechanism for evaporite free sequences (Magaritz et al., 1980). Therefore, dolomitization through the Lawson Formation may be formed by regional mixing of meteoric pore fluids with marine phreatic fluids that indicates an intermediate stage diagenesis. This is also evidenced by absence of evaporites within the thin sections.

5.1.5 Recrystallization

Recrystallization is widely observed in the Lawson Formation based on petrographic studies. It is the most prominent feature through the diagenetic features in the studied formation.

Recrystallization (aggrading neomorphism) affects both allochems and matrix, which makes identification of facies and skeletal allochems more difficult. According to Folk (1965), the indicative feature of aggradational neomorphism (recrystallization) is replacement of finely crystalline carbonate by coarser calcite mosaic.

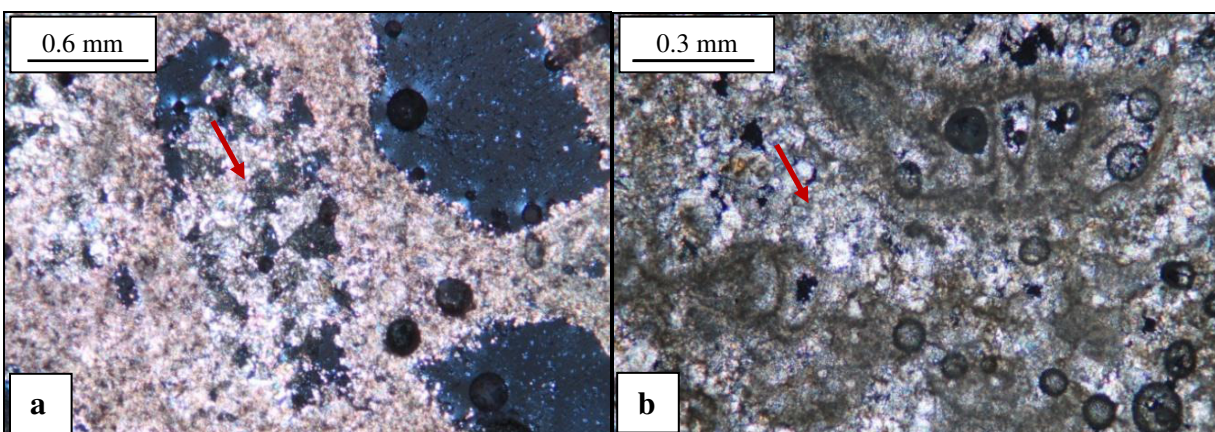


Figure 5.3. Photomicrographs (XPL) of recrystallization observed in the Lawson Formation. Finer crystals are replaced by coarser crystals indicating aggrading neomorphism at a depth of 4740-4750 ft (~1445-1448 m) (a). Note that micritic size fabric have been altered to coarser fabric due to the recrystallization at a depth of 4540-4550 ft (~1384-1387 m) (b).

Figure 5.3 indicates aggradational neomorphism in the Lawson Formation where micritic size fabric has been altered to coarser fabric diagenetically. In this process, the mineral before and after the reaction is the same, the difference is the shape, crystal size and the orientation of the mineral (Folk, 1965). This diagenetic process is attributed to the freshwater phreatic environment (Carozzi, 1989). Therefore, recrystallization through the Lawson Formation was subjected to diagenesis under freshwater phreatic environment.

5.2 Diagenetic Features of Cedar Keys Formation

Analysis of thin sections has yielded considerable information reflecting the diagenetic history of these rocks. The most striking diagenetic processes acting on the Paleocene Cedar Keys Formation include cementation, dissolution, recrystallization and dolomitization. In addition to these features, evaporite diagenesis plays an important role in the Cedar Keys Formation due to the high volumes of evaporite minerals interbedded with carbonates. Evaporites are susceptible to complex post-depositional diagenetic processes. Tectonic activity, burial depth, and location within the basin may lead to transformation of gypsum to anhydrite. Anhydrite may transform back to gypsum when the conditions are convenient to this process (Hardie et al., 1985). In Murray's (1964) description, there are 3 types of anhydrite deposited with carbonates, bedded anhydrite, replacement anhydrite and pore filling anhydrite, that are also observed in the Cedar Keys Formation (Appendix B, Plate 3). In general, gypsum is found near the surface and in recent sediments. However, anhydrite is the common form in the subsurface (Murray, 1964). The primary gypsum in Cedar Keys Formation was transformed diagenetically into anhydrite. The dominant evaporitic mineral in the Cedar Keys Formation during burial is anhydrite. Gypsum does not occur at depths greater than 500 m in the subsurface. Therefore, lack of gypsum

throughout the formation is expected. According to Murray (1964), anhydrite results from the recrystallization of gypsum. He inferred that after burial (below 3500 ft) with an increase in temperature, the gypsum recrystallizes to anhydrite. It is believed that the anhydrite studied in this facies resulted from post burial alteration of the gypsum, as described above. The nodular anhydrite beds reflect gypsum growth by displacement of soft sediment. This must be considered as an early diagenetic facies. Bedded evaporites in geologic record include thick sequences of nodular anhydrite (Murray, 1964). Replacement anhydrite generally occupies the space of a bioclastic material that used to be there. This process indicated dissolution of host rock and precipitation of evaporite mineral (Murray, 1964). Nodular anydrites are formed by the primary growth of gypsum that tranforms into anhydrite under diagenesis.

5.2.1 Cementation

The most important cementation type that affected the Cedar Keys Formation is evaporitic cement because of the widespread evaporite minerals observed throughout the formation.

According to Boles and Ramseyer (1987), gypsum and anhydrite cement may be removed during evaporite dissolution and this only takes place where sediments are flushed with meteoric fluids.

Evaporite cements may also form from hyper-saline subsurface waters and in deep burial.

Evaporite minerals and evidence of their former presence are very common throughout the Cedar Keys Formation. Pore-filling anhydrite cement as well as small pore filling sparry calcite cement are observed in the Cedar Keys Formation (Appendix B, Plate 4). Most probably, sparry calcite cement in primary pore spaces is precipitated before precipitation of evaporitic cement.

Evaporite cement may also represent some sort of early cementation. Sparry calcite cements were formed at the end of early stage diagenesis during early transition from the marine phreatic

environment to meteoric diagenetic environment. Another example of pore-filling evaporite cement can also be seen in Appendix B, Plate 4. In addition to the pore filling microspar calcite cement, the isopachous bladed calcite rim cement is also observed in the thin sections representing the Cedar Keys Formation (Appendix B, Plate 4). This type of cement is precipitated in the marine phreatic diagenetic environment (Moore, 1989; Nelson and James 2000) and indicates submarine cementation that includes either aragonite or high magnesium calcite. Other types of calcite cements may not have been observed because of the high recrystallization through the thin section samples and dissolution of evaporites affected the carbonates.

5.2.2 Dissolution

Solubility of the minerals affects the dissolution. The solubility of calcium carbonate rises from low-Mg calcite to aragonite and high-Mg calcite (Tucker and Wright, 1990). Dissolution in Cedar Keys Formation generates three types of porosity which are moldic, intraparticle and vuggy porosity. The vuggy porosity reflects the non-fabric selective porosity (Choquette and Pray, 1970). It includes dissolution of matrix, cement and grains. The Cedar Keys Formation represents vuggy porosity as non-fabric porosity (Appendix B, Plate 4). Intraparticle porosity is observed as primary and fabric selective in the intraskeletal pores. During diagenesis primary porosity is reduced partially by calcite and anhydrite cement and increased by moldic porosity formed after the dissolution of unstable allochems. In the Cedar Keys samples moulds of benthic foraminifera are partially filled with calcite cement. In general, primary porosity is commonly filled during meteoric diagenesis and secondary is created. The Cedar Keys Formation shows high porosity of both types (primary and secondary) in thin sections.

5.2.3 Dolomitization

The dolomitization of limestones under diagenesis is a widespread feature of carbonates. The Cedar Keys Formation suggests dolomitization in mixing of meteoric and marine phreatic environments. Dolomites are often associated with evaporites. Therefore, one of the most common dolomitization models, seepage-reflux, may explain dolomitization in the Cedar Keys Formation. In the seepage-reflux model high Mg/Ca ratios in pore-waters are formed by evaporation beneath tidal flats and sabhkas (Adam and Rhodes, 1960). The most widespread sedimentary feature during the deposition of the Cedar Keys Formation is evaporite deposition in sabhka environments. Petrographic studies show that dolomite occurred as a replacement mineral of calcite showing dolomite is not a primary precipitate. This interpretation is based on stained thin sections and skeletal allochems disseminated through the thin sections (Appendix B, Plate 4). According to thin sections both allochems and matrix have been dolomitized. Dolomitization that took place in the Cedar Keys Formation includes both very fine grained microcrystalline dolomite and probably euhedral to subhedral crystals. However, high dissolution due to the evaporites and recrystallization prevent interpretation of crystal types and other features. As a result, the dolomitization model of the Cedar Keys Formation could not have been interpreted directly. It may either resulted from direct precipitation of evaporites or have resulted from dolomitization that took place through the mixing zone of marine and meteoric phreatic environments

5.2.4 Recrystallization

Recrystallization is one of the main diagenetic processes that affected the Cedar Keys Formation (Appendix B, Plate4). Aggrading neomorphism occurs due to the accumulating sedimentary

rocks causing burial pressure and temperature. The aggrading neomorphism of the skeletal particles is common in most of the studied thin sections representing the Cedar Keys Formation. Many limestones and dolostones in the Cedar Keys Formation have a homogeneous crystalline appearance consisting of sparse fossils. Moreover, limestones and dolomites may be confused because of the crystalline appearance. At this point, stained thin section studies showed that both limestone and dolomite minerals are recrystallized. According to Longman (1977), the recrystallization process occurs long after deposition.

CHAPTER 6

DISCUSSION

The overall goal of this thesis is to better determine the lithostratigraphy, depositional environment and diagenetic history of the Pine Key, Lawson and Cedar Keys formations. The work presented here will help to improve understanding of petroleum potential of these rocks in future studies as well as the general geology of the studied formations. As described previously, the dominant lithologies discovered in the Pine Key Formation are mostly white, tan and light gray to gray chalky limestone with few fragments of dolomite lenses and small amounts of pure white anhydrite (1 to 8 %). According to Faulkner and Applegate (1986), the oldest Cenozoic formation (Paleocene Cedar Keys Formation) overlies the Late Cretaceous Pine Key Formation conformably in the South Florida Basin. The Pine Key Formation in South Florida Basin is composed of both Taylor Age Rocks and the Lawson Formation. Because Taylor Age Rocks in this study fit the description of Pine Key Formation, I have assigned the term of Pine Key Formation for these chalky limestones. Therefore, I separated the Upper Cretaceous rocks into the two formations, the Lawson Formation and Pine Key Formation, based on previous studies and lithologic descriptions observed in the studied well.

Due to the lack of thin section samples representing this formation, I have not been able to interpret depositional environments and diagenetic features. However, descriptions that have been done under the stereo microscope enabled me to determine the lithologic description of this formation, which match the descriptions of Winston (1991) and Faulkner and Applegate (1986) well, indicating deposition in shallow marine environments both in central and south Florida.

6.1 Rudistid Fragments of the Lawson Formation

As pointed out in the previous chapters, according to Maher and Applin (1968), the Lawson Formation is light-colored chalky limestone that forms a limestone facies. They also emphasized indicative features such as rudists and rudist fragments that characterize the facies in the Florida Peninsula. Based on petrographic observations and descriptions, the Lawson Formation includes some rudist fragments observed at several depths. However, high diagenetic features prevented me from interpreting the depositional environment accurately. More detailed petrographic descriptions are needed to interpret the rudists of this formation. In general, depositional environments of the Lawson Formation are shelf edge reef, shelf lagoon to restricted shelf lagoon representing subtidal to intertidal depositional environments. As indicated in the previous chapters, rudists represent several life habitats and not all of them are reef builders (Flügel, 2004). Detailed study may show exact depositional environment of rudists. However, here it is interpreted as an indicator of a shelf edge reef representing patch reefs because the faunal content and cementation observed through the walls of rudists may indicate normal marine, upper subtidal depositional environments. Recognizing composition, fabric, texture, and sedimentary structures are key observations to obtain clues to determine depositional environments. Because of the amount and type of diagenesis that took place after deposition of this formation, most of the features such as fabric, texture, and sedimentary structures were difficult to determine.

6.2 Evaporites of the Cedar Keys Formation

Deposition in shallow-marine environments was continuous through the beginning of the Cenozoic time. However, peninsular Florida was exposed to restricted conditions that resulted in anhydrite deposition during the Paleocene. Development of a barrier reef may have caused the

restriction (Rainwater, 1970). According to Winston (1991) and (1995), the Cedar Keys Formation is a sequence of thick anhydrite and euhedral dolomite which is interpreted as being deposited behind the Rebecca Shoal Barrier reef as a lagoonal facies. However, the Cedar Keys Formation is mostly tan to gray, highly porous, crystalline dolomite interbedded with thick anhydrite and minor amounts of limestone in the studied interval.

Additionally, the carbonate-evaporite sequence represents the formation, which shows evaporites played an important role during the deposition of the formation. The depositional environments of the evaporites deposited through the Cedar Keys Formation differ from intertidal to supratidal. The formation also includes microfacies representing the shallow subtidal environment. Therefore, the carbonate-evaporite sequence may show a typical back-reef environment according to Winston (1991). However, extensive diagenetic alteration within the rocks studied has destroyed many of the original depositional textures that prevented from making an accurate interpretation about the depositional environment. Nevertheless, it can be interpreted that restricted marine circulation caused deposition of evaporites from time to time indicating the sabhka environment which is interrupted by the deposition of carbonates reflecting the shallow subtidal to intertidal depositional environments.

The Cedar Keys Formation includes anhydrite facies that formed as a relic mineral, which replaced gypsum minerals during diagenesis. The nodular anhydrite beds reflect gypsum growth by displacement of soft sediment. This is generally considered as an early diagenetic facies. Therefore, first nodular gypsum was formed through the Cedar Keys Formation and then gypsum altered to nodular anhydrite.

6.3 Distribution and Relative Timing of Diagenetic Processes

Following deposition of the Lawson Formation sediments through the environments interpreted above, early diagenesis began in the marine phreatic environment and comprised micritization of grains and precipitation of minor calcite fibrous cement and isopachous rim cement. This type of cementation reflects the early cementation. Dolomitization in the Lawson Formation were formed at the transition from marine phreatic to the meteoric phreatic diagenetic environment. This kind of dolomitization requires occurrence of marine to meteoric (mixing) diagenetic environments. The relation between pore space and fabric elements of carbonate facies indicates fabric selectivity is important in examining the time of origin of porosity in relation to other events (Choquette and Pray, 1970). Dissolution in the Lawson Formation is important because of the high percentage of secondary porosity indicating beginning of the meteoric diagenesis. Porosities such as vuggy and moldic are considered secondary porosity that formed after deposition due to the effect of diagenetic processes. Dolomitization through the Lawson Formation also affected the porosity causing intercrystalline porosity. Additionally, when pore spaces filled with meteoric waters some bladed, drusy and granular cements were precipitated (late cementation). Recrystallization is interpreted to be the final stage representing diagenesis under freshwater phreatic environment which it made difficult to determine sedimentary structures through the thin sections. Relative timing of diagenetic phases is difficult to establish in the Cedar Keys Formation. This is because of the evaporite cement and uncertain sedimentary structures, fabric and texture due to the effects of high recrystallization and dissolution. The first stage of diagenesis starts with the isopachous bladed calcite rim cement indicating marine phreatic diagenetic environment. Micritization has not been observed during the examination of thin sections. Evaporite cement is generally observed together with calcite cement. Because

evaporite cement generally takes place where sediments are flushed with meteoric fluids or form from hyper-saline subsurface waters and in deep burial, usually calcite cement is precipitated before the evaporite cement. However, some sort of late cements representing meteoric phreatic environments may form after the evaporitic cement precipitation. Therefore, timing of evaporite and calcite cement may be controversial in this study.

One of the most controversial topics of the the Cedar Keys Formation is when dolomitization during the diagenesis process. There are several possible sources for the dolomite within the Cedar Keys Formation. The Cedar Keys Formation may reflect either occurrence of dolomitization related with direct precipitation of evaporites or dolomitization that is formed in the mixed zone of marine and meteoric phreatic diagenetic environments. Even though, the dolomites of Cedar Keys Formation are related with evaporites, they are more likely a result of replacement of calcite. This is evidenced by skeletal allochems disseminated through the dolomitized sections. Thus, mixed zone diagenetic environment may represent the dolomitization in this study, which indicates intermediate stage diagenesis. In general, primary porosity is commonly filled during meteoric diagenesis and secondary is created. This shows the beginning of the meteoric diagenetic stage. Rrecrystallization was subjected to diagenesis under freshwater phreatic conditions representing probably the final stage of diagenesis present throughout the Cedar Keys Formation.

6.4 Petroleum Potential

According to Palacas (1978), the uppermost Cretaceous carbonates in Florida Peninsula are most probably not source rocks of petroleum because of the immaturity and low amounts of organic carbon content. However, in some wells, especially in the upper parts, spotted oil stains and oil-

stained fossils were observed. Similarly, lower parts of the Cedar Keys Formation show low amounts of organic matter and immaturity that represents non-source rocks of petroleum. However, it is also indicated that thick evaporite-carbonate sequences such as Cedar Keys Formation represents favorable conditions for petroleum reservoir rocks as well as the source rock development (Rainwater, 1970). General comparison of organic carbon content in carbonate rocks of South Florida Basin and basins of the world is shown in Figure 6.1. High percentage of organic carbon content of the Lower Cretaceous Rocks can be observed in Figure 6.1. As pointed in previous chapters, extensive studies have been conducted in the nearby South Florida Basin compared to central part of the Florida Peninsula. Lower Cretaceous rocks, especially Sunniland Formation have the greatest potential among all of the formations. Even though the uppermost Cretaceous and Paleocene units have low petroleum potential compared to Lower Cretaceous carbonates in South Florida Basin, some oil stained samples in the Lawson Formation described in this study may contribute to exploration of petroleum studies throughout the Florida Peninsula. Figure 6.2 shows that pore spaces contain traces of organics or maybe tar which is heavier residue of crude petroleum. In addition to this, the presence of abundant secondary porosity due to the dissolution potential of skeletal constituents as well as the dolomitization resulted in intercrystalline porosity of the Lawson Formation, which can serve as a good reservoir for hydrocarbons.

6.5 Changes in Sea Level

Sea level fluctuation with regard to a land surface is described as relative sea level change (Vail et al., 1977). The land surface, sea level or combination of both may fall or rise in course of sea level changes. When sea level changes occur as a successive rise and fall, it is called cycle of

relative sea level change. In general, a cycle includes gradual rise, standstill and rapid fall in relative sea-level (Vail et al., 1977). Smaller scale sets of rapid rise and standstills represent the gradual rise, which is called as paracycles (Vail et al., 1977). In this study, sea-level changes were interpreted as transgressions and regressions in reference to changes in marine facies and depositional environments. Because of the lack of the age control tools (fossils, magnetostratigraphy, Sr-Isotopic stratigraphy) from this studied well, sea-level changes couldn't be integrated at a global stage and detection of eustatic fluctuations were not possible. Therefore observations are only local to basin-wide in scale, and should be able to provide basic information for future Mesozoic-Cenozoic sea-level studies throughout the area. Likewise, sufficient data are not available to definitively identify the cause of relative sea level rise or fall from this locality, and therefore relating these facies changes to actual global eustasy or subsidence of the local basin is difficult. More detailed study and data are needed to correlate regional relative sea-level changes with the global sea-level curves (Haq, 2014).

According to Rainwater (1970), the Late Cretaceous was a time of marine transgression in Florida and many other parts of the world. Global sea level rise during this time period and regional, uniform subsidence led to the deposition of shallow-marine dolomite and limestone in the study area. Relative sea level begins to drop, increasing the amount of restricted facies allowed to form at the end of the Cretaceous. Therefore, evaporite deposition in the company of carbonate deposition took place at the beginning of the Paleocene. The Upper Cretaceous Lawson Formation represents a general rising trend in sea level compared to Paleocene Cedar Keys Formation. It also includes regressive cycles from time to time due to the dolomitization formed in more restricted environment. Regional sea level curves of the Lawson Formation are shown in

Appendix C. In this study, cycle characters differ stratigraphically and due to the depositional environment. Thick evaporite deposition throughout the investigated portion of the Cedar Keys Formation indicates more restricted environment representing a transgression or sea-level fall. Sea level fall at the end of the Cretaceous leads to formation of evaporites. The sequence of carbonate and evaporite deposition of the Cedar Keys Formation represents a transgressive-regressive cycle during the deposition of the Cedar Keys Formation (Appendix C). Limestone facies and evaporite-dolomite facies show many transgressions and regressions that affected the shallow seas locally.

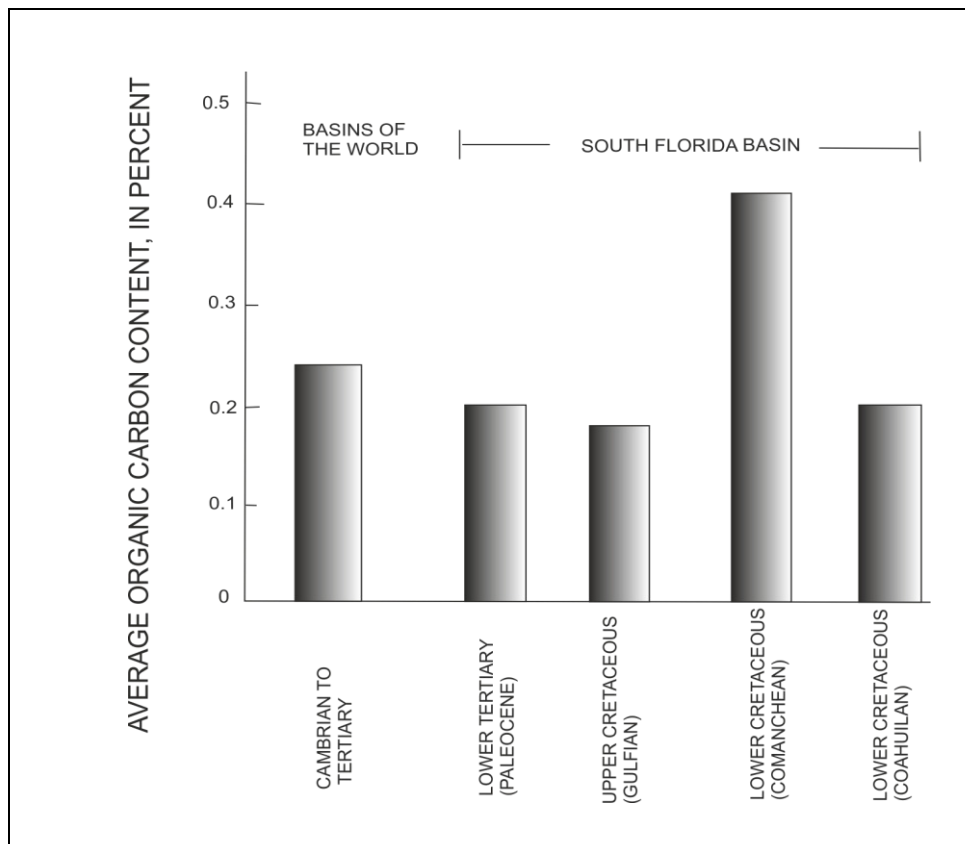


Figure 6.1. Comparison of SFB rocks' organic carbon content and sedimentary basins of the world (modified from Hunt, 1961).

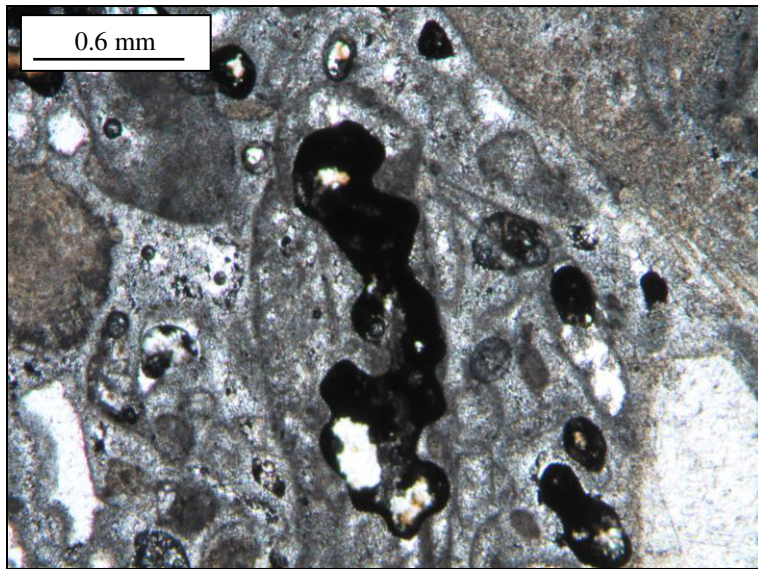


Figure 6.2. Photomicrographs (XPL) of pore spaces filled with organics or tar at a depth of 4740-4750 ft (~1445-1448 m).

CHAPTER 7

CONCLUSIONS

The studied section composes of 3400-5700 ft (~1,036 and 2,193 m) of the TEC DIW-1 well located in Polk County, Florida. According to the previous studies as well as the petrographic descriptions, three formations have been determined that represent the studied interval. These formations are Upper Cretaceous Pine Key Formation, Lawson Formation and Paleocene age Cedar Keys Formation. The conclusions below are generated from the detailed laboratory and petrographic studies that have been carried out on the rocks with respect to the studied interval.

1) My observations indicate that the Cedar Keys Formation ranges between 3,400 and 4,400 ft [~1,036-1,341 m]) indicating almost 1000 ft thickness in the study area. Almost 700 ft (~213 m) is from the Lawson Formation (4,400-5,100 ft [~1,341- 1,555 m]) and 600 ft (~183 m) is from the Pine Key Formation (5,100-5,700 ft [~1,555- 1,737 m]), The studied interval in this study comprises only the lower part of the Cedar Keys Formation and the upper part of the Pine Key Formation. The transitions through the formations were not distinct.

2) According to stereo microscope studies that have been carried out on the Upper Cretaceous Pine Key Formation, this rock unit is observed as white, tan and light gray to gray chalky limestone with few fragments of dolomite lenses and small amounts of pure white anhydrite. From the petrographic studies, the Lawson Formation includes two members. The Lower member is represented by white to tan limestone that recrystallized from time to time including small amounts of anhydrite and a thick dolomite layer at the base of the member. The Upper

member is represented by white, tan to gray, recrystallized and highly porous limestone interbedded sparsely with light to dark brown dolomite layers and includes small amounts of anhydrite layers and lenses. The Cedar Keys Formation is observed as tan to gray, highly porous, crystalline dolomite interbedded with thick anhydrite layers and minor amounts of limestone layers in the studied interval.

3) Depositional environments and diagenetic history of the Pine Key Formation couldn't be interpreted due to the lack of thin section samples representing this formation. Future studies are needed to describe and interpret environments of deposition and diagenetic features of the Pine Key Formation.

4) This study recognized and described six microfacies in the Lawson Formation. These are dolomitized foraminiferal wackestone, fossiliferous grainstone, fossiliferous wackestone, peloidal fossiliferous packstone/grainstone, and foraminiferal packstone/grainstone facies. On the basis of microfacies interpretation the Lawson Formation is interpreted to have been deposited in shelf lagoon, restricted shelf lagoon-tidal environments representing shallow subtidal to intertidal depositional environments. The Lawson Formation also includes shelf edge reef (patch reefs) depositional environment. In conclusion these microfacies represent mostly two facies belts of Wilson (1975), which are FZ7 and FZ8.

5) The presence of several diagenetic features indicate that the Lawson Formation has been subjected to various post-depositional alterations. The diagenetic sequence determined for the Lawson Formation include several stages on the basis of textural relationships, in the following

relative order of occurrence: micritization, precipitation of minor calcite fibrous cement and isopachous rim cement (early cementation), dolomitization, dissolution, late cementation, recrystallization. Therefore, marine phreatic, mixed marine and meteoric phreatic and meteoric phreatic diagenetic environments representing early to late diagenetic stages were proposed on the basis of petrographic studies.

6) The sediments of the Paleocene Cedar Keys Formation have been deposited in shallow subtidal, intertidal and supratidal facies belts. The petrographic study led to the distinction of four microfacies. These are evaporite facies, dolomitized peloidal packstone, dolomitized foraminiferal wackestone, and dolomitized foraminiferal wackestone/packstone facies. The Cedar Keys Formation was deposited by different depositional environments. These are shelf lagoon, restricted shelf lagoon and sabhka environments. The anhydrite observed in the evaporite facies is interpreted to reflect post burial alteration of the gypsum.

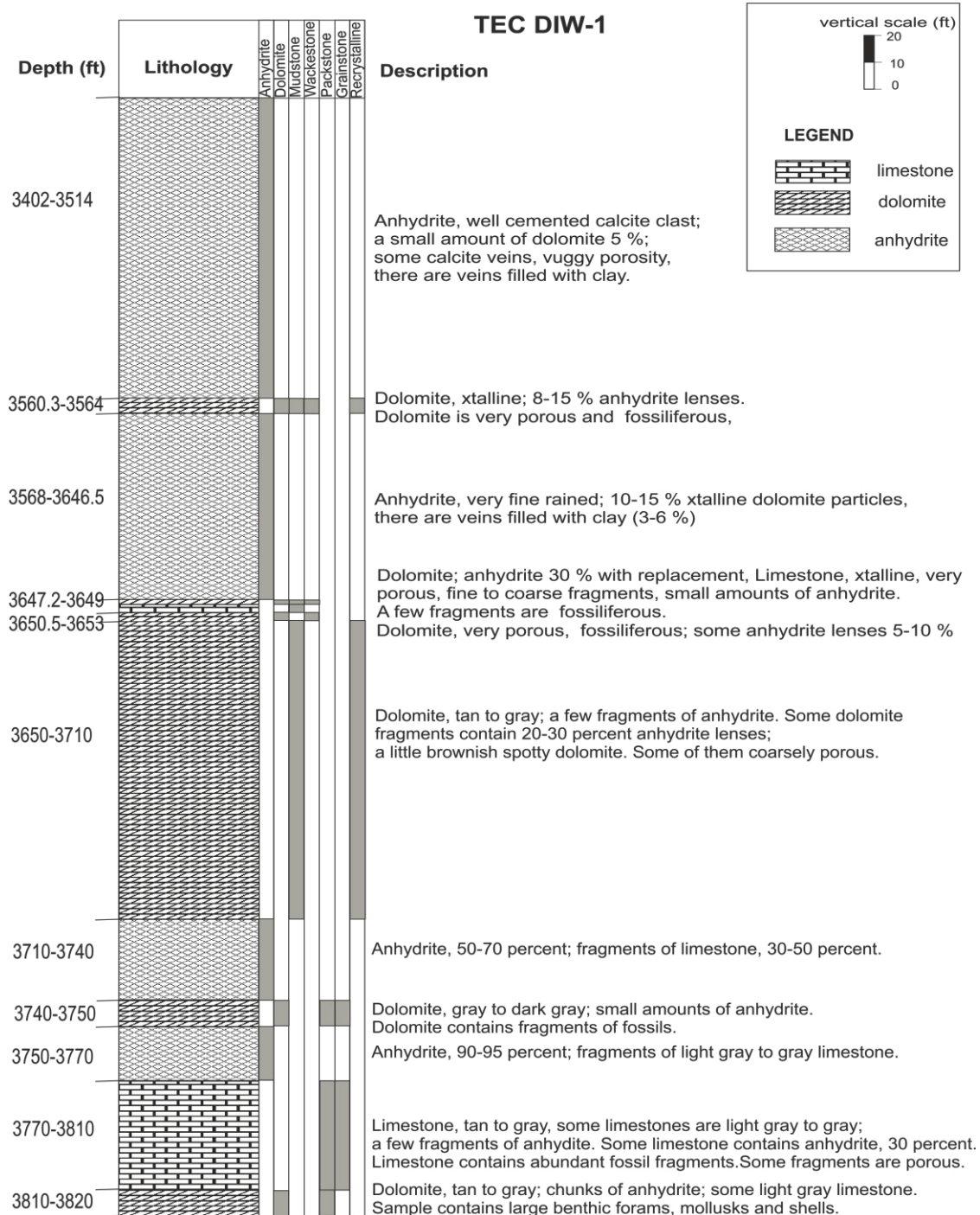
7) Several diagenetic processes affected on the Cedar Keys Formation that have both early and late phases. Due to the evaporite cement and uncertain sedimentary structures, fabric and texture, relative timing of diagenetic phases is difficult to establish in the Cedar Keys Formation. Therefore, the relative order of the diagenetic features affected the formation could be interpreted as follows: isopachous bladed calcite rim cement, controversial timing of evaporite cement and dolomitization, dissolution, and recrystallization. Thus, early to late diagenetic stages were observed in the Cedar Keys Formation reflecting the diagenetic environments of marine phreatic to meteoric phreatic.

8) Very fine to coarse crystalline dolomite including anhydrite nodules formed by replacement of limestones. This kind of dolomite is most probably not related with evaporites. Meteoric water-sea-water mixing process probably formed the dolomites of the Cedar Keys Formation.

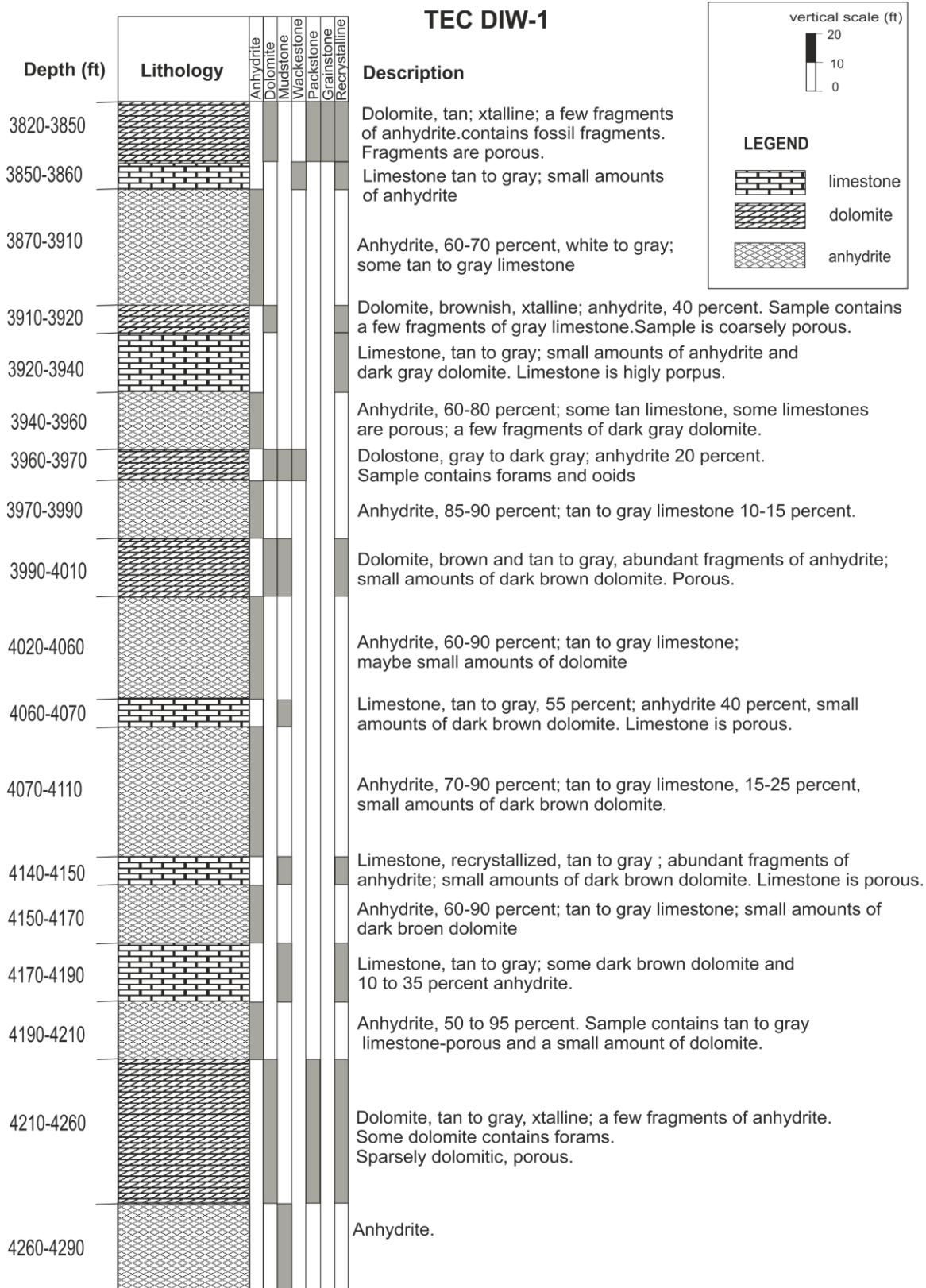
9) During the examination of petrographic thin sections and rock cuttings at the estimated transition depth of Cretaceous-Paleocene in the study area, I have not been able to determine any signatures of bolide impact or tsunami deposits as indicated in previous chapters. Future studies are needed to determine the transition from Upper Cretaceous to the Paleocene units as well as the definition of foraminifera at a species level.

APPENDIX A

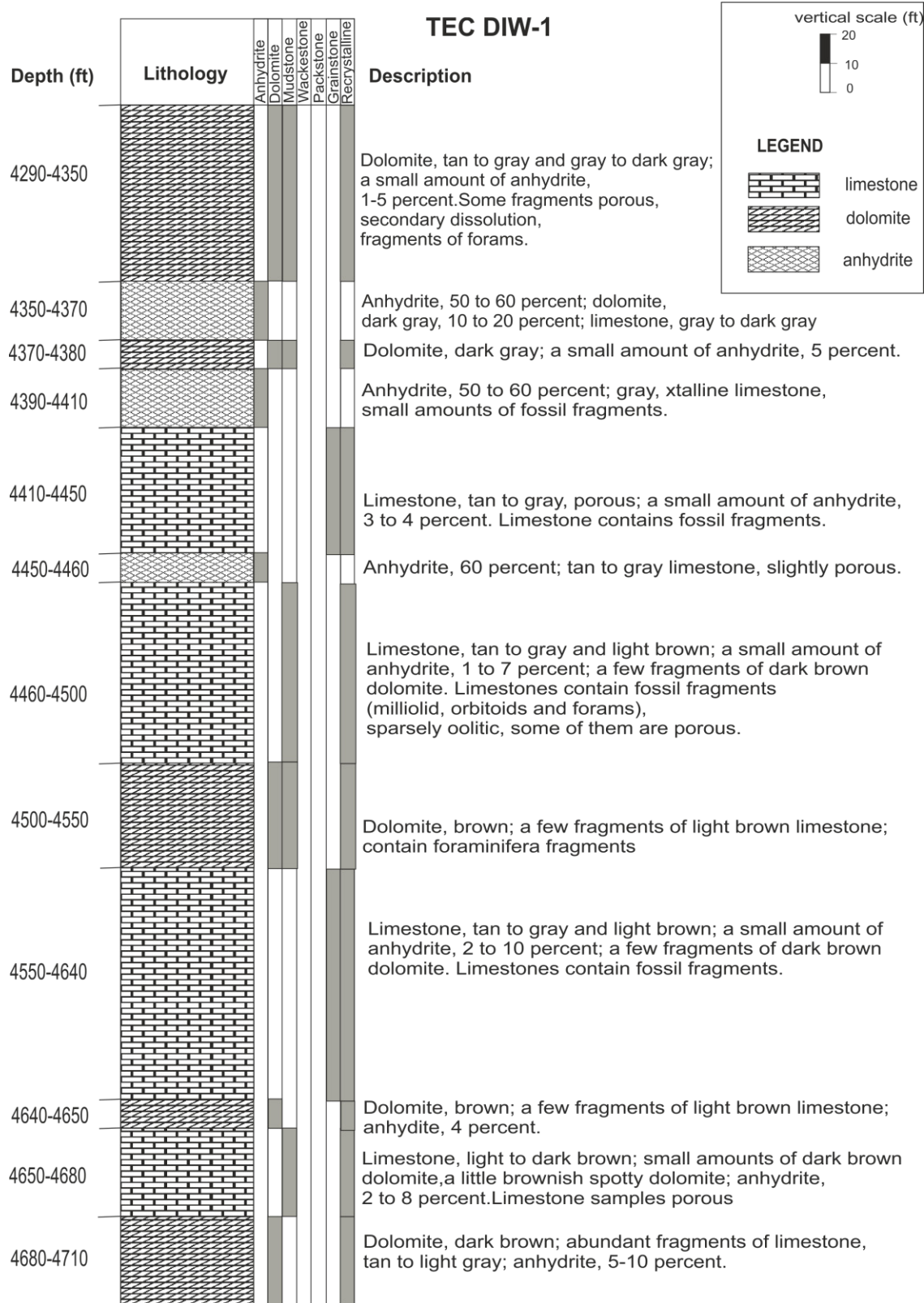
DETAILED LITHOSTRATIGRAPHY



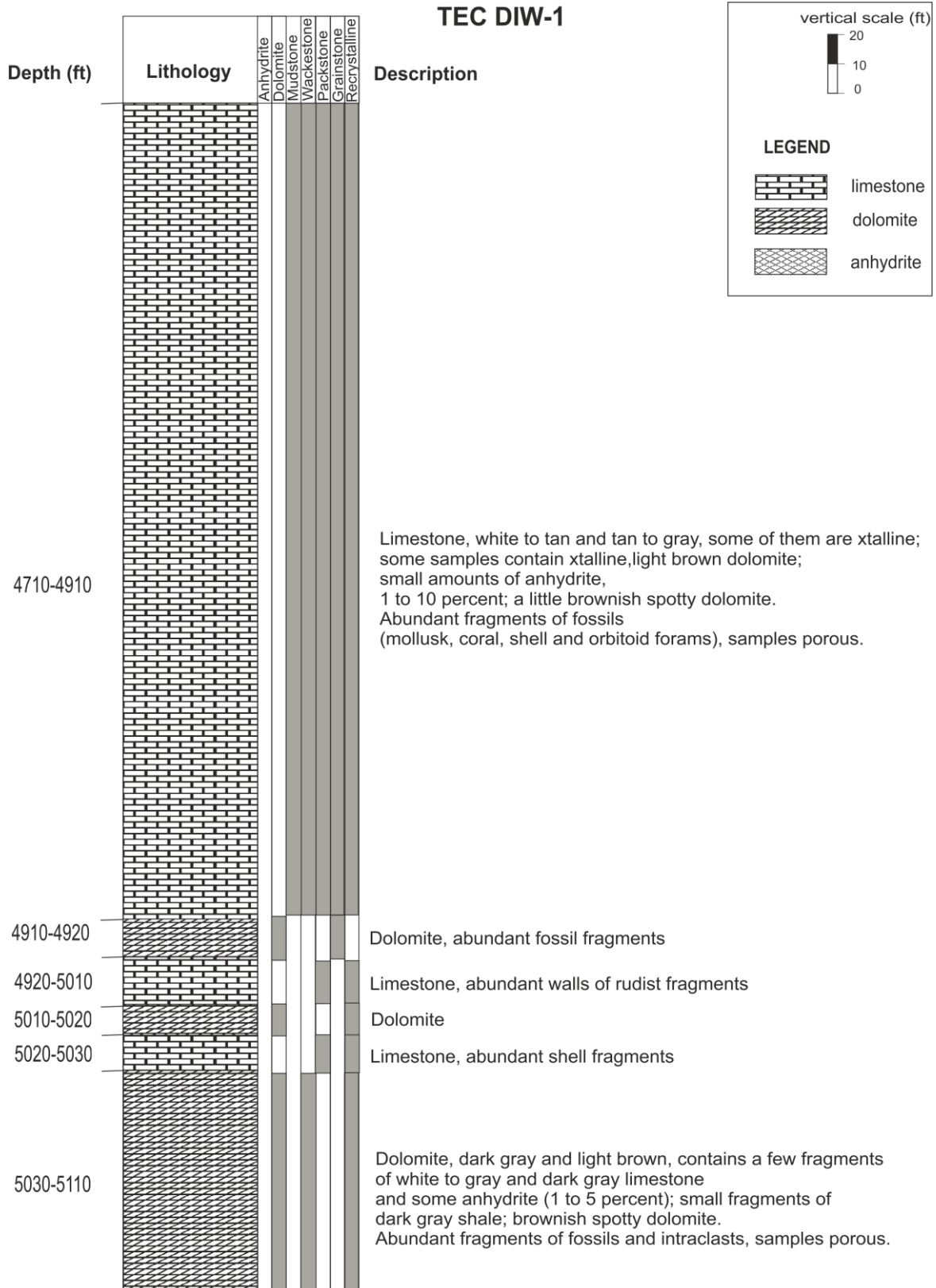
Detailed lithostratigraphic column of Upper Cretaceous-Paleocene section of TEC DIW-1 well discussed in this study [3402-3820 ft (~1037-1164 m)].



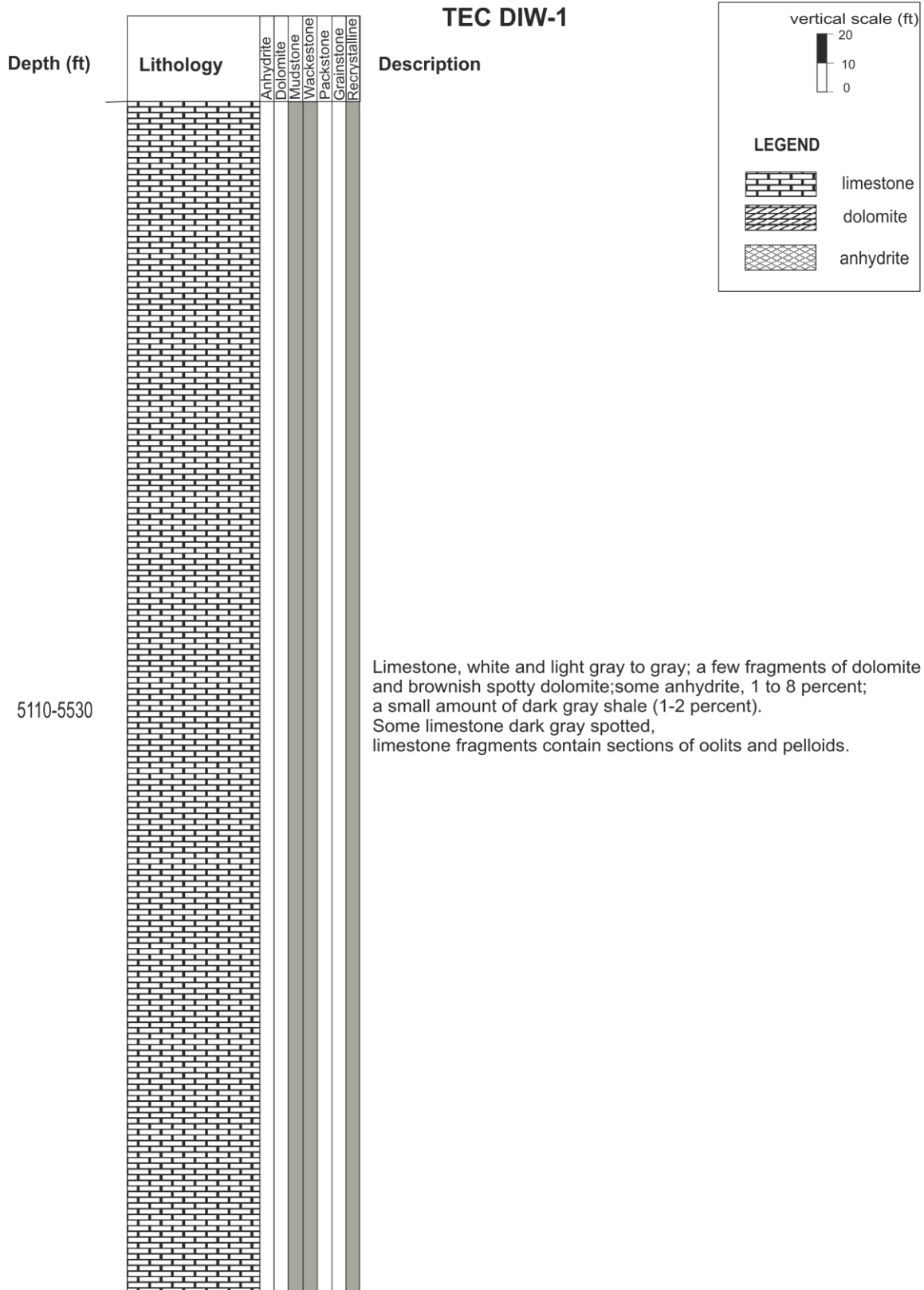
Detailed lithostratigraphic column of Upper Cretaceous-Paleocene section of TEC DIW-1 well discussed in this study [3820-4290 ft (~1164-1308 m)].



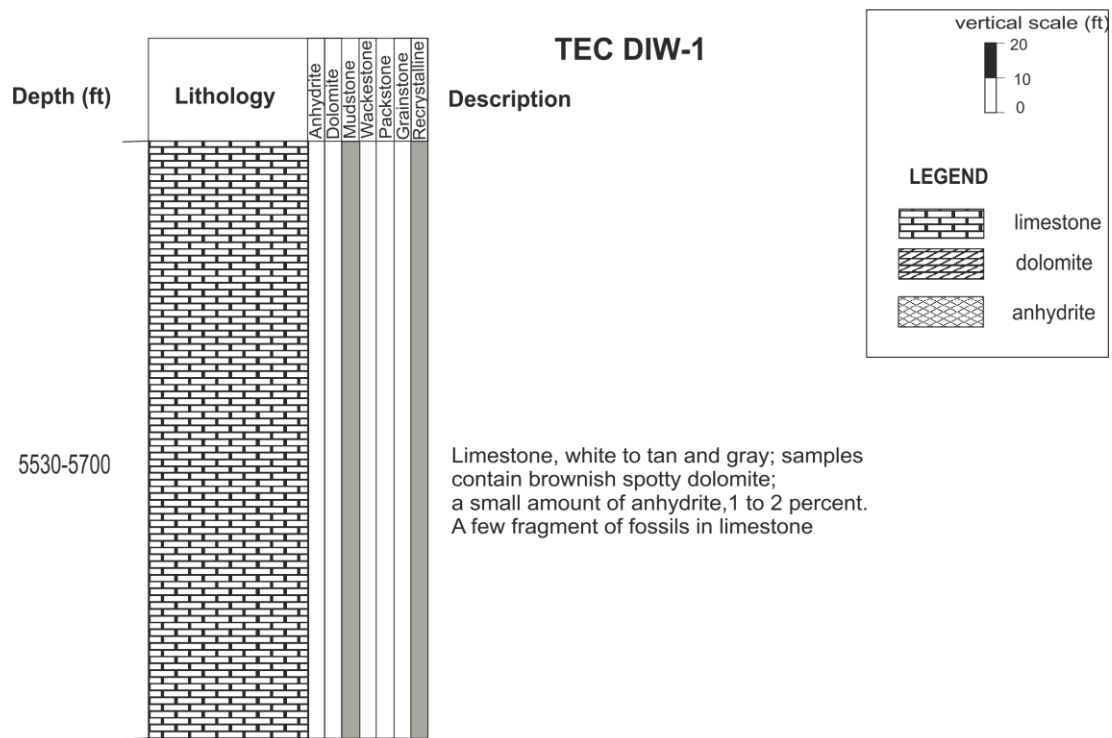
Detailed lithostratigraphic column of Upper Cretaceous-Paleocene section of TEC DIW-1 well discussed in this study [4290-4710 ft (~1308-1436 m)].



Detailed lithostratigraphic column of Upper Cretaceous-Paleocene section of TEC DIW-1 well discussed in this study [4710-5110 ft (~1436-1558 m)].



Detailed lithostratigraphic column of Upper Cretaceous-Paleocene section of TEC DIW-1 well discussed in this study [5110-5530 ft (~1558-1686 m)].

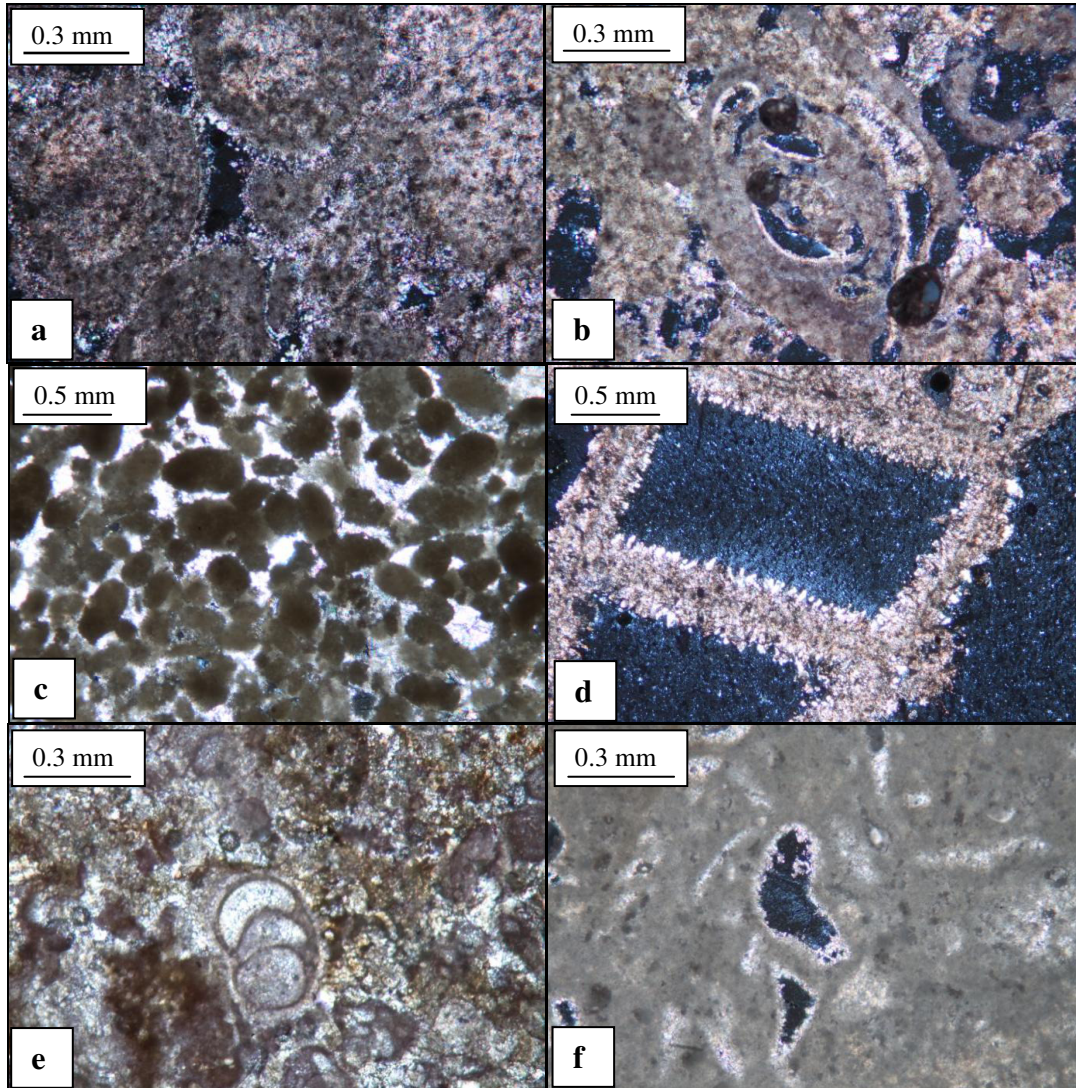


Detailed lithostratigraphic column of Upper Cretaceous-Paleocene section of TEC DIW-1 well discussed in this study [5530-5700 ft (~1686 -1737 m)].

APPENDIX B

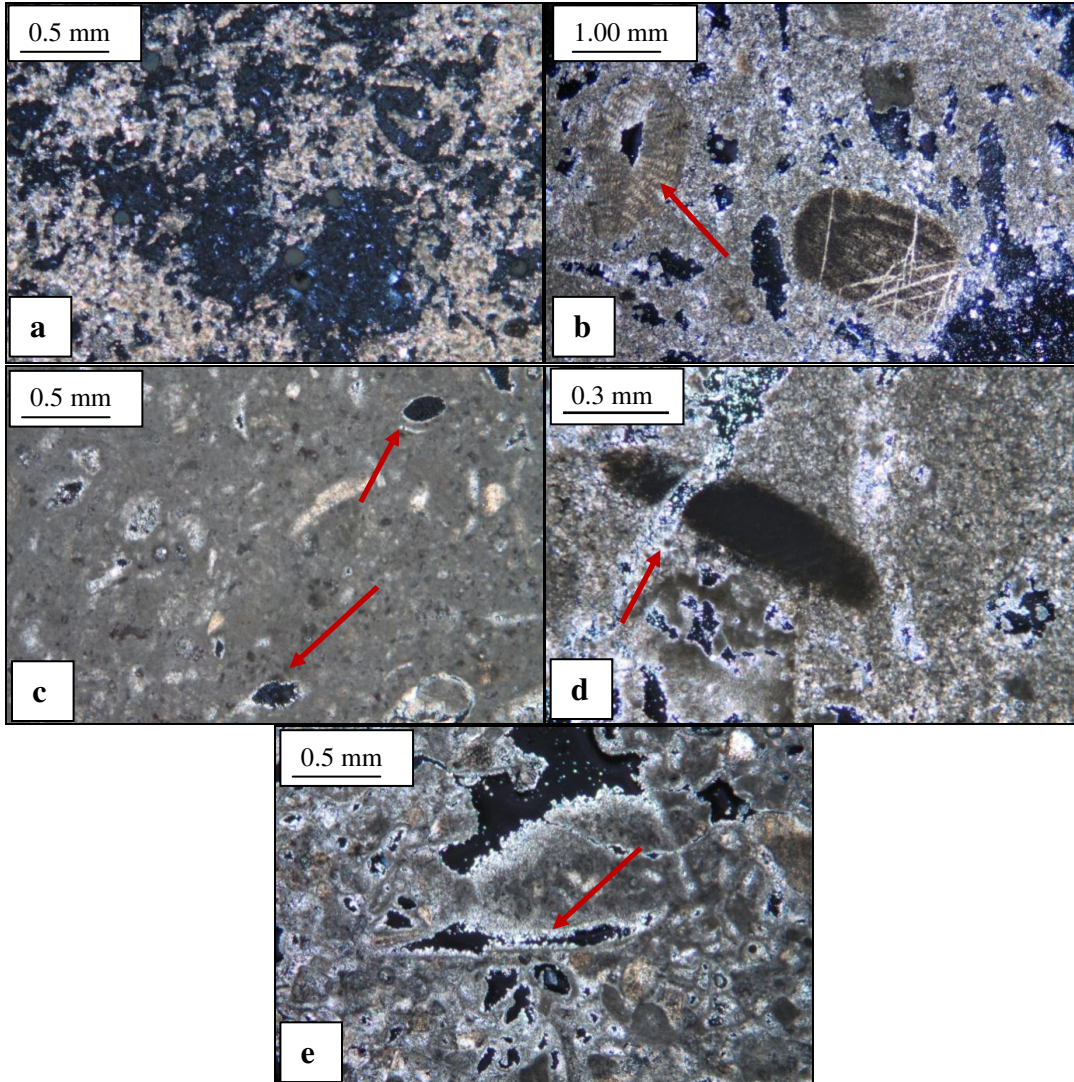
PLATES

Plate 1



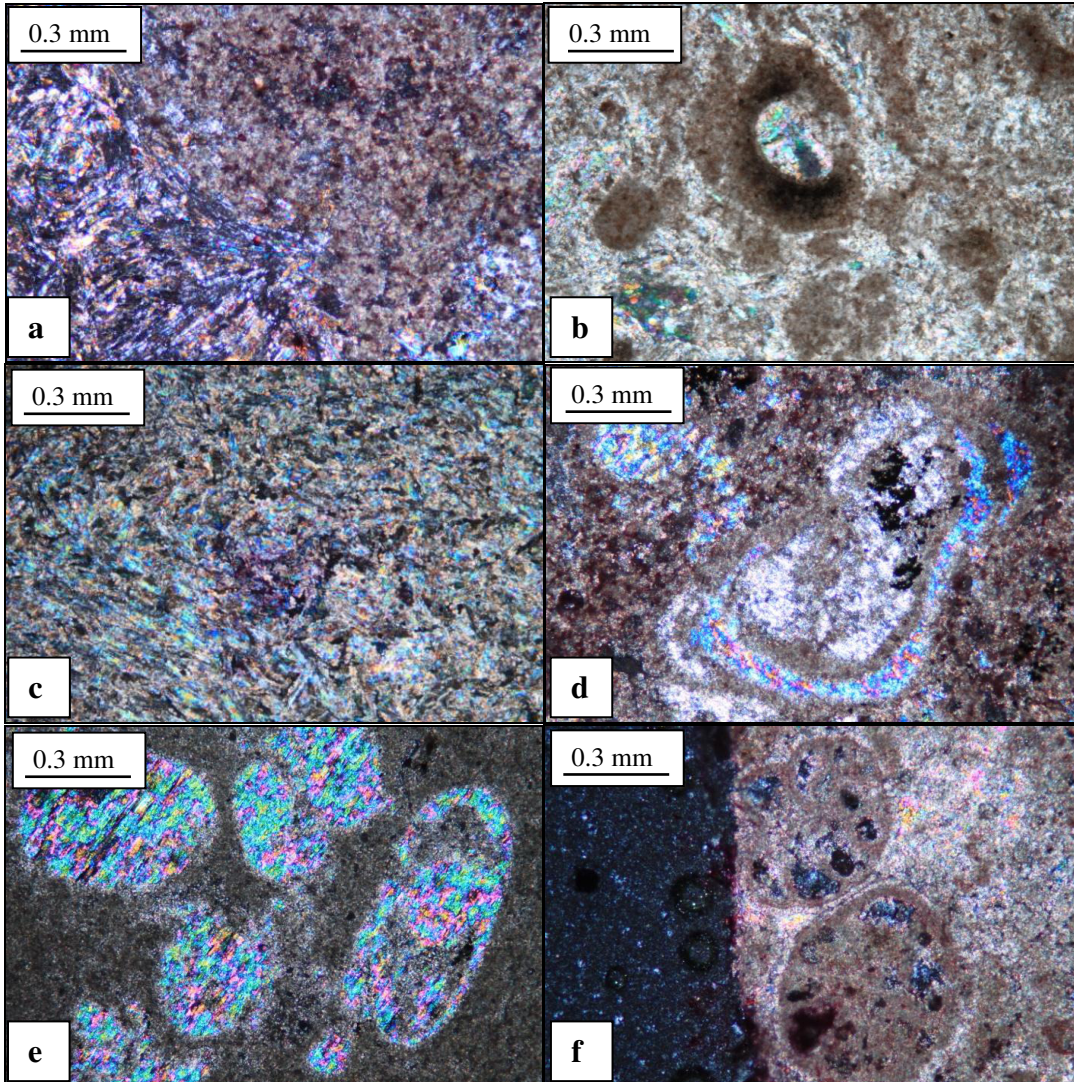
Photomicrographs (XPL) of different cement types of the Lawson Formation at several depths. Isopachous rim calcite cement at 4840-4850 ft (~1475-1478 m) (a). Fibrous marine calcite cement filling the primary porosity of a skeletal allochem at 4600-4610 ft (~1402-1405 m) (b). Pore filling granular calcite cement at 4610-4620 ft (~1405-1408 m) (c). Bladed calcite cement growing through the rudist walls at 4740-4750 ft (~1445-1448 m) (d). Drusy cement increasing in size toward the center at 4540-4550 ft (~1384-1387 m). Note that micritization surrounding the skeletal allochem (e). Secondary fabric selective porosity and bladed calcite cement filling the secondary porosity at 4770-4780 ft (~1454-1457 m) (f).

Plate 2



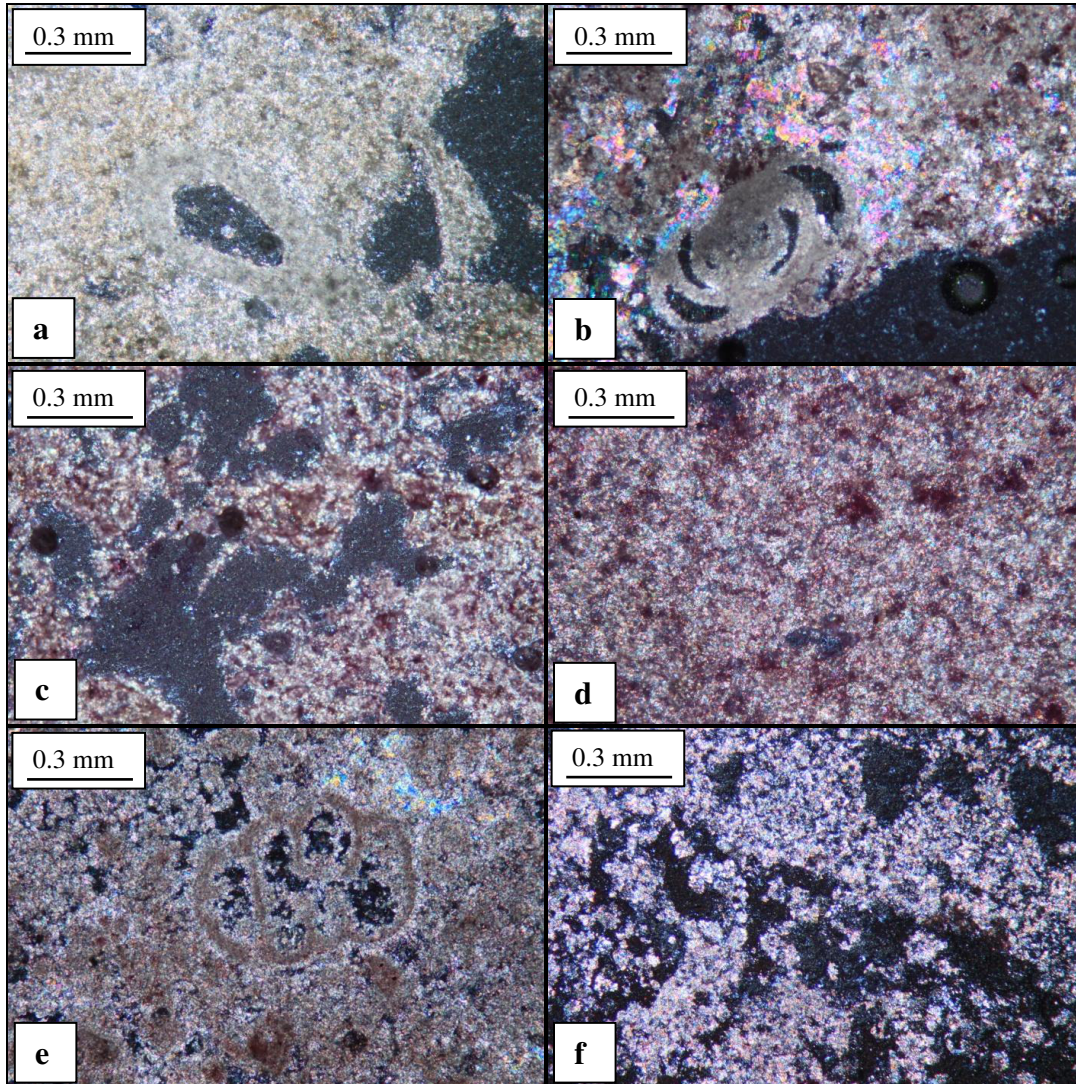
Photomicrographs (XPL) of different types of porosity observed in the Lawson Formation at several depths. Non-fabric selective vuggy porosity at 4500-4510 ft (~1372-1375 m) (a). Fabric selective intraparticle secondary porosity at 5060-5070 ft (~1542-1545 m) (b). Fabric selective moldic porosity at 4770-4780 ft (~1454-1457 m) (c). Fabric selective, secondary porosity at 5060-5070 ft (~1542-1545 m) (d). Note that infilling of moldic porosity with sparry calcite cement at a depth of 4910-4920 ft (~1497-1500 m) (e).

Plate 3



Photomicrographs (XPL) of diagenetic features of anhydrites and cement types observed in the Cedar Keys Formation. Note that anhydrite replacement at a depth of 3649.9 ft (~1112.5 m) (a). Pore filling anhydrite is determined at 3512.8 ft (~1070-70 m) (b). Anhydrite bedded interval at 3402 ft (~1037 m) (c). Note that the primary calcite cement precipitation before evaporitic cement precipitation at a depth of 3560.3 ft (~1085 m) (d). Replacement of the carbonate minerals/allocherts by evaporite minerals at 3562.9 ft (~1086 m) (e). Photomicrograph showing isophacous calcite cement appears as rim cement around skeletal grain at 3563 ft (~1086 m) (f).

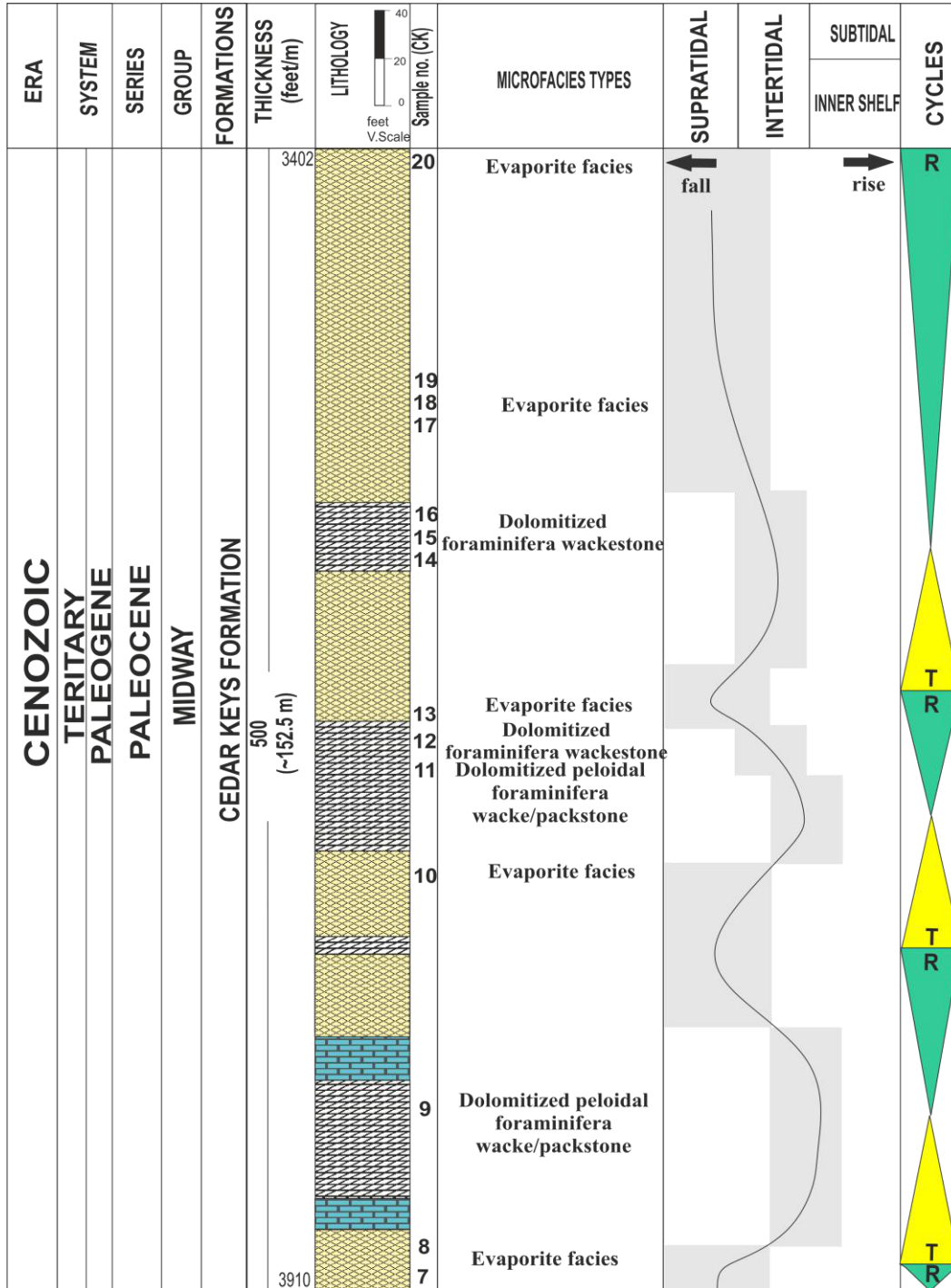
Plate 4



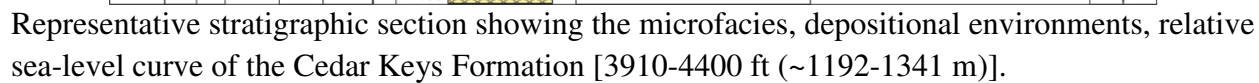
Photomicrographs (XPL) of diagenetic features observed in the Cedar Keys Formation. Fabric selective secondary moldic porosity at 3649 ft (~1112 m) (a). Fabric selective primary intraparticle porosity at 3650.3 ft (~1113 m) (b). Non fabric selective vuggy porosity at 3649 ft (~1112 m) (c). Dolomitization distinguished by stained calcite minerals at a depth of 3649.9 ft (~1113 m) (d). Micritic matrix is replaced by coarser crystals indicating aggrading neomorphism at a depth of 3563 ft (~1086 m) (e). Recrystallization resulted in coarser crystals indicating aggrading neomorphism at 3650 ft (~1113 m) (f).

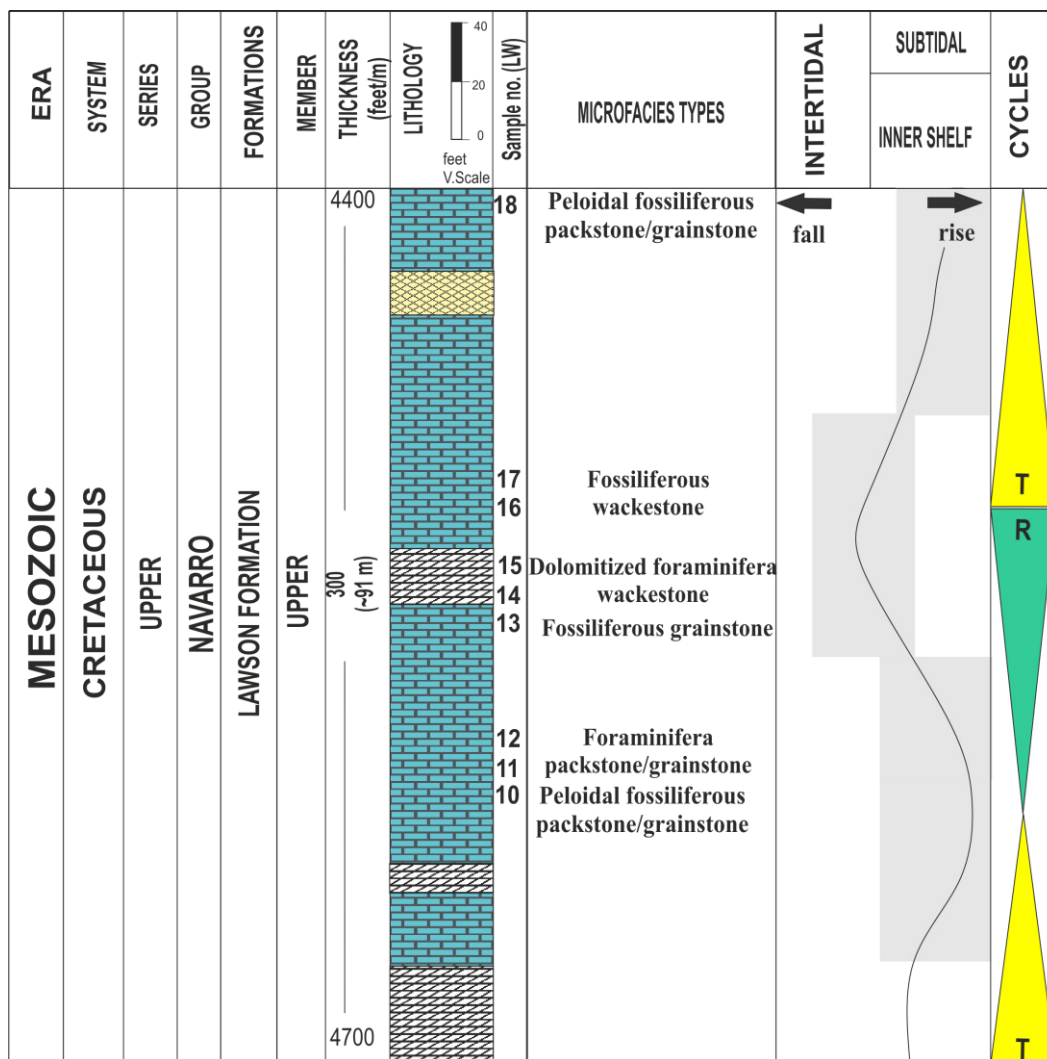
APPENDIX C

SEA-LEVEL CYCLES

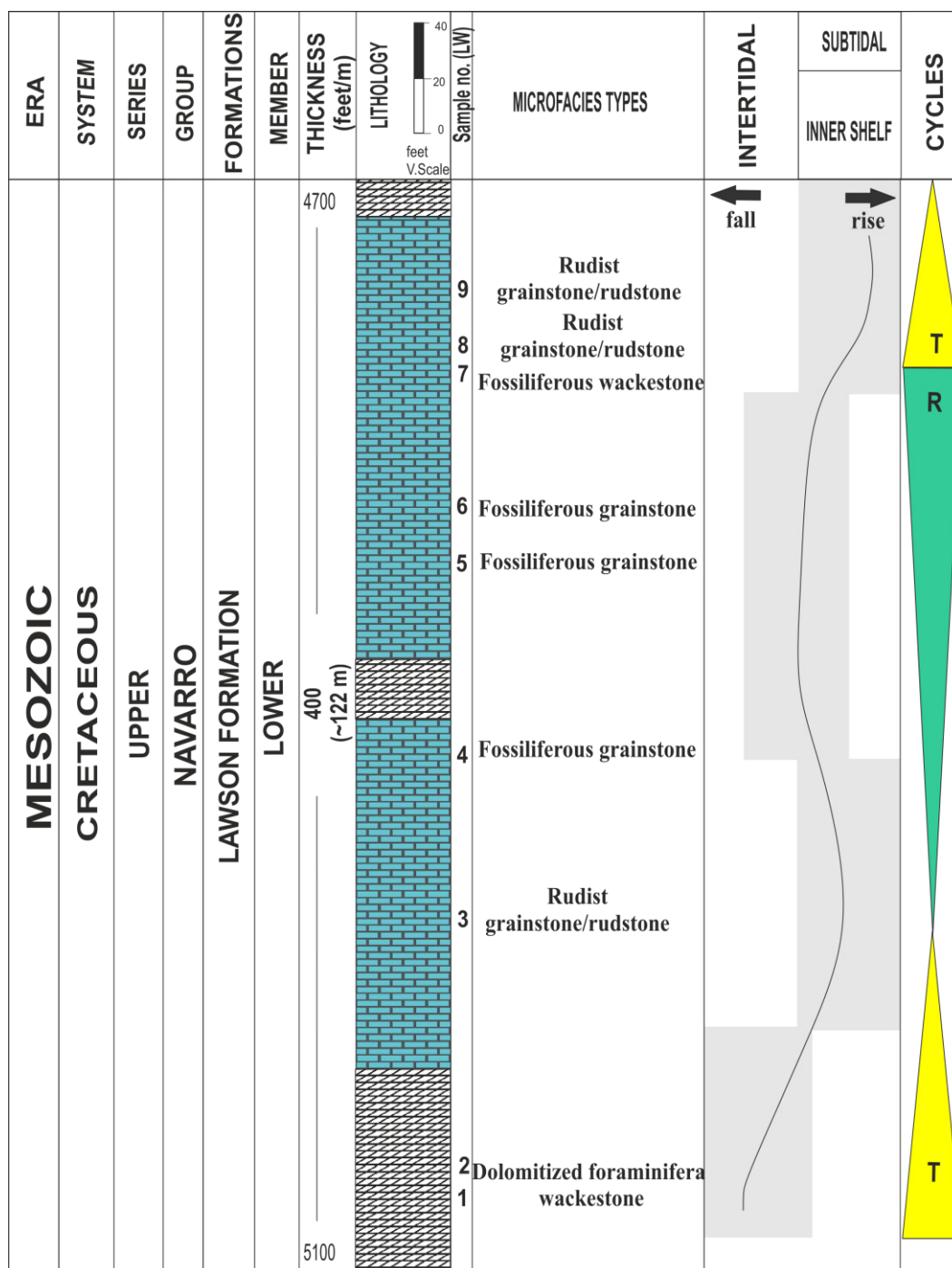


Representative stratigraphic section showing the microfacies, depositional environments, relative sea-level curve of the Lawson Formation [3402-3910 ft (~1037-1192 m)].





Representative stratigraphic section showing the microfacies, depositional environments, relative sea-level curve of the Lawson Formation [4400-4700 ft (~1341-1433 m)].



Representative stratigraphic section showing the microfacies, depositional environments, relative sea-level curve of the Lawson Formation [4700-5100 ft (~1433-1554 m)].

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BIOGRAPHICAL SKETCH

Ekin Ozakar

Ekin Ozakar was born in Eskisehir, Turkey on the 16th of May, 1986. She received her Bachelor of Science degree in Geological Engineering from Ankara University in the semester of Spring 2010. After graduation, she decided to concentrate on organic geochemistry and enrolled in a graduate program at the Ankara University. While she was studying on her research, she also started to work as a geologist in a drilling company. At the same time she achieved a full financial support sponsored by Turkish Petroleum Company for graduate education in the US. After getting her master of sciences degree in Turkey, she enrolled in a graduate program at Florida State University in the fall of 2013 where she studied sedimentology under the guidance of Dr. William Parker. She completed her Master's degree in the Summer 2015.