

The Case for High-Order, Pleistocene Sea-Level Fluctuations in Southwest Florida

by

Paul Octavius Knorr

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
Department of Geology
College of Arts and Sciences
University of South Florida

Major Professor: Peter Harries, Ph.D.
Gregory Herbert, Ph.D.
Eric Ochse, Ph.D.

Date of Approval:
July 26, 2006

Keywords: cyclothem, Bermont, stratigraphy, subaerial exposure, mollusk, subsidence

© Copyright 2006, Paul Octavius Knorr

For Jenn and Andrew, the two shining stars of my life.

Acknowledgements

I would like to thank my major professor, Dr. Peter Harries, for his guidance, support, and understanding over the last two years. His profound breadth and depth of paleontological, paleoecological, and stratigraphical knowledge as well as his dedication to quality research are inspiring.

Additionally, many thanks to Dr. Eric Oches and Dr. Gregory Herbert for sharing their insights and enthusiasm about all things geological. Thanks to Dr. Al Hine for sparking my interest in sequence stratigraphy in the first place.

A very special thanks goes to the 2005 REU team: Jennifer, Rachel, Leila, Troy, Katie, Bill, Patricia, Paul, and Sarah. Without their efforts, far more of my own sweat and blood would have been shed over the final year of my research. Their contributions are much appreciated and have been specifically referenced as appropriate.

Finally, I would like to recognize the National Science Foundation for funding the main project, namely the aforementioned REU, of which my own research has been a small part.

Table of Contents

List of Tables	iii
List of Figures	iv
Abstract	vi
Chapter One Introduction	1
The Nature of Sea-Level Change in Florida	1
Brief Overview of the Longan Lakes Study Locality	2
Depositional Framework	7
Subsidence Rates	9
Chapter Two The Pleistocene Bermont Formation at Longan Lakes	11
The Bermont “Formation”	11
Difficulty of Determining Age of Strata	17
The Age of the Bermont Formation	19
Chapter Three Materials and Methods	22
Chapter Four Results	24
Evidence of Subaerial Exposure in Packstone Beds	24
Water Depth During Deposition of Shell Beds	32
Bivalve and Gastropod Analysis	34
Chapter Five Models of Sea-Level Change	37
Sequence Stratigraphy	37
Cyclostratigraphy	38
Orbital Forcing by Obliquity	40
Fischer Plots and the Relationship between Time and Cycle Thickness	41
Correlation of the LL Bermont Strata with a Eustatic Curve	43
Impacts of Uplift and Subsidence	49
Modelling Early Pleistocene Sea-Levels with the Bermont Strata	51

Chapter Six Conclusions	54
References Cited	56
Appendices	70
Appendix A: Lithologic Data	71
Appendix B: Grain-size Data	78
Appendix C: Bivalve Data	82

List of Tables

Table 1. Weighted Average Minimum Bivalve Depth for Longan Lakes Shell Beds.	36
Table 2. Duration of Sea-Level Cycle Orders.	39
Table 3. Summary of Interval Characteristics within the Longan Lakes Sequence.	42
Table 4. Summary of Early Pleistocene Interval Characteristics.	47
Table 5. Summary of Grain Size Analysis.	78
Table 6. Sorting Coefficient by Bed.	79
Table 7. Weighted Average Bivalve Depth in Meters for Representative Beds from LL.	82
Table 8. Weighted Average Bivalve Depth per Cycle.	83

List of Figures

Figure 1. Overview of Florida geology.	3
Figure 2. Simplified stratigraphy of the Bermont ‘formation’ at Longan Lakes.	4
Figure 3. Recent sea-level.	5
Figure 4. + 13 m early Pleistocene high sea level (1.2 Ma).	6
Figure 5. Stratigraphic column of early Pleistocene Bermont formation at LL Quarry.	13
Figure 6. Longan Lakes Quarry strata.	14
Figure 7. Close-up of packstone bed 3a (above scale) overlying shell bed 3b.	14
Figure 8. Small-scale karstic collapse.	25
Figure 9. Bed 2a, Alizarin Red S staining (X20).	27
Figure 10. Bed 2a, Alizarin Red S staining (X30).	28
Figure 11. Bed 3a, Alizarin Red S staining (X100).	28
Figure 12. Bed 3a, etched surface (X30).	29
Figure 13. Bed 4a, Titan Yellow staining (X20).	29
Figure 14. Bed 5a, Alizarin Red S staining (X10).	30
Figure 15. Bed 6a, Titan Yellow staining (X30).	30
Figure 16. Bed 6a, etched (X70).	31
Figure 17. Cumulative grain sizes for lower portions of shell beds.	33
Figure 18. Fischer plot for Longan Lakes strata.	42
Figure 19. Bermont-age eustatic fluctuations correlated with Longan Lakes strata.	46

Figure 20. Spatial relations of the Bermont ‘formation’ at Longan Lakes.	52
Figure 21. + 6.3 m Pleistocene high sea level based on <i>Anodontia alba</i> (1.2 Ma).	53
Figure 22. Cumulative grain sizes.	80
Figure 23. Cumulative grain sizes.	81

The Case for High-Order, Pleistocene Sea-Level Fluctuations in Southwest Florida

Paul Octavius Knorr

ABSTRACT

Florida's Plio-Pleistocene strata record episodes of sea-level highstands. The age of the strata is often ambiguous as there are no consistently reliable dating techniques that can be unequivocally applied to many of the units. The lack of preservation of continuous Plio-Pleistocene sedimentary sequences is a consequence of Pleistocene mean sea-levels not flooding peninsular Florida, the low volume of sedimentary supply, and the lack of new accommodation space. This study investigates a 6 m cyclothem-type set of six shallow-marine shell beds separated by five subaerially exposed packstone beds. These strata are part of the biostratigraphically-defined early Pleistocene (1.1 – 1.6 Ma) Bermont formation and were likely deposited during a 160 kyr interval between 1.3 and 1.1 Ma.

The shell beds are mollusk-rich and contain moderately well-sorted fine sands. The packstones contain sparry calcite cements and show evidence of subaerial weathering, such as an irregular upper solution surface, root molds, and sparry freshwater calcite cements. The upper surfaces of the packstones are unconformities that separate five episodes of highstand deposition.

A grain-size analysis shows an upward-coarsening trend between depositional episodes, which most likely indicates a progressively decreasing water depth. The

bivalve assemblages suggest a mean paleodepth during the deposition of the shell beds of approximately 7.5 m; alternatively, in situ *Anodontia alba*, which colonized these units after deposition, point to a depth of 1 m. A subsidence rate of 6 m/Ma is inferred from the thickness of deposits near the locality.

Based on a comparison of the height of the strata with existing eustatic curves, the early Pleistocene age of the formation, and the 6 m/Ma subsidence rate, the most parsimonious duration for the interval between the cyclothems is 41 kyr, dominantly forced by obliquity orbital variability. Combining the data indicates that the early Pleistocene sea level was between 11.2 and 14.4 m above sea level (asl); previous estimates of early Pleistocene highstands have shown an elevation approximately 15 m asl. If the 1 m depth of *Anodontia alba* is used, the depth was likely 6.3 m asl.

Chapter One

Introduction

The Nature of Sea-Level Change in Florida

The links between changes in the Earth's orbital parameters, glaciation, and absolute sea level are well established (e.g., Hays et al., 1976; Zachos et al., 2001). The Florida Platform has a low-gradient slope (Hine et al., 2003) and low surface relief (Schmidt, 1997), so small fluctuations in sea level can expose or submerge large areas of the shelf in a geologically short amount of time. Marine deposits are preserved primarily during periods of peak transgression (Emery and Myers, 1996), therefore Florida's Plio-Pleistocene geologic column at any specific location is, as Charles Lyell proclaimed of the entire geologic record, an imperfect record. Florida stratigraphy records a series of discrete intervals rather than a temporally complete continuum.

Because current sea level is relatively high compared to much of the past 3 Ma (e.g., Hallam, 1992), for most of this interval sea level was necessarily below the current level; therefore, only a minority of earlier marine deposits have the potential of being preserved in locations that are today emergent. As a consequence of the Florida platform's tectonic stability (Smith and Lord, 1997), strata that were deposited during times of lower sea level relative to the Recent are located offshore or have been reworked, notwithstanding localized pockets of accommodation space (Scott, 1997), such as valley-fill sequences, or putative uplift due to karstification (Opdyke et al., 1984).

As a result of these limitations, Florida's strata can be used as a sea-level "dipstick" in which highstands are recorded in a series of episodic snapshots. Unfortunately, as will be demonstrated later in the study, it is hard to assign a numerical age to many of these deposits and, therefore, the temporal position of these deposits is difficult to constrain precisely.

Florida's stratigraphy, shown in Figure 1, dominantly reflects the highstand intervals of sea-level fluctuations. During the Miocene, thick, phosphate-rich strata collectively assigned to the Hawthorn Group were deposited during multiple intervals of high sea level (Scott, 1997). After a pronounced Late Miocene sea level fall, Pliocene sea levels rose and deposited a patchy veneer of fossiliferous strata, including the Tamiami and the Caloosahatchee formations, across the peninsula (Scott, 1997). At the same time the Isthmus of Panama closed completely, changing ocean current and salinity patterns in the Gulf of Mexico and affecting the extent of northern sea ice (Coates et al., 1992, 2004; Driscoll and Haug, 1998; Ruddiman, 2001).

Brief Overview of the Longan Lakes Study Locality

This study will focus on a cyclothem-type (*sensu* Wilson, 1975) set of shallow-marine shell beds and subaerially-exposed packstone beds that are part of the informally named Pleistocene Bermont formation (Lyons, 1991). The strata, located at the Longan Lakes Quarry (LL) near Immokalee, Florida, are shown in Figure 2. A detailed description will be provided later in this study. Relative to strata being deposited in areas of high tectonic subsidence (e.g. New Zealand), the LL strata are comparatively thin; the height of the column totals less than 6 m and represents an interval that might be as long

as 600 kyr, based on a synthesis study by Lyons (1991). In all, six shell beds separated by five subaerially-exposed packstone beds were documented at the LL locality. By comparison, New Zealand's Wanganui basin hosts a 1-km-thick, continuous Plio-Pleistocene sequence composed of 20 individual progradational cycles that were deposited in ≈ 1 Ma (Naish and Kamp, 1997).

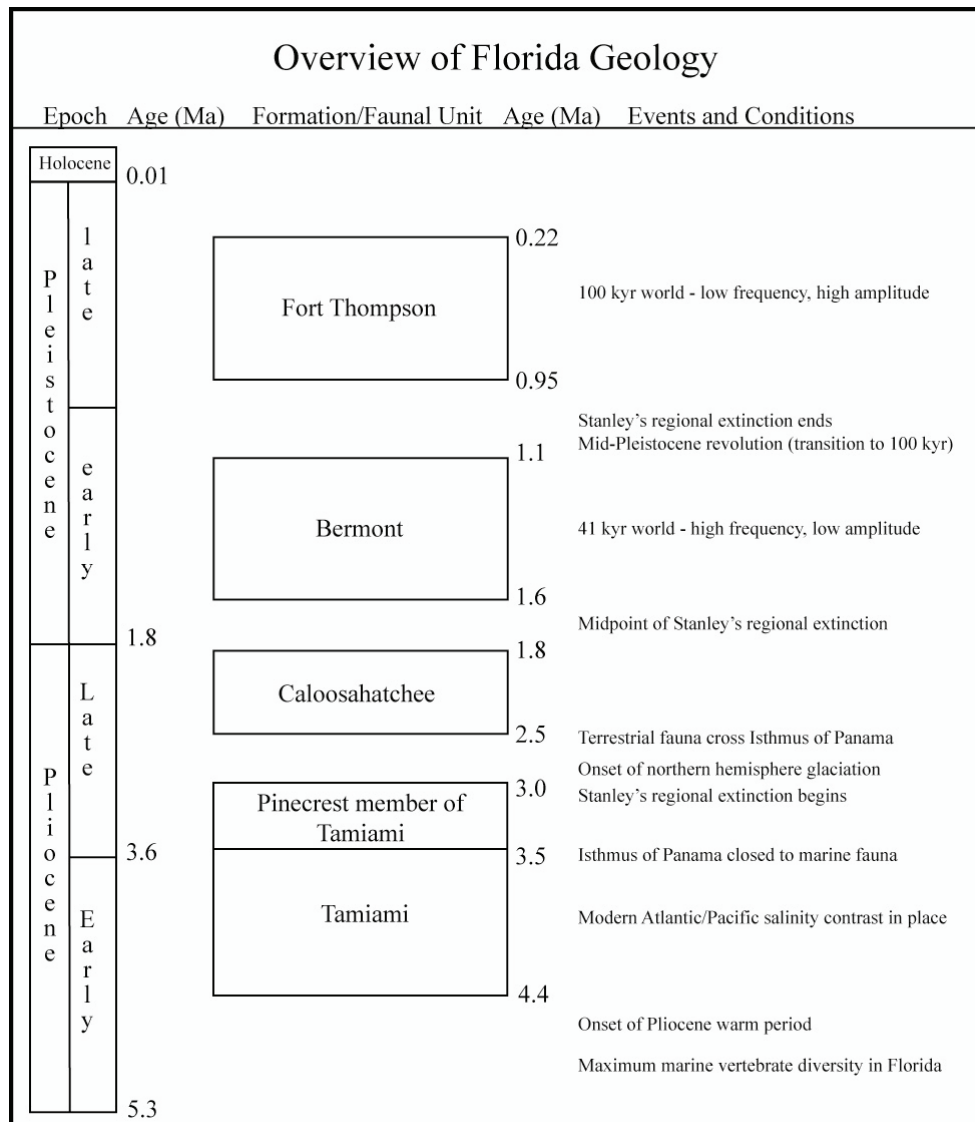


Figure 1. Overview of Florida geology. Figure synthesized from Stanley (1986), Lyons (1991), Allmon et al. (1996), Haug et al. (1998), and Herbert (2004).

The Bermont formation, shown in Figure 2, was probably deposited in the early Pleistocene between 1.6 Ma and 1.1 Ma (Lyons, 1991) during a period of relative glacial quiescence that lasted from 1.5 Ma through 1.0 Ma (Richmond and Fullerton, 1986). The frequency of sea-level fluctuations changed between 1.2 Ma and 0.65 Ma, transitioning from low-amplitude 41 kyr cycles to high-amplitude 100 kyr cycles (Diekmann and Kuhn, 2002). The subsequent late Pleistocene high-amplitude, sea-level fluctuations are characterized by a slow accumulation of ice followed by rapid deglaciations resulting in asymmetric sea-level fluctuations; the late Pleistocene Fort Thompson formation is a product of this paleoclimatic control.

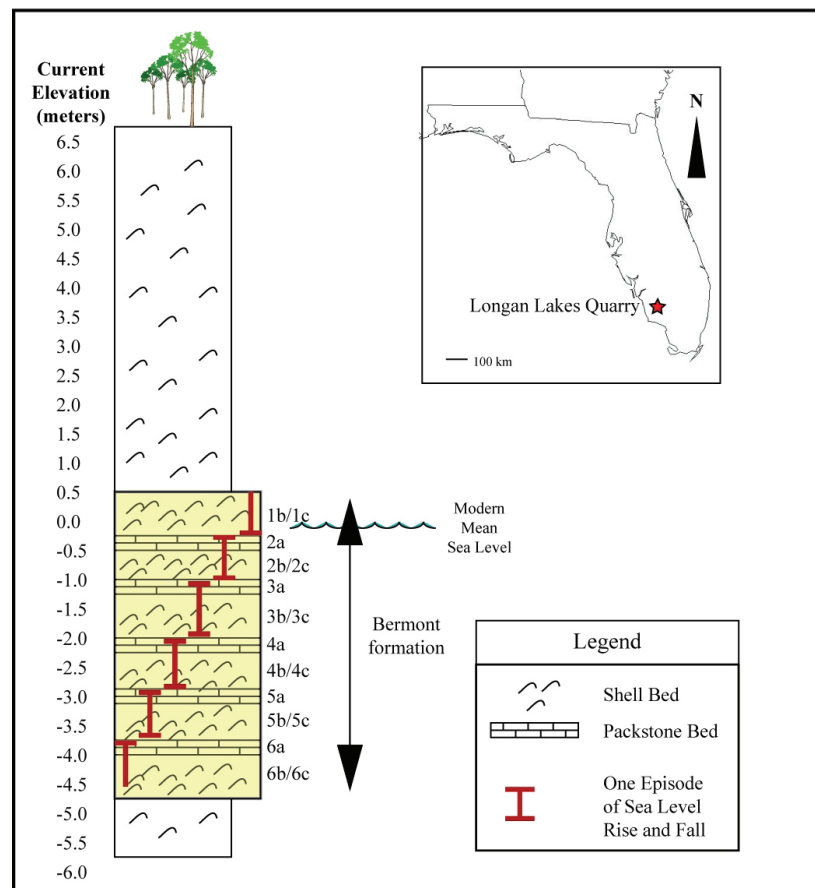


Figure 2. Simplified stratigraphy of the Bermont 'formation' at Longan Lakes.

To help visualize the extent of Pleistocene sea-level highstands, two sea-level reconstructions are presented: 1) a representation of modern sea level (Fig. 3); and 2) a reconstruction of a +13 m sea level stand that is inferred for the LL Bermont strata, which are the subject of this study (Fig. 4). Because modern elevations were used to create the maps, Figure 4 is representative only of the area that was submerged; the specific coastal morphology is likely to have been different.

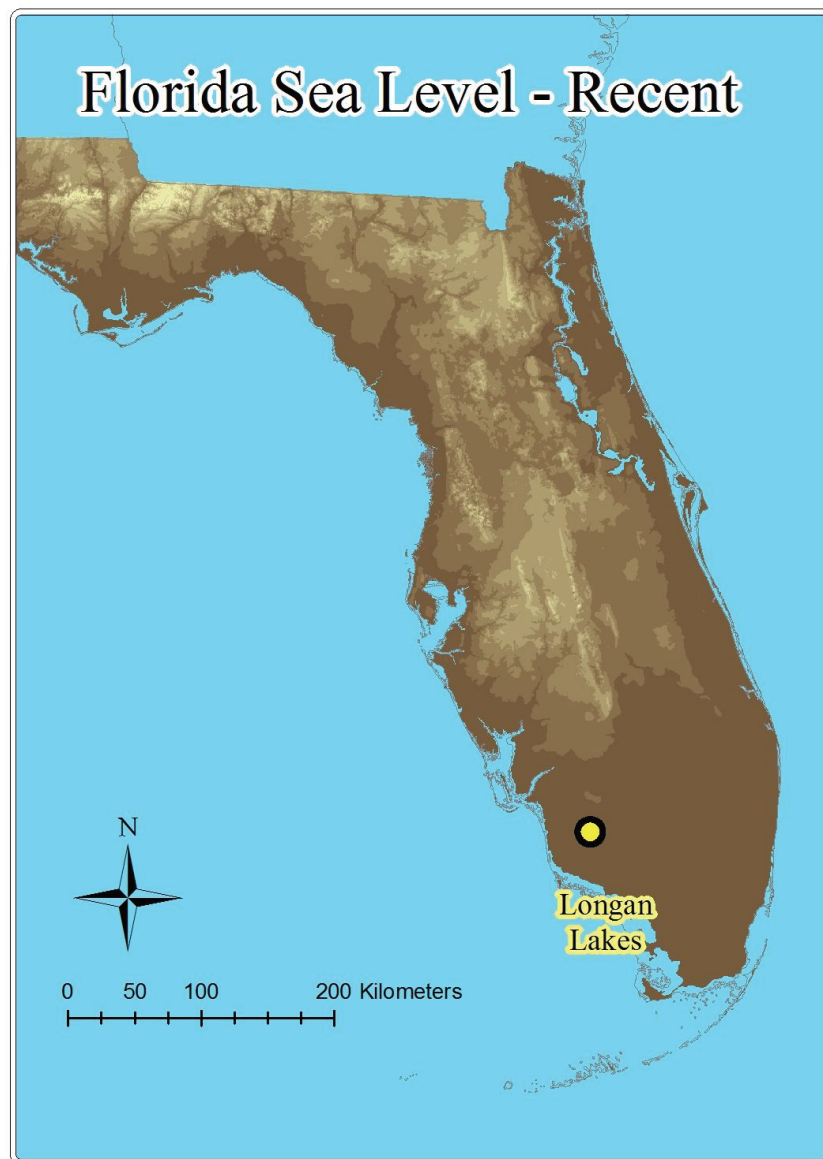


Figure 3. Recent sea-level.

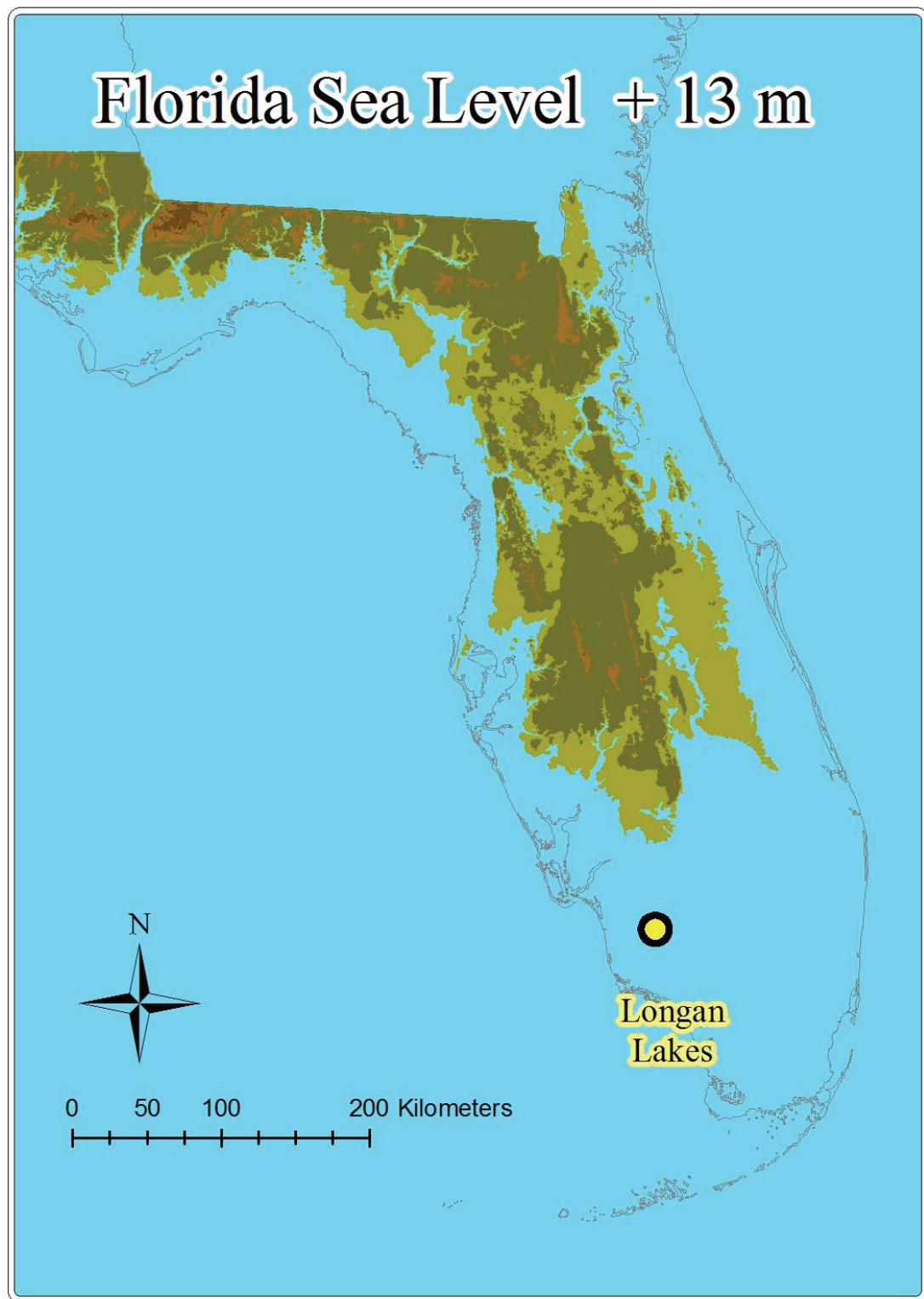


Figure 4. + 13 m early Pleistocene high sea level (1.2 Ma).

Depositional Framework

Peninsular Florida, located on the Florida Platform, hosts some of the world's most expansive and taxonomically diverse shell beds. The Fort Thompson, Bermont, and Caloosahatchee formations, shown in Figure 1, occupy three important Plio-Pleistocene portions of Florida's stratigraphic column (Scott, 1992). However, because of the limited volume of accommodation space, the Fort Thompson, Bermont, and Caloosahatchee formations are not generally exposed within a single stratigraphic section. The volume of accommodation space is restricted by the low subsidence rate of the Florida Platform (Mullins and Neumann, 1979) as well as the low-gradient slope (1:2,000 to 1:5,000) of the underlying carbonate ramp (Hine et al., 2003). A high rate of subsidence coupled with high sediment supply is conducive to preservation, as evidenced by Naish and Kamp's (1997) study of New Zealand's Wanganui basin; the low subsidence rate of the Florida platform (Mullins and Neumann, 1979), coupled with low siliciclastic input, is conversely a major reason for the lack of preservation of continuous Pliocene and Pleistocene sedimentary sequences.

Another reason that portions of Florida's Plio-Pleistocene column are dominated by non-deposition is due to the elevation of peninsular Florida relative to paleo-sea levels. The currently emergent portions of the Florida platform were generally not submerged during the Plio-Pleistocene's non-highstand intervals.

It should be noted that pockets of accommodation space have been created intermittently by fluvial erosion and karstification during sea-level lowstands (Allmon, 1992; Scott, 1997; Ferguson and Davis, 2003). Also, thicker sedimentary sequences

appear along the platform's southern margin where carbonate environments dominate (Perkins, 1977).

As a result of the limited accommodation space, Pleistocene deposits of southern Florida are characterized by thin and discontinuous deposits (DuBar, 1974; Missimer, 1992; Zullo and Harris, 1992) that represent the stranded remnants of highstand sequences (Harris and Zullo, 1993; Hine et al., 2001). An additional consequence of the limited accommodation space is that portions of older deposits were eroded and reworked during sea-level lowstands. Some of these sediments were then incorporated into later deposits (Davis, 1994b; Hine et al., 2003). Eroded and reworked Miocene and Pliocene sediments provide the siliciclastic material for Pleistocene deposits (Scott, 1997).

Deposition is also impacted by the degree of relief along the pre-depositional surface. High-relief (relative to surrounding geomorphology) paleokarst topography and the incision of paleodrainages can provide increased accommodation space in the form of voids and provide areas that favor sedimentary accumulation (Allmon, 1992). As a result, the thickness of a formation may vary by orders of magnitude over small distances, as thicker deposits accumulate in valleys and thinner deposits cap the surrounding highlands (Scott, 1997; Duncan et al., 2003; Ferguson and Davis, 2003); the contribution of any given formation to a particular outcrop is often ambiguous and uncertain, over distances that range from over 100 km (Lyons, 1992) to tens of meters (Allmon, 1992).

To further complicate matters, there is a lack of consensus over the ages of the Fort Thompson, Bermont, and Caloosahatchee formations, caused in large part by the lack of suitable numerical dating methods for the early Pleistocene (Lyons, 1991; Scott,

1992). This combination of laterally discontinuous deposition and chronologic uncertainty hampers the interpretation of Pleistocene sea-level behavior in Florida.

On a local scale, it can be difficult to pinpoint the processes that lead to the formation of shell beds (Allmon, 1992). For example, changes in sedimentation rates and dissolution processes can both impact a depositional cycle's lithological end-product (Kidwell, 1986; Allmon, 1992). A study by Roof et al. (1991) of Plio-Pleistocene sediments recovered from the northwestern portion of the West Florida carbonate platform indicated that pattern of regional sedimentary depositional cycles passed through three stages: from 5.4 to 2.8 Ma the sedimentation was aperiodic, from 2.8 Ma to 0.8 Ma it was dominated by 30- to 60-kyr cycles that were a consequence of 41 kyr orbital periodicity, and from 0.8 Ma to the present sedimentation has been dominated by 100-kyr cyclicity. That study also found it likely that the provenance of the sediments was the Mississippi River delta, and that the greater portion of sand-sized and larger material was diverted or deposited before the Loop Current could carry it to the West Florida carbonate platform (Roof et al., 1991). A Miocene influx of sediment to peninsular Florida from the Appalachian Mountains (Scott, 1997) is postulated as an additional source of siliciclastic material.

Subsidence Rates

Specific rates of subsidence are difficult to quantify in absolute terms, especially on passive margins. However, the relative rate of subsidence or uplift compared to eustatic change is more important to sedimentary deposition or erosion than the absolute rate. Mullins and Neuman (1979) used drill-hole data to calculate a rate of 18 m/Ma for

the Oligocene-Holocene in the South Florida-Bahamas region. The area for which the rate was calculated includes the Miami Terrace, a part of the East Florida Slope (Hine, 1997) and, therefore, a part of the Florida Platform. A similar rate, 19 m/Myr, based on well data ranging to the mid-Miocene is given for the central west Florida carbonate platform (Mullins et al., 1988).

However, existing cross-sections of the south Florida platform demonstrate that subsidence, if present, is most likely differential, with greater values (i.e., 18 m/Myr) to the east and lesser values (calculated below) to the west (Warzeski et al., 1996; Cunningham et al., 2001). To quantify subsidence, the height of two cross-sections showing the thickness of the Miocene Peace River Formation were measured. The two points used, W-16523 (Warzeski et al., 1996) and W-17534 (Cunningham et al., 2001), are well points (rather than interpolated portions) and are 29 km and 31 km, respectively, from the LL locality. In order to apply the most conservative approach, which yields the lowest subsidence rates, the earliest and latest dates (Compton, 1997) for the Peace River Formation, from the early Middle Miocene (16.4 Ma) to Early Pliocene (3.6 Ma), are used as the duration of the formation. The two measured sections were approximately 60 m (Warzeski et al., 1996) and 90 m (Cunningham et al., 2001) thick. Thus, the two subsidence rates are 5 m/Myr, and 7 m/Myr, respectively.

The mean of these two values, 6 m/Myr, will be used as the subsidence rate for the LL site. This subsidence rate provides reasonable values when compared to existing cross-sections and estimates of sediment thickness in south Florida (Warzeski et al., 1996; Scott, 1997; Cunningham et al., 1998; 2001; 2005).

Chapter Two

The Pleistocene Bermont Formation at Longan Lakes

The Bermont “Formation”

Lyons (1991) published a comprehensive summary of the various chronostratigraphic approaches that have been applied to Florida’s Plio-Pleistocene faunal assemblages. The beds that contain these faunal assemblages, incorrectly and informally defined as formations using biostratigraphy, represent a significant portion of the near-surface strata of the south Florida peninsula (Scott, 1997).

In accordance with accepted stratigraphic guidelines (NACSN, 2005), Scott (1992) placed these assorted faunal assemblages and their associated strata into the informally named Okeechobee formation, defined solely on the basis of lithostratigraphy. The Okeechobee formation incorporates the Fort Thompson, Bermont, and Caloosahatchee formations as “faunas.” However, to conform with current usage among the majority of researchers of Florida’s Neogene, the units will be referred to as formations, albeit informally named and defined on the basis of biostratigraphy. A more appropriate classification would be assemblage biozone or allostratigraphic units (NACSN, 2005), but formal biostratigraphic definition of these three formations is beyond the scope of this study.

The active LL quarry is located approximately 30 km east of the Gulf of Mexico at 26.21.22N, 81.33.53W, North American Datum 1927 (see Fig. 2). The elevation at the

surface of the quarry is ≈ 6.4 m above mean sea level (msl). The stratigraphic section that is described in this study is located at an elevation between ≈ 4.4 m below msl and ≈ 0.6 m above msl.

The strata exposed at LL consist of six lithologically and depositionally similar meter-scale unconsolidated shell beds; five of the shell beds are capped by packstone beds formed by diagenetic alteration during subaerial exposure prior to burial by the next shell bed. A stratigraphic column depicting this relationship is provided in Figure 5. A photograph of the entire section is provided as Figure 6, and a close-up photograph showing a contact between a shell bed and a packstone bed is provided as Figure 7. Additionally, a description of each bed is provided in Appendix A. As will be demonstrated later, the LL beds contain fossil material from the early Pleistocene Bermont fauna.

The shell beds consist of meter-scale sequences of unconsolidated bivalve and gastropod fragments within a moderately well-sorted fine sand matrix. Based on the molluscan taxa found in the shell beds, the beds appear to have been deposited in a nearshore marine environment.

The packstones (Dunham, 1962; Embry and Klovan, 1972) contain both sparry calcite cements and secondary micrite. The packstones show evidence of subaerial weathering, specifically an irregular upper solution surface, root molds, solution cavities, and sparite cements. There are no signs of soil development beyond the root molds and that material was likely stripped off during the subsequent transgression. The upper surfaces of these packstones form the unconformities that bound distinct episodes of

Stratigraphic Column, Longan Lakes Quarry, Collier County, Florida

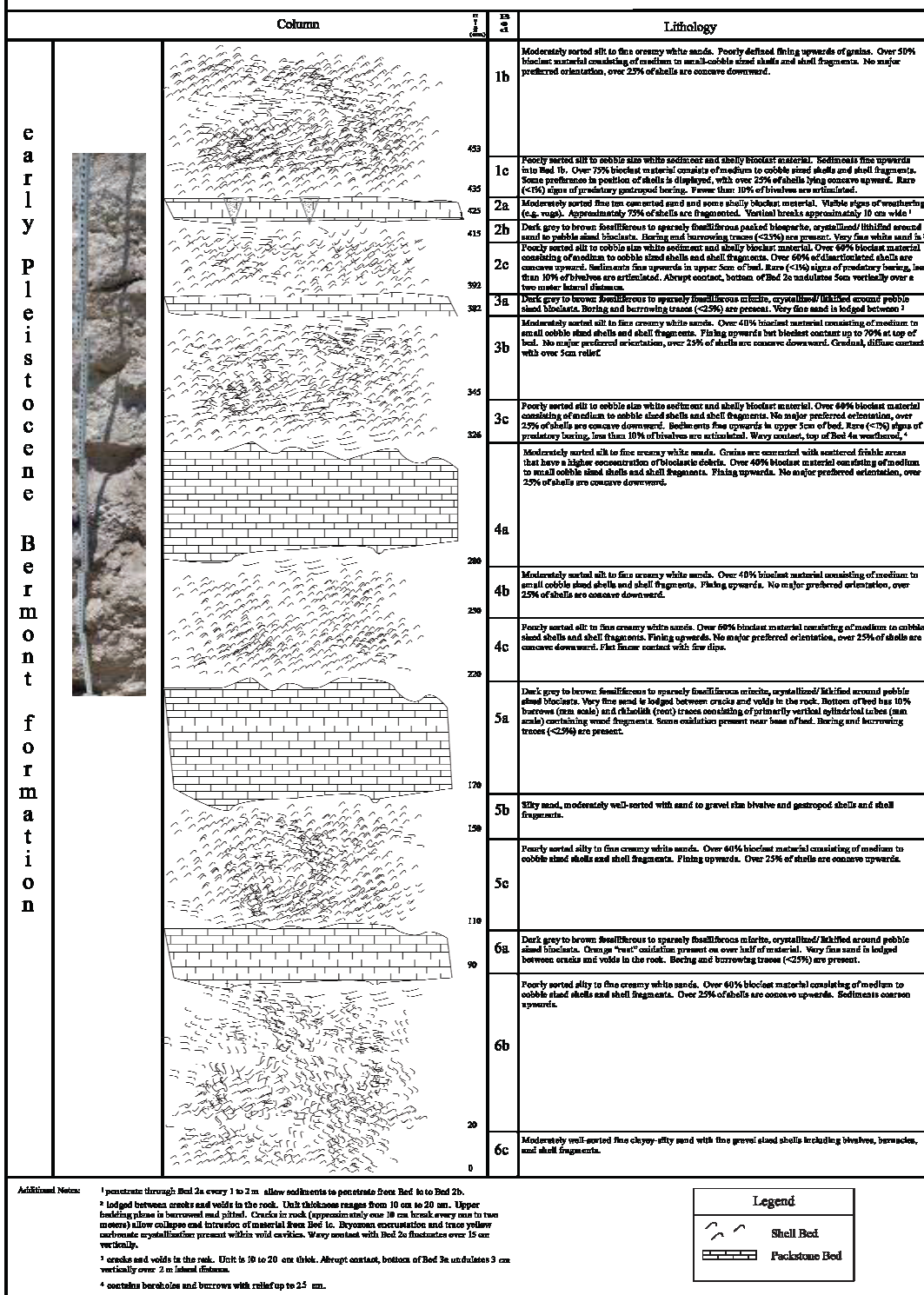


Figure 5. Stratigraphic column of early Pleistocene Bermont formation at LL Quarry.



Figure 6. Longan Lakes Quarry strata. The Bermont formation encompasses the lower half of the photo and is approximately five meters high.



Figure 7. Close-up of packstone bed 3a (above scale) overlying shell bed 3b. Scale is approximately 20 cm long.

highstand deposition. A model for the proposed sequence of events leading to the formation of these packstone beds is:

1. An unconsolidated, nearshore shell bed is deposited, as evidenced by the grains and shells found in the packstone.
2. After eustatic fall of sea level, the shell beds were subaerially exposed, or at least located in the meteoric vadose zone in close proximity to the land surface. An influx of water undersaturated in calcium, derived from convective rainfall (Chen and Gerber, 1990) falling on the newly exposed carbonate surface, leads to the development of characteristic karst features, most notably cementation followed by increased secondary porosity (Wright, 1982).
3. The increased amounts of the rainfall that led to karstification also cause meteoric (freshwater) water to accumulate at the top of the phreatic zone. Shell beds are ultimately cemented in the vadose zone with freshwater sparite (Wright, 1982).
4. Sea level begins to rise, scouring the upper surface of the now-cemented bed and then depositing an overlying shell bed, thus renewing the cycle.

Shell beds and packstone beds are similar from one layer to the next and cannot be distinguished from one another visually. However, minor variations of the faunal content between the six shell bed layers have been documented. Specifically, changes in molluscan species richness and evenness, guild structure, and community structure have been noted between the cycles (Banasiak et al., 2006; Chelladurai et al., 2006; Greene et al., 2006). Despite these variations, the beds as a whole consistently contain key faunal

components of the Bermont formation. The temporal relationship between the strata is unclear, but they appear to document an uninterrupted series of cycles of transgression and regression. This will be discussed in greater detail below.

The Bermont formation is lithologically and faunally similar to both the Caloosahatchee and the Fort Thompson formations. The Bermont formation is characterized primarily by two criteria: 1) the absence of a number of typical Caloosahatchee species; and 2) the presence of a few species that are found in the Fort Thompson and absent from the Caloosahatchee (DuBar, 1962; 1974).

The following biostratigraphically diagnostic bivalve and gastropod taxa, all present in the LL shell beds, have been documented from the Bermont and younger units (DuBar, 1962; DuBar, 1974): *Codakia orbicularis*, *Terebra concava*, *Vokesinotus griffini*, *Anadara lienosa*, *Chione elevata*, *Arcinella cornuta*, *Macrocallista maculata*, *Alabina adamsi*, *Oliva sayana*, *Strombus alatus*, and *Vermicularia spirata*. *Trachycardium muricatum* and *Nassarius albus* have been documented from the Bermont and older units (DuBar, 1962; DuBar, 1974); both of these taxa are present in the LL shell beds. *Fasciolaria okeechobensis*, *Nassarius albus*, *Sinistrofulgur roseae*, *Strombus erici*, *Strombus evergladesensis*, and *Strombus lindae*, all present in the LL shell beds, are documented as being exclusive to the Bermont (DuBar, 1962; 1974).

Therefore, based on the presence of the aforementioned taxa, the LL beds correlate to the biostratigraphically defined Bermont formation.

Difficulty of Determining Age of Strata

Dating of the LL beds is problematic. Amino acid racemization (AAR) can be used to obtain the relative age of fossils with ages ranging from several thousand to several million years (Oches and McCoy, 1995; Bradley, 1999); however, the technique is best suited for relative dating and for greatest accuracy requires calibration by an external, numerical dating method (Rutter et al., 1985; Miller and Brigham-Grette, 1989). The application of AAR holds promise in establishing the presence and continuity of cyclothemic-type beds; if AAR demonstrates that the relative amount of time that separates the beds is constant, the presence and possibly duration of cyclicity can be established (Sanford et al., 2006).

Radioisotopic dating methods are expensive and not easily applied to marine deposits. Although the mineral glauconite, of marine origin, can be dated using $^{40}\text{Ar}/^{39}\text{Ar}$ dating (Bradley, 1999), the potential incorporation of Miocene and Pliocene palimpsest sediments into Pleistocene strata (Scott, 1997) would produce unreliable results. Numerical dating by $^{234}\text{U}/^{238}\text{U}$ may be possible using diagenetically pristine fossil corals (McCartan et al., 1982; Schwarcz and Blackwell, 1985) although the result of recent work has been discouraging; for example, in a study by Muhs et al., all 14 of the Pleistocene coral samples analyzed failed to meet the closed-system conditions necessary for accurate dating (Muhs et al., 1992). In any event, $^{234}\text{U}/^{238}\text{U}$ dating has not been successful with samples that are older than approximately 400 ka, precluding its use to strata older than the Fort Thompson.

Several cobble-size pieces of coral were embedded in the LL strata; however, they did not appear to have grown *in situ* and are thus of questionable age relative to the

time of LL deposition. The coral appeared to have been broken off from larger pieces and showed signs of damage by transport. It is, therefore, uncertain whether the corals grew during the same sea level stand that led to the deposition of the beds in which they are found, or whether they are remnants of reworked pre-existing strata, especially as the underlying Caloosahatchee in the region is dominated by reefal facies.

As a result of the aforementioned difficulties, biostratigraphic zonation has been the primary method used to correlate Florida's Plio-Pleistocene strata. Florida's diverse vertebrate faunal assemblages (MacFadden, 1997) were used, in combination with a suspect magnetostratigraphic approach and $\text{Sr}^{87}/\text{Sr}^{86}$ chronology, to bracket the Bermont formation (Hulbert and Morgan, 1989; Webb et al., 1989); unfortunately, no identifiable vertebrate fragments were found at the LL locality. In any event, vertebrate biochronology does not have the resolution necessary to distinguish the time that elapsed between the shell beds.

Because they are far more common than vertebrates, assemblages of invertebrate fossils are typically used to differentiate and identify Plio-Pleistocene strata. The inclusion or omission of a series of fossils, typically mollusks, is the primary method of determining the relative age of a unit. The primary drawback to this method is the lack of age-resolution; the 21 kyr to 100 kyr range (e.g., Coe, 2003) of orbital periodicity cannot be resolved with invertebrate biostratigraphy.

Despite these problems in constraining the chronostratigraphic framework of the Florida Pleistocene, it is possible to investigate aspects of the discontinuous nature of sea-level change in Florida during the Pleistocene. This will be accomplished by holistic integration of lithologic observations, paleoecological information, and stratigraphic

principles. Although a robust sequence stratigraphic model cannot be developed from the strata used in this study, light can be shed on the nature of higher-order sea-level fluctuations in the Pleistocene.

The Age of the Bermont Formation

Lyons (1991), in a comprehensive review and summary of the geochronology of Florida's Plio-Pleistocene formations, considers the probable ages of the Fort Thompson formation to be between 0.22 Ma and 0.95 Ma, the Bermont formation between 1.1 Ma and 1.6 Ma, and the Caloosahatchee formation between 1.8 Ma and 2.5 Ma (Fig. 1). These age ranges were established using a combination of radiometric dating methods as well as correlation with contemporaneous units in the Coastal Plain whose dates are well-documented.

Lyons (1991) arrived at the age range for the Bermont formation by synthesizing several existing studies, a brief summary of which follows. The Bermont has been alternately referred to as the "Glades formation" by Vokes (1963), "Unit A" by Olsson (1964), "Unit F" by DuBar (1962), and more recently as a portion of the "Bellegladean" and the "Loxahatchee" faunas by Petuch (1993; 2003). DuBar later renamed "Unit F" the Bermont formation (1974), differentiating the strata from the subjacent Caloosahatchee formation primarily by the absence of a number of biostratigraphically determinant taxa and the presence of a several species not found in the Caloosahatchee. Critical gastropods named by DuBar (1974) that are restricted to the Bermont include: *Fasciolaria okeechobensis*, *Fusinus watermani*, *Melongena bispinosa*, and *Strombus*

mayacensis; unfortunately, these key taxa are absent from the stratotype. A number of additional species have been added to the original list by later workers (Lyons, 1991).

Early works placed the Bermont within the early Pleistocene (Vokes, 1963; Hoerle, 1970). Taylor (1966), as cited in Lyons (1991), considered it to belong to the late Pliocene or early Pleistocene. Based on $\text{Th}^{230}/\text{U}^{234}$ and $\text{U}^{234}/\text{U}^{238}$ ratios, Waller (1969), using Broecker's ((1969) as cited in Waller) data, considered the deposits to be early Pleistocene. DuBar (1974), however, considered the Bermont formation to be in the “medial” Pleistocene. Mitterer (1974; 1975) performed amino acid racemization analysis on a series of Floridian shells including Bermont correlative material in the mid-1970s and, by applying a linear kinetics model, generated an age of 324 ka for the underlying Caloosahatchee formation. Wehmiller and Belknap (1978), who found the linear nature of the model inappropriate, re-evaluated the data using a non-linear model and arrived at an age of 800 ± 200 ka for the Bermont formation. To further complicate matters, the shells that were sampled were of uncertain origin and may have been incorrectly assigned to the various units (Lyons, 1991).

In the late 1980s, workers found beds containing terrestrial vertebrate fossils in Hillsborough County that bracket the Bermont formation (Hulbert and Morgan, 1989; Webb et al., 1989). The overlying mammalian fauna are 1.5 Ma to 1.0 Ma in age and the underlying mammalian fauna is less than 1.7 Ma. Webb et al. (1989) used a combination of magnetostratigraphy, strontium isotope chronology of *Chione elevata*, and mammalian biochronology to arrive at an overall age of 1.1 Ma to 1.66 Ma. Lyons (1991) found that the last set of values, 1.1 Ma to 1.6 Ma, correlated well with Blackwelder's M-3 interval-

zone (1981), an early Pleistocene Atlantic Coastal Plain mollusk zone which does not contain a Floridian equivalent.

Thus, this study will follow the conclusions of Lyons (1991) and will use an age of 1.1 Ma to 1.6 Ma for the Bermont formation. In any event, although a few of the points made in this study rely on this specific time range, the majority of the points are still applicable if the beds are of a more recent (e.g., middle Pleistocene) origin.

Given this age for the Bermont, then the formation and its fauna occupy a critical period of paleoecological and evolutionary transition between two paleoclimatically different epochs (Stanley, 1986; Imbrie et al., 1993). This was an interval during which communities and organisms responded to environmental changes that were ultimately driven, at least in part, by the change of glaciation from a 41 kyr periodicity to 100 kyr periodicity (Imbrie et al., 1993). Because the early Pleistocene Longan Lakes Bermont formation deposits preserves a series of cyclical marine shell beds and subaerially exposed packstones, the post-extinction evolution of lineages and the response of faunal communities can be studied through a series of five chronologically distinct episodes.

Chapter Three

Materials and Methods

Three stratigraphically continuous bulk samples, approximately 20 l each, were collected from each bed as part of an NSF-funded, REU project. Thicker beds, or beds displaying variations in sedimentary structure and lithology, were subsampled. Each set of strata was surveyed relative to the local land surface using a Brunton compass and stadia rod. The elevation relative to modern sea level was calculated by comparing the surveyed strata height to local land surface elevation as determined from USGS maps and digital elevation models.

Upon returning to the laboratory, unlithified bulk samples were wet sieved and all material, including shell fragments and sediment, was retained. The fossil material from these samples was then sorted, identified, the presence and abundance of gastropod and bivalve species were tabulated, and a grain-size analysis of the sediment was performed. For each of the lithified units, thin sections were prepared to investigate their diagenetic histories. In order to maintain continuity, the specific details of each method are described in conjunction with the results and interpretation.

The stratigraphy of the strata, the lithology of the beds, and thin sections of the packstone layers were used to identify the presence of the subaerially exposed layers. These subaerially exposed layers delineate five units that represent separate intervals of highstand deposition. The identification of gastropods and bivalves were used to verify

that the LL strata are part of the Bermont formation; furthermore, bivalve depth ranges were used to constrain the probable water depth during the deposition of the shell beds. The grain-size analysis was used to determine if the mean water depth was constant during the deposition of each set of shell beds.

Chapter Four

Results

Several indicators of elevated and lowered sea levels were investigated to confirm and quantify the extent of sea level fluctuations at the LL locality. Indicators of subaerial exposure, and consequently lowered sea level, include the presence of freshwater cements, traces of dissolution on the upper surfaces of beds, root molds, and karstification. Characteristics of the strata at the outcrop and thin sections of the packstone beds were used to confirm that subaerial exposure occurred.

Indicators of elevated sea level include the presence of abundant marine fossils in the shell beds. The depth range of occurrence of bivalve species present in the shell beds was analyzed to determine the probable paleodepth during time of deposition. Additionally, a grain-size analysis was performed to examine the relationship between depositional intervals.

Evidence of Subaerial Exposure in Packstone Beds

Strata that show signs of persistent subaerial exposure, for example the presence of freshwater cements, upper solution surfaces, root molds, and karstification, are indicators of intervals of lower sea level. Several indicators suggest that the majority of the shells that constitute the shell beds at Longan Lakes were formed in the same cycle in which they are found. The composition of the bivalve assemblages between beds is

relatively consistent (Chelladurai et al., 2006) and *in situ* bivalves are present. When bivalves are found in life position, they are typically clustered in groups, so it is improbable that their position is the result of chance deposition after transport. Additionally, much of the unfragmented shell material, even very thin shelled specimens, is in good condition and much of the ornament is virtually pristine, indicating that it has not been reworked by taphonomic processes (Dodd and Stanton, 1981).

Dissolution cavities and root molds are present in each of the subaerially exposed packstone beds, occupying 5-10 % of the volume of the packstone. Decimeter-scale changes in relief, apparently dissolution features, were present on the upper surfaces of the packstone beds. Traces of root molds and secondary porosity, which are indicators of subaerial exposure (Budd et al., 2002), were present in all the packstone beds. Post-lithification molluscan boreholes are present on the upper surfaces of the packstone beds; these boreholes suggest that marine organisms inhabited these hardgrounds after cementation of the packstone but prior to the deposition of the overlying shell-rich units.

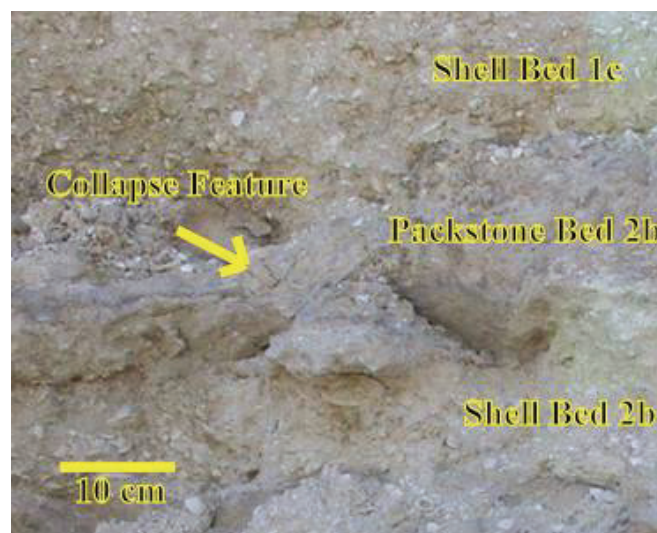


Figure 8. Small-scale karstic collapse. Collapse feature penetrates packstone bed 2a and connects shell beds 1c and 2b.

Karstic collapse was observed neither in the LL section that was studied in detail nor in the surrounding quarry walls, except in bed 2a. A collapse feature penetrating bed 2a approximately 10 cm wide and 10 cm high was noted and is shown in Figure 8; this conduit connected beds 1c and 2b. The feature appears to have been caused by dissolution of bed 2a packstone, followed by a localized collapse, and subsequently by the intrusion of material from bed 1c. There were no fragments of bed 2b found in either the underlying or overlying strata, so a mechanical origin (e.g., collapse of bed 2a due to the weight of overburden) appears unlikely. Thus, the packstone beds appear to be an early merokarst rather than a mature holokarst (*sensu* Dreybrodt, 1988).

Thin sections were prepared for each of the packstone beds: LL-2a, LL-3a, LL-4a, LL-5a, and LL-6a. Five sets of thin section samples were then subjected to various treatments to elucidate the nature of the sediments and cements. The first set was a control, and was left unaltered. The second set was etched with dilute HCl and washed in deionized water using the method outlined by Friedman (1959). The third set was etched with HCl and stained with Alizarin Red S dissolved in dilute HCl (Friedman, 1959). The fourth set was etched in dilute acetic acid and stained with Clayton Yellow dissolved in NaOH and EDTA using the method outlined by Scholle (1978) with some modifications as described by Choquette and Trusell (1978). The fifth set was impregnated with blue-dyed casting resin by immersing the rock chips in a blue resin bath inside a vacuum chamber for approximately fifteen minutes (Adams and MacKenzie, 1998). Thin sections were digitally imaged in plane polarized light using a Nikon SMZ-1500.

A description of the characteristics common to the five packstone beds is followed by characteristics specific to each bed; the implications of the findings are

summarized following the descriptions. A photograph representative of the beds is shown in Figure 9.

All thin sections show indications of subaerial exposure in the form of secondary porosity (“karst”) and root molds. Over 50% of the grains are moderately-sorted, well-rounded quartz. Abundant molluscan bioclast fragments, carbonate grains, and a small number of other grains including phosphorite and dolomite are present.

Micrite composed of low-Mg calcite fills over 50% of the space between grains. However, dissolution cavities, void space within biotic fragments, and root molds are almost uniformly filled with low-Mg calcite sparite. Sparry calcite, shown in Figures 10 and 11, is almost uniformly blocky cement or a drusy, mosaic, pore-filling cement. Trace amounts of circumgranular sparry calcite cement is visible on the edges of grains that protrude into pore space. Some calcite crystals, usually with a dogtooth habit, are found precipitated on the insides of mollusk fragments.

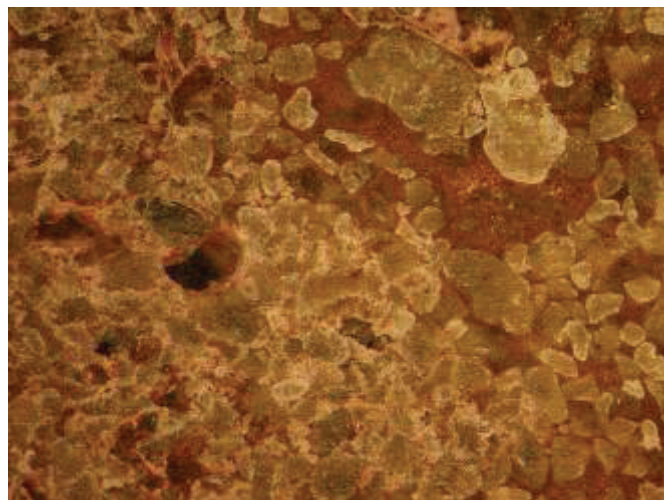


Figure 9. Bed 2a, Alizarin Red S staining (X20). Photograph is representative of packstone beds and shows typical grain distribution and micritic matrix. Stained portions (red) indicate calcite. Sparry calcite is often much lighter red than micrite due to differential absorption of stain and grain size.

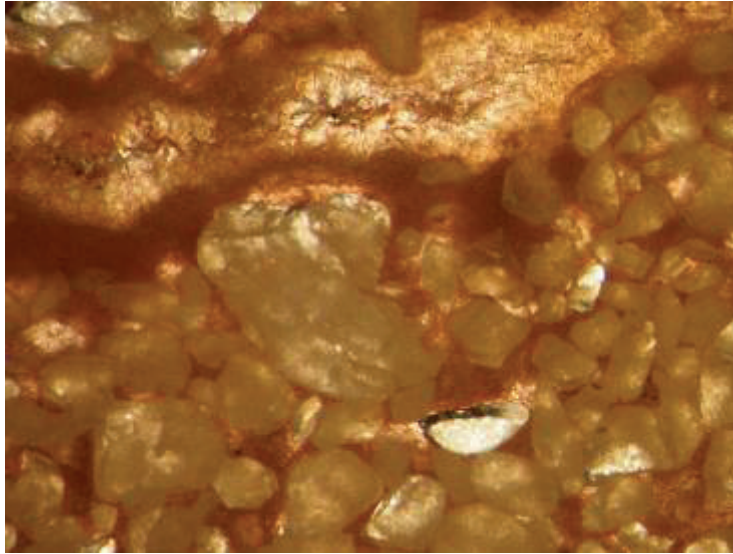


Figure 10. Bed 2a, Alizarin Red S staining (X30). Meteoric sparry calcite precipitated within a dissolution cavity.

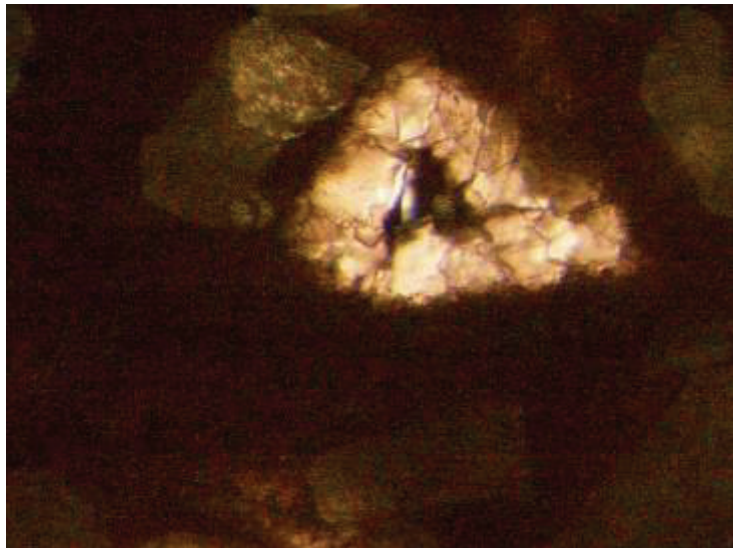


Figure 11. Bed 3a, Alizarin Red S staining (X100). Closeup of meteoric calcite sparite in a root mold (cross-section).

Observations specific to individual beds include:

- Bed 2a: Abundant pore space is present; some smaller pores are not completely filled with sparry calcite.

- Bed 3a: Most root molds are almost completely filled with drusy mosaic sparry calcite (Fig. 13). Some dolomitization noted, typically coinciding with portions that appeared weathered.

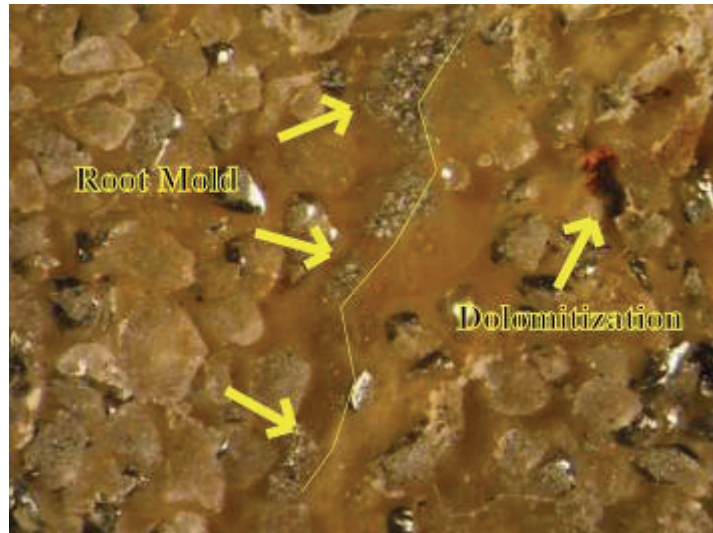


Figure 12. Bed 3a, etched surface (X30). Meteoric sparry calcite within a root mold.

- Bed 4a: Grains are tightly packed, and the amount of pore-filling sparite is sparse. Lack of dolomite is shown in Figure 13.

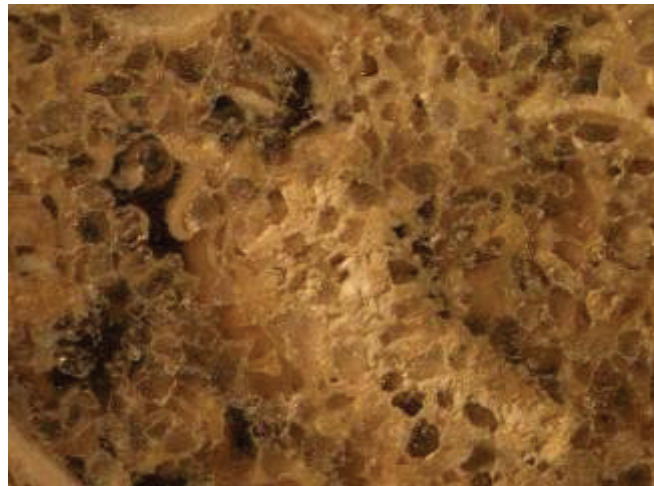


Figure 13. Bed 4a, Titan Yellow staining (X20). Note lack of significant high-Mg calcite or dolomite, which would be stained red. White mass appears to be weathered shell fragment. Some phosphorite grains.

- Bed 5a: Sparse high-Mg calcite or dolomite is present, typically associated with mollusk fragments. Abundant root molds are present, almost uniformly filled with a drusy mosaic pore filling cement (Fig. 14).

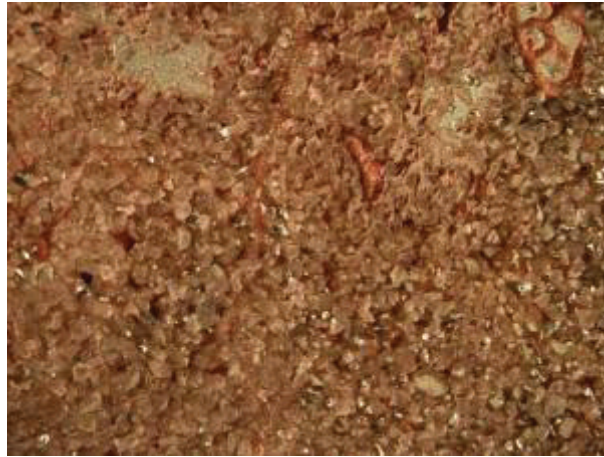


Figure 14. Bed 5a, Alizarin Red S stain (X10). Meteoric sparry calcite in a root mold.

- Bed 6a: Some High-Mg calcite or dolomite is present, typically associated with mollusk fragments (Fig. 16). Abundant root molds, almost uniformly filled with drusy mosaic pore filling cement (Fig. 17). Smaller pores are not completely filled with sparite.

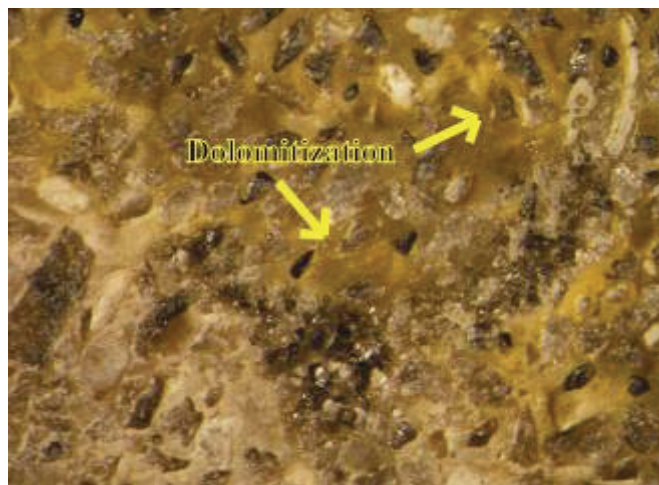


Figure 15. Bed 6a, Titan Yellow staining (X30). Meteoric sparry calcite precipitated within a dissolution cavity. Dolomitization near shell debris is indicated by the arrows.

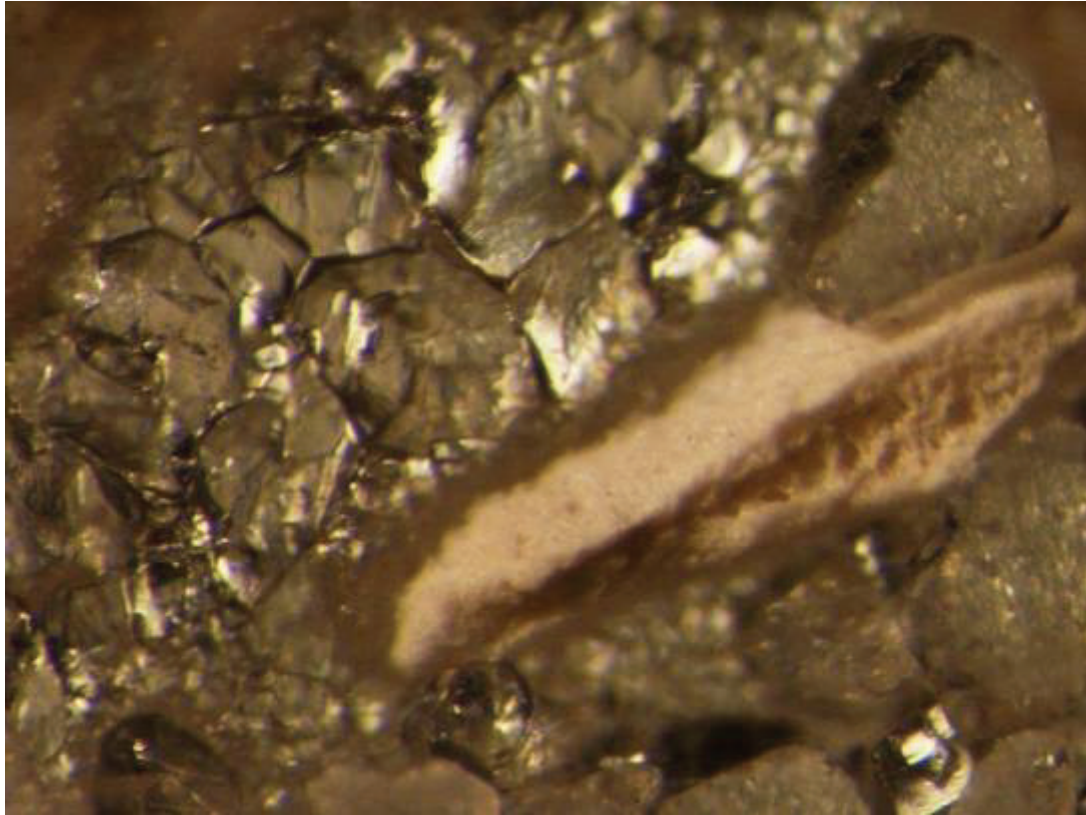


Figure 16. Bed 6a, etched (X70). Meteoric sparry calcite precipitated within a dissolution cavity.

The cement that binds the packstone appears to consist of two distinct types. The more abundant is an interstitial micrite composed of low-Mg calcite. This micrite fills most of the original interstitial space and likely formed due to the alteration of pre-existing aragonitic grains (Perkins, 1977; Scott, 1997).

Blocky cement, drusy-mosaic cement, circumgranular sparry calcite, and calcite crystals with a dogtooth habit are all indicative of a meteoric vadose or meteoric phreatic diagenetic environments (Longman, 1980; Flügel, 2004). Low-Mg calcite is very strongly associated with a freshwater (non-marine) origin (Land, 1970; Folk, 1973; Flügel, 2004). Additionally, paleokarst can be recognized by the presence of vadose cements (Wright, 1982).

Thus, the morphology of calcite crystals as well as the mineralogy and fabric of the sparry calcite cement all indicate a period of exposure to meteoric waters. Additionally, karstic dissolution, development of secondary porosity, and root molds are present in each of the packstone beds, further indicating periods of subaerial exposure. Because the overlying and underlying shell beds show no significant signs of any of these processes, each of the packstone beds was subaerially exposed before being buried by the overlying shell bed. The presence of interstitial micrite, exclusive to the packstone beds, appears to be related to the presence of meteoric sparry calcite cement and thus the formation of packstone. If the packstone beds formed in the vadose zone, then the boundary between the lower surface of each packstone bed and the immediately underlying shell bed may represent the average level of the water table following deposition of an individual unit.

The original fabric and lithology of the packstone beds appears to have been similar to the underlying shell beds; a fine- to medium-grained quartz and carbonate packstone with abundant fossil material. However, post-depositional dissolution, micritization, and cementation by sparite have partially obscured the original similarity between the shell beds and the packstones.

Water Depth During Deposition of Shell Beds

A grain-size analysis was performed to identify possible trends in water depth between the depositional intervals. A coarsening upward trend is typical of a shallowing upward series; a fining upward trend is conversely indicative of a deepening series. Grain size was measured using the following method, adapted from Griffiths (1967) and

Selley (2000). A sample weighing approximately 100 g was gathered from one of the stratigraphically-continuous bulk samples for each bed. Particles larger than -1Φ – dominantly consisting of shell material – had previously been removed, so the analysis only focused on sediments within the clay to sand range. Prior to analysis, the samples were then oven-dried at approximately 50°C for eight hours.

After drying, the samples were weighed to the nearest 0.01 g and placed at the top of a series of sieves sized at -1Φ , 0Φ , 1Φ , 2Φ , 3Φ , and 4Φ . Each set of sieves was agitated using a Ro-Tap[®] for fifteen minutes. The residue in each sieve was weighed and the sieves were cleaned between each sample. The fine fraction in the catch tray, i.e., sediment $< 4 \Phi$, was analyzed using a Malvern laser diffractometer.

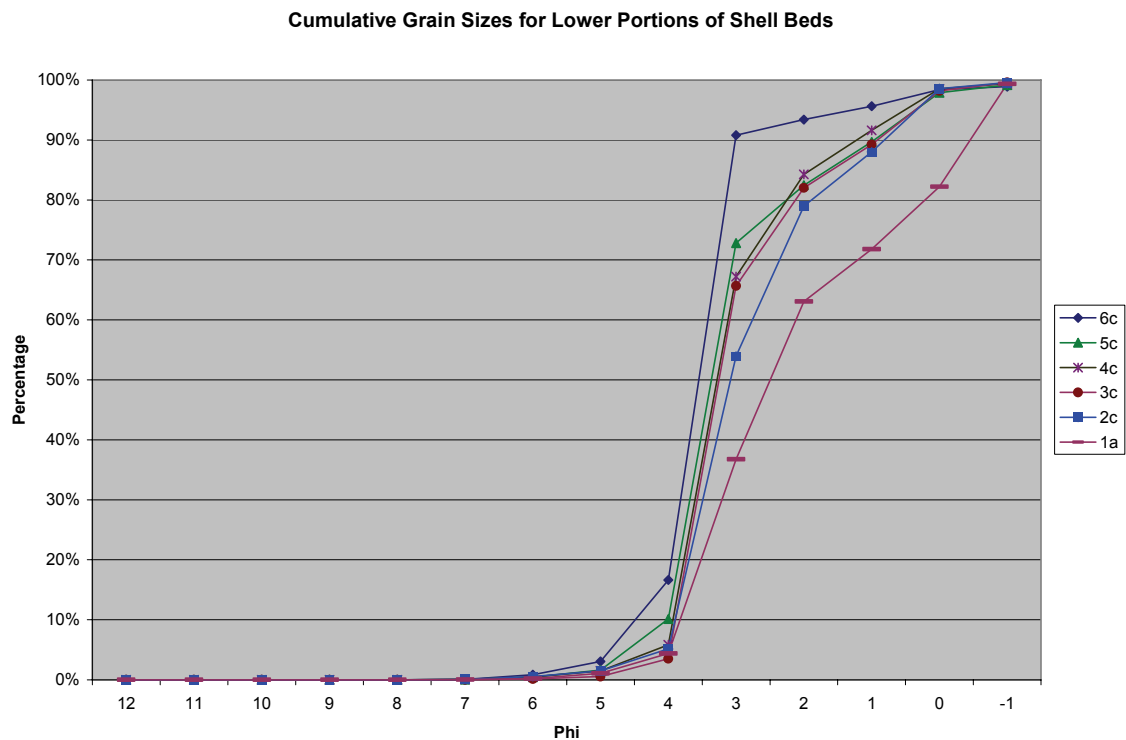


Figure 17. Cumulative grain sizes for lower portions of shell beds.

Detailed results of the grain size analysis are provided in Appendix B. Figure 17 shows a summary of the results. The grains are very well sorted and are composed almost exclusively of size 2Φ to 3Φ particles: medium to fine sand. The silt and clay fraction is negligible but present. This sorting pattern is typical of tidal or beach-type environments (Visher, 1969; Davis, 1994a), hardly surprising in light of the nature of the deposit or the faunal assemblage.

A non-quantitative analysis of the sand-, silt-, and clay-sized sediment in the shell beds was performed by adding 2 M HCl to the sieved residue until all carbonate material dissolved. A visual estimate of post-dissolution volume showed that at least 50 % of the sediment in size ranges 0 to 4Φ remained and is therefore non-carbonate.

The key trend, however, is that there is an upward increase in the relatively coarse fraction between shell beds. There is a pronounced shift from fine sand to medium and coarse sands between the lower shell beds (5 and 6) and the upper shell beds (1 and 2). A coarsening upward trend is indicative of the slow encroachment of an increasingly higher-energy (i.e., shallower) depositional environment (Prothero and Schwab, 1996; Posamentier and Allen, 1999). Therefore, this series of deposits appears to represent a vertically stacked series of near-shore marine deposits that were deposited at increasingly shallow water depths.

Bivalve and Gastropod Analysis

Existing bivalve and gastropod faunal lists (Chelladurai et al., 2006; Greene et al., 2006) of the LL shell beds were verified and enhanced by comparison with bulk samples and sorted collections from the LL shell beds. Gastropods were listed as either present or

absent from the section as a whole and were, as previously discussed, used primarily to verify that the section was part of the Bermont fauna (DuBar, 1962; DuBar, 1974).

Bivalves species abundance by shell bed was recorded, then depth information was compiled from the Malacolog database (Rosenberg, 2005) and literature (Abbott et al., 1995; Redfern, 2001). Bivalves were used to verify the section's placement in the Bermont formation as well as to estimate the water depth at which the biota that formed the shell beds resided. Such an estimate would provide an approximate depth of formation of the shell beds provided that transport was relatively limited. A weighted average of minimum and maximum depth was calculated incorporating all species for which a depth was available in the literature. Species for which no depth information was available were disregarded; this amounted to 19 species out of 97 total; 14 of these species were represented by three or fewer specimens out of a total sample of 13,793.

Details of the bivalve assemblage analysis are provided in Appendix C. Table 1 shows a summary of the results of a weighted average analysis. The average minimum water depth in which the bivalve fauna of the shell beds lived was 4 ± 2 m. A total of 41 of the 78 species have maximum depths less than 13 m; these species represent 12,125 specimens of 13,793 total, or 88.9 % of the bivalve population. By comparison, only 4 of 78 species had minimum depths that were greater than 13 m; these species represent 64 specimens of 13,793, or 0.5% of the bivalve population. The deep-water specimens may have been transported into shallower waters (< 13 m) by taphonomic processes; alternately, the currently known minimum range is incorrect.

There is no minimum depth trend; all beds fall within the first standard deviation. The water depth range of the bivalve taxa is 2 m to 13 m, within a 90 % confidence

interval; the mean of this range, 7.5 m, will be used in subsequent calculations of sea level. Bed 6b is shallower than the other beds due to an abundance of *Chione elevata*, which has a minimum depth of 0.6 m.

The majority of the bivalves were not articulated and showed damage and wear indicative of local transport; thus, the bivalve depth ranges provide an estimate of the overall depth during the deposition of the shell beds, rather than the precise depth at any specific instant.

Table 1. Weighted Average Minimum Bivalve Depth for Longan Lakes Shell Beds.

Weighted Average Minimum Bivalve Depth for Longan Lakes Shell Beds		
Bed	n	Weighted Minimum Depth (m)
2c	2649	5
3c	1504	5
4c	2592	6
5c	3280	4
6b	3571	2

However, *Anodontia alba*, found in life position at the tops of beds 2, 3, and 4, occurs exclusively in shallow water, with a listed live depth range of 1 m (Abbott et al., 1995; Rosenberg, 2005). If the presence of *Anodontia alba* in life-position is a reliable indicator of the water depth of the underlying shell material, this constrains the water depth to 1 m and would change the sea-level calculations undertaken later in the study.

Chapter Five

Models of Sea-Level Change

Models not involving transgression that can account for marine deposits overlying freshwater or subaerial deposits are unlikely to occur in tectonically stable southern Florida (Smith and Lord, 1997). Additionally, southern Florida is not proximal to a siliciclastic sediment source capable of overwhelming the eustatic signal (White, 1970; Roof et al., 1991) nor are any the sediments comprising the units dominated by silicilastics. Eustatic changes should therefore necessarily impact Florida's coastline in a relatively straightforward manner. If eustatic sea level rises, Florida's coastline should retreat; if eustatic sea level falls, Florida's coastline should prograde – i.e., the Florida Platform is therefore an excellent sea-level 'dip stick'.

Sequence Stratigraphy

Because the age of Florida's early Pleistocene shell beds is difficult to constrain, the strata are chronostratigraphically ambiguous. This chronological ambiguity is additionally problematic when a sequence stratigraphic model is applied. The marine flooding surfaces and erosional unconformities that delineate parasequence and sequence boundaries, respectively, are present, but correlation of such boundaries between different locations is difficult, if not impossible.

Florida's Miocene and Pliocene sequence stratigraphy has been studied in some detail (Evans, 1989; Evans and Hine, 1991; Mallinson and Compton, 1995; Cunningham et al., 1998), but Pleistocene deposits have received only cursory attention, typically as a footnote in studies of older sections (Perkins, 1977; Zullo and Harris, 1992; Harris and Zullo, 1993; Warzeski et al., 1996; Cunningham et al., 2001; Cunningham et al., 2005). As a result, the impacts of Miocene and Pliocene eustatic changes on the south Florida platform stratigraphy are better known than more recent Pleistocene changes.

Although the identification of unconformities and their correlative conformities in deeper marine settings is one of the key criteria used to distinguish sequence stratigraphic units (Van Wagoner et al., 1988), the technique is difficult to apply in locations: 1) represented by chronologically ambiguous vertical sequences which obscure the differences between sequence and parasequence boundaries; 2) with lithologic homogeneity that confounds meaningful lateral correlation; and 3) in regions with discontinuous lateral beds, thus preventing the ready application of Walther's law of correlation of facies. Florida's Pleistocene shell beds represent all three of these potential shortcomings, and these make sea-level reconstruction difficult. Cyclostratigraphic techniques are similarly difficult to apply but are instead hampered primarily by the lack of high-resolution numerical dating of Florida's Plio-Pleistocene record.

Cyclostratigraphy

Because the tools of sequence stratigraphy (Van Wagoner et al., 1988; Van Wagoner et al., 1990), as discussed earlier, suffer from a number of limitations, a different method to model the origins of the strata at LL would likely be more

informative. At first glance, cyclostratigraphy seems suited for this type of data.

However, cyclostratigraphic methods have two major requirements: 1) the cycles must represent equal intervals of time; and 2) the duration of the interval must be known (Schwarzacher, 1993). The LL strata fail to meet either of these requirements.

To detect cycles that are missing from a sequence, Goldhammer, et al. (1990; 1993) developed a method to detect the presence of “missed beats”. However, their model produces useful results only with long sections (over 700 m in both the 1990 and 1993 studies) that contain third- through sixth-order cycles. An attempt by Goldhammer et al. (1990; 1993) to model five Florida Pleistocene marine subtidal units from the Florida Keys previously described by Perkins (1977) met with limited success; the model showed a 67,000 yr periodicity, which is not in tune with any known orbital forcing mechanism (Goldhammer et al., 1990; Joyce, 1990; Berger and Loutre, 1991). They concluded that this anomalous frequency was a consequence of “missed beats”. In short, the set of beds at LL is too limited stratigraphically, too poorly constrained temporally, and contains too few cycles to analyze with cyclostratigraphic techniques; missing beds within the LL strata cannot be identified.

Table 2. Duration of Sea-Level Cycle Orders. After Kerans and Tinker (1997), Emery and Myers (1996), Posamentier and Allen (1999), Coe et al. (2003), Van Wagoner (1990), Vail et al. (1991), and Schlager (2005).

Duration of Sea-Level Cycle Orders			
Cycle Order	Duration	Terminology	Cause
First	> 50 Myr		Tectono-eustasy
Second	3 – 50 Myr	Supersequence	Tectonic subsidence
Third	0.5 – 3 Myr	Sequence	Tectono-glacio-eustasy
Fourth	0.08 – 0.5 Myr	Parasequence set	Glacio-eustasy
Fifth	0.03 – 0.08 Myr	Parasequence	Glacio-eustasy
Sixth	0.01 – 0.03 Myr		Glacio-eustasy

As cyclostratigraphy is no panacea, the imperfect but robust methods of sequence stratigraphy will be used to help determine the relationship between sea-level fluctuations and the Bermont strata. Table 2 displays the cycle orders and the inferred causes of that order of cycle. Third-order deposits are referred to as sequences (Coe, 2003) and form the fundamental unit of sequence stratigraphy (Kerans and Tinker, 1997). Fourth-order deposits are referred to as parasequences sets (Van Wagoner et al., 1990), and fifth-order deposits are parasequences (Vail et al., 1991; Kerans and Tinker, 1997; Schlager, 2005).

Orbital Forcing by Obliquity

Because the 41 kyr frequency was the dominant periodicity during the deposition of the early Pleistocene (Joyce, 1990), the likely interval for Bermont formation deposition, the most parsimonious value for the time interval between the parasequence cyclothem, provided there are no ‘skipped beats’, is 41 kyr. This frequency represents variation in Earth’s obliquity cycle and its concomitant impact on solar insolation and ultimately on the Earth’s climate (Schwarzacher, 1993).

Therefore, based on the inferred development times for the packstone beds, which will be discussed below, and the dominant orbital forcing periodicity, the LL strata most likely represent fifth-order cycles superimposed on a longer fourth-order cycle and should be therefore termed parasequences.

Fischer Plots and the Relationship Between Time and Cycle Thickness

Fischer plots (Sadler et al., 1993) are used to analyze cycle thinning and thickening patterns, normalized to a uniform rate of subsidence (Read and Goldhammer, 1988; Kerans and Tinker, 1997). Table 3 shows the values that were used to construct the Fischer plot; the thickness of each individual interval, the averaged thickness of all the intervals, and the subsidence rate (6 m). A Fischer plot of the LL intervals, illustrated in Figure 18, was constructed.

The single peak of the Fischer curve indicates that the deposition took place during a single lower-order, sea-level cycle (Kerans and Tinker, 1997). As was shown earlier, the lower-order cyclicity shown on the plot is most likely fourth order and that each packstone bed marks the end of a shorter fifth-order cycle. Assuming sea-level highstands reached the same elevations, the thinning of cycles upward indicates that available accommodation space was being filled by deposits at a higher rate than it was being created by subsidence (Kerans and Tinker, 1997).

At this point, it should be noted that Sadler et al. (1993) favor a “lower limit of 50 cycles per section in order to produce a Fischer plot that merits interpretation” because short sections suffer from the same problems as small sample – a high standard deviation. Because Fischer plots innately force the starting and ending points to be at the same horizontal position, small numbers of cycles often force specific interpretations. Because the LL strata only represent one cycle, as previously demonstrated, the range of interpretations is limited.

Sadler (1993) recommend discarding the thickest cycle to check the impact on the mean and standard deviation. Additionally they found that the standard deviation was 1/7

Table 3. Summary of Interval Characteristics within the Longan Lakes Sequence.

Summary of Interval Characteristics within the Longan Lakes Sequence				
Unit Forming Top Bed of Cycle	Upper Karst Bed (cm)	Lower Shell Bed (cm)	Net Thickness of Cycle (cm)	Depositional Rate cm / kyr
2a	10	33	43	1
3a	10	56	66	2
4a	46	60	106	3
5a	50	60	110	3
6a ¹	20	≥ 90	≥ 110	≥ 3
Total Thickness	168	247	415	
Mean	27	52	81	2
Standard Deviation	19	13	32	1
¹ Lower portion of cycle 6a is not included in calculations because of unknown thickness				
Subsidence Rate 6 m / Myr = 25 cm / 41k				

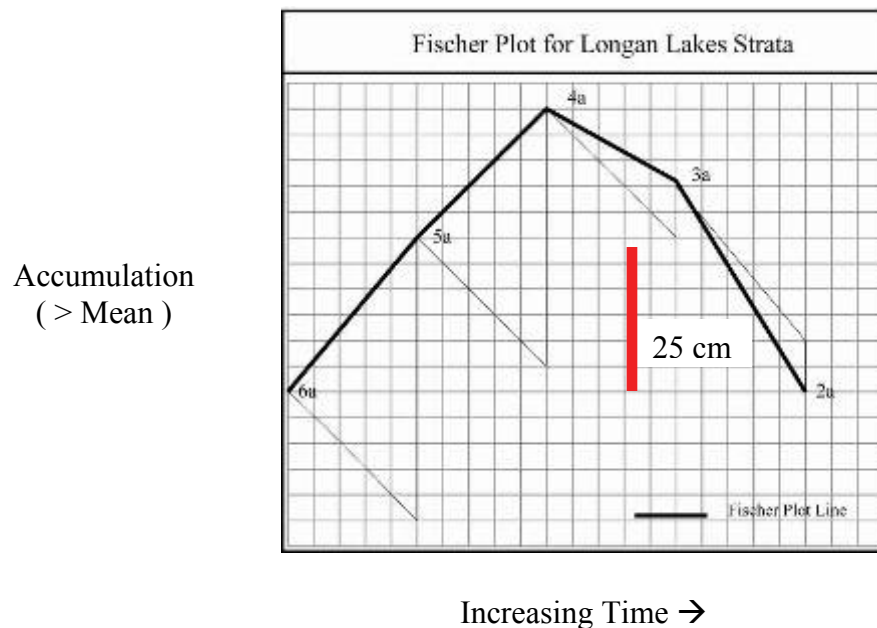


Figure 18. Fischer plot for Longan Lakes strata. The Fischer plot is a graphical summary of combined effects of subsidence and cycle-specific sediment accumulation. The peaked curve indicates the presence of a single highstand, presumably 4th-order, made up of four shorter 5th-order segments.

of the cycle thickness when using a sample with at least 50 cycles. Applying this technique to the LL strata shows that the heights of the cycles change from 81 ± 32 cm to 72 ± 31 cm when the thickest parasequence is excluded. If that standard were applied to the LL mean cycle thickness of 81 cm, one would expect the standard deviation to be no greater than 22 cm. The standard deviation is 32 cm, approximately 50% higher than if a 50-cycle section had been used.

Correlation of the LL Bermont Strata with a Eustatic Curve

The amount of time that passed between the deposition of a shell beds and the underlying karstified packstone layers is uncertain; however, as was previously demonstrated, a reasonable estimate is 41 kyr because the primary orbital signature of the early Pleistocene epoch was obliquity. As will be shown below, the time required to form a shell bed and packstone interval falls within this time span. A complicating factor includes the fact that paleosols, often found at sequence boundaries, are not recognizable in the LL strata, having been eroded or otherwise removed (Selley, 2000).

On a cautionary note, Drummond and Wilkinson (1993) concluded, using a computational model, that multiple cycles can develop during one highstand. For example, sea-level has fluctuated during the Holocene highstand; sea-level stood at -9 m at 7.7 ka, rose to +2 m between 6.8 and 4.8 ka (Blum et al., 2001), dropped to -4 m at 3 ka (DePratter and Howard, 1981), and then rose to the present level.

However, Drummond and Wilkinson's (1993) model postulates conditions of rapid sedimentation, limited accommodation space, and long duration of platform flooding, only the first of which is especially applicable to the LL site. Additionally, the

formation of packstone beds between the LL shell beds indicates that sufficient time was available to allow for cementation, dissolution, and micritization of the original shell beds prior to burial by the next shell bed. Flügel (2004) gives a range from 10^3 to 10^5 years as the time required for meteoric diagenesis to occur; shallow burial generally correlates with lower rates of diagenesis and deep burial with higher rates. Because the LL packstones were subaerially exposed, a rate of diagenesis in the lower half of Flügel's range, from 10^3 to 10^4 kyr, will be used in subsequent discussion.

To place the LL strata within existing eustatic curves, the lowstands represented by the packstone beds were correlated with sea-level reconstructions based on variability in the $\delta^{18}\text{O}$ record. The shape of the $\delta^{18}\text{O}$ curve, shown in Figure 19, shows similar patterns of glaciation during the Bermont and later Pleistocene; an interval of intensified glaciation followed by a slightly faster deglaciation (Joyce, 1990). However, the asymmetry in timing between interglacial and glacial intervals during the early Pleistocene, forced by the 41 kyr obliquity cycle, appears to be less pronounced than the younger eccentricity-driven late Pleistocene glaciation; glaciations appear to take only slightly longer than deglaciations, and the differences in peaks and troughs of the curve are not as pronounced.

Conversely, such an asymmetrical eustatic pattern would result in an interval of regression followed by a slightly more rapid transgression. In any event, the shell beds would be subaerially exposed for 10^3 to 10^4 kyr, which coincides Flügel's temporal estimates for near-surface diagenesis.

A preliminary correlation of Florida's Plio-Pleistocene shell beds with third-order coastal-onlap cycles of an existing sequence stratigraphic model for the Salisbury and

Albemarle embayments of Virginia and North Carolina was published by Zullo and Harris (1992) and Harris and Zullo (1993); in their model, the Bermont formation was assigned to the third-order sequence cycle 3.9; this cycle is bounded by ages of 0.8 and 1.6 Ma.

Their placement of the Bermont into a sequence stratigraphic context, however, was based on an older Cenozoic coastal onlap chart published by Haq et al. (1987). A more recent reconstruction specific to the Plio-Pleistocene record in the Gulf of Mexico (Wornardt and Vail, 1991) places this same interval in the third-order cycle 3.8. According to their Mio-Pleistocene Sequence Chronostratigraphy Chart, fourth-order sequence boundaries, which are indicative of lower sea level, occurred at 1.9, 1.4, and 1.1 Ma. Maximum flooding surfaces, indicative of sea-level high stands, are placed at 1.47, 1.3, and 0.92 Ma.

A more recent revision of these dates (Wornardt, 1999) places the fourth-order sequence boundaries at 2.09, 1.56, and 1.40 Ma, and maximum flooding surfaces at 1.59, 1.47, and 0.96 Ma; however, to date the majority of researchers continue to use the 1987 and 1991 values (Cunningham et al., 1998; Cunningham et al., 2001; Duncan et al., 2003; Le Roux et al., 2004). This study will use the sequence boundary and maximum flooding surface values published in 1987 and 1991 because they are widely accepted and were developed specifically for the Gulf of Mexico; the newer ages were derived from European basins and are less likely to be reflective of conditions in the Gulf of Mexico. If the newer values were used, the ages discussed below would be approximately 100 kyr younger, still within the potential age range of the Bermont as delimited by Lyons (1991).

A eustatic curve, drawn after Haq et al. (1987), is depicted in Figure 19. As discussed earlier in this study, the highstand value at 1.2 Ma represents a sea level between 10 m and 20 m above modern levels. There were two periods of transgression and highstand during the early Pleistocene, as well as two periods of sea-level fall. These relationships are shown in Table 4 and Figure 19. Haq et al. (1987) show the 1.4 Ma lowstand which separates the two highstands as having a duration of 50 to 100 kyr.

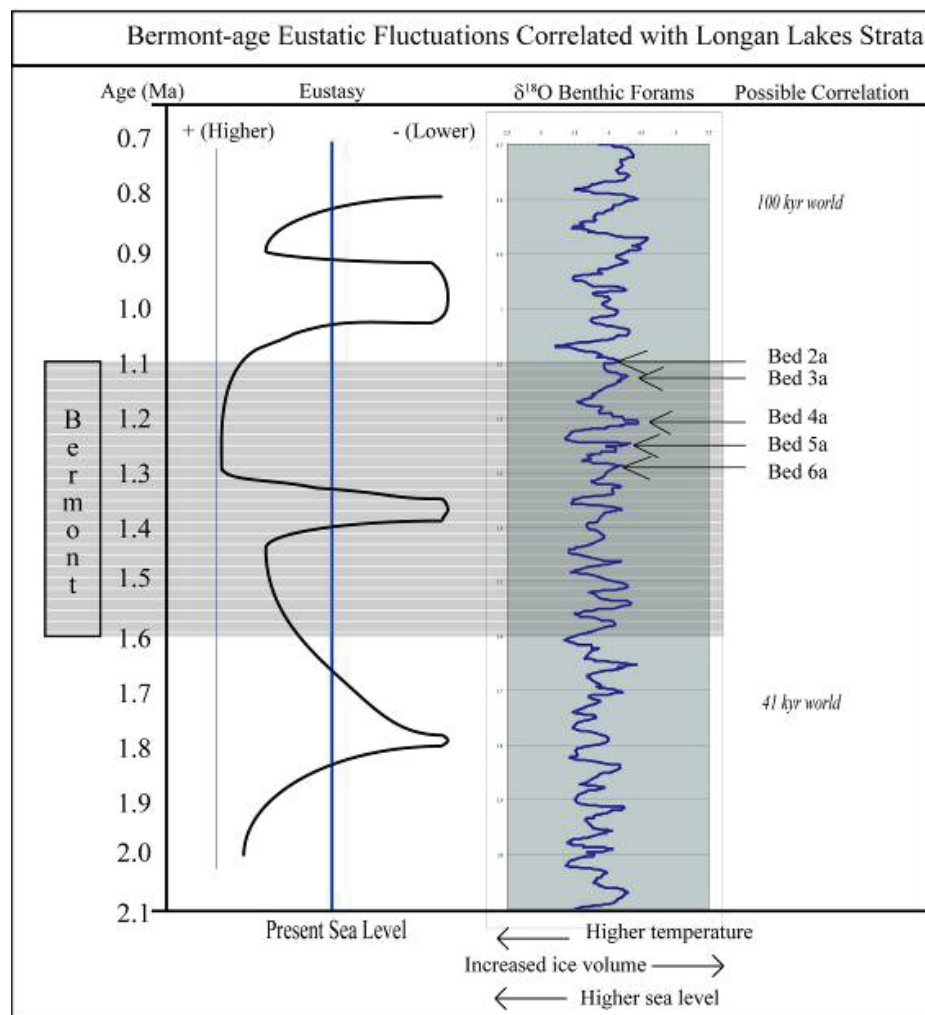


Figure 19. Bermont-age eustatic fluctuations correlated with Longan Lakes strata. LL strata are correlated with eustatic highstand between 1.1 and 1.3 Ma and the $\delta^{18}\text{O}$ curve; packstone beds form during periods of lower sea level/increased ice volume. Figure incorporates data from Lyons (1991), Wornardt and Vail (1991), Mix et al.(1995a; 1995b), and Allmon et al. (1996).

As previously discussed, the Bermont formation was most likely deposited as a number of fifth-order parasequences that resemble cyclothems. The LL strata consists of five parasequences of shell beds capped by subaerially exposed packstones, labeled 6, 5, 4, 3, and 2. Because the top of parasequence 1 was not observed, this bed will not be included in subsequent sea-level or temporal calculations.

Table 4. Summary of Early Pleistocene Interval Characteristics. Only highstand deposits are recorded in Florida; other portions are missing. After Van Wagoner et al. (1988), Wornardt and Vail (1991), and Wornardt (1999).

Summary of Early Pleistocene Interval Characteristics		
Period	Eustatic activity	Expected Systems Tract
1.40 – 0.96	Sea level rise and highstand	Transgressive/ highstand sequence tract
1.47 – 1.40	Sea level fall	Lowstand systems tract
1.56 - 1.47	Sea level rise and highstand	Transgressive/ highstand sequence tract
1.59 – 1.56	Sea level fall	Lowstand systems tract

The previously discussed consistent upward coarsening pattern of grain size provides evidence of a shallowing upward series of shell beds. If a major (e.g., fourth-order) lowstand with a duration of 100 kyr interrupted the LL strata, it is unlikely that deposition would recommence without signs of a significant unconformity. Such an unconformity might be indicated by the presence of paleosols, a change in grain-size counter to the existing coarsening upwards trend, karstification of the existing strata, or a shift in fauna indicating a change in water depth. Because none of these indicators are present to any significant degree at the unconformities located at the upper surface of the packstones, it will be assumed that the strata were not interrupted by a 100 kyr lowstand.

Thus, if a 41-kyr control by obliquity is the primary forcing mechanism, consistent with the $\delta^{18}\text{O}$ record, at least approximately 160 kyr must have passed between

the development of the lower and uppermost subaerial exposure beds. As shown in Table 4 and in Figure 19, if Wornardt and Vail's (1991) eustatic curve is correct, then there are two periods of transgression and highstand that are coeval with the age Lyons (1990) designated for the Bermont. As previously shown in this study, the LL Bermont strata were most likely deposited during a period of fourth-order highstand. The older interval, from 1.60 Ma to 1.45 Ma, had a duration of less than 150 kyr; the younger interval spanned from 1.35 Ma to 1.1 Ma. Highstand systems tracts are deposited during periods when the relative rate of sea-level rise decelerates (Emery and Myers, 1996); according to Wornardt and Vail's (1991) eustatic curve, the younger highstand interval took place between 1.3 Ma and 1.1 Ma. Therefore, the LL Bermont strata were likely deposited during the younger interval.

Because the volume of ice sheets can be estimated using the $\delta^{18}\text{O}$ of benthic foraminifera as a proxy (Mix et al., 1995a; Hoefs, 2004), an approximation of sea level can be calculated (Fairbanks, 1989). As the ice volume decreases, sea level rises and the relative proportion of ^{18}O in the ocean decreases. Although a quantitative correlation of the shell beds with existing $\delta^{18}\text{O}$ curves is beyond the scope of this study, a possible qualitative correlation which assigns shell bed intervals to sea level highstands between 1.3 and 1.1 Ma is depicted on Figure 19.

Using Pleistocene corals from Barbados, Fairbanks and Matthews (1978) calculated that a sea level rise of 1 m would occur for every of 0.011‰ reduction in $\delta^{18}\text{O}$. However, this value is specifically linked to the last glaciation (Hoefs, 2004) and assumes that all changes in $\delta^{18}\text{O}$ are linked to ice volume. There could also be temperature effects that are superimposed upon the changes in $\delta^{18}\text{O}$ forced by ice-volume fluctuations.

Therefore, using the 0.011‰/m relationship to calculate earlier sea-level fluctuations will result in an approximation that most likely overestimates the actual amount of changes. In any event, if the 0.011‰/m relationship is reflective of the interval between 1.1 Ma and 1.6 Ma, the average range of sea-level fluctuations during the early Pleistocene would have been approximately 110 meters. This value was calculated from the $\delta^{18}\text{O}$ smoothed curve in Figure 19.

An additional consequence of the time of deposition relates to the inferred subsidence rate, 6 m/Ma. Approximately 1 m of subsidence took place over the 160 kyr interval that most likely represents the time required to form the LL strata. The measured height of the parasequences (6a to 2a) is 3.4 m. The mean depth determined by the use of bivalve depth ranges, as previously demonstrated, was 7.5 m. Therefore, in order to encompass both the mean bivalve depth of the shell beds and the subaerially exposed packstones, the amplitude of the fifth-order, sea-level fluctuations must have exceeded approximately 10 m (7.5 m + 3.4 m height of strata - 1 m of subsidence). This is at the lower end of estimates of fifth-order sea-level fluctuations, which range from 1 m to 150 m (Kerans and Tinker, 1997).

Impacts of Uplift and Subsidence

Absolute elevation changes of the depositional environment relative to the geoid are a factor that must be considered. The causal mechanisms can include karstic collapse, uplift induced by karstification of overburden, and subsidence. Compared to active-margin regions, such as Barbados and Papua-New Guinea, where changes in Quaternary sea level have been investigated (Chappell, 1974; Fairbanks, 1989; Chappell and Polach,

1991), subsidence and uplift is not a major factor in southern peninsular Florida.

However, considering the comparatively small thickness of the sections, even relatively small amounts of change in the platform's elevation could impact the stratigraphic signature. Previous studies typically assume that the Florida platform is stable (Denizman and Randazzo, 2000) and ignore subsidence and uplift.

Reductions in the mass of overburden by erosion or dissolution (e.g. karstification) can lead to isostatic uplift, particularly in areas with abundant karst and major springs; calculated rates of loss of elevation of limestone due to dissolution (1 m limestone/38 ka) and the corresponding isostatic uplift in response to the loss of limestone (1 m/41 ka) are approximately equal (Opdyke et al., 1984), leading to no significant net change in elevation. However, this uplift phenomenon appears to be restricted to the karst-rich northern portion of the Florida Peninsula (Opdyke et al., 1984).

The LL overburden is 5.5 m thick and composed primarily of sands with some fossil material. These sediments lack any indication of karstification and is sufficiently thin so that it should not be a factor in potential uplift. Additionally, because the elevation of the modern surface is 5 m above sea-level and the post-Bermont highstand was approximately 10 m above modern sea-level (DuBar, 1974; Wornardt and Vail, 1991), the mass of potentially absent overburden material (i.e., material that may have been deposited during the post-Bermont highstand and that has since eroded) is less than 5 m. Thus, the potential loss of overburden is unlikely to have caused uplift at LL. Furthermore, as previously discussed, there was not evidence of karstification in the LL Bermont strata beyond an early merokarst.

Modeling Early Pleistocene Sea Levels with the Bermont Strata

Given the age assigned to the Bermont of 1.1 Ma to 1.6 Ma (Lyons, 1991), the 6 m/Ma subsidence rate yields a range of Bermont-age subsidence relative to the present day elevations from 6.6 m for younger strata to 9.6 m for older strata, with a mean of 8.1 m. As a result, the LL Bermont sequence should be located an average of 8.1 m below its original elevation of deposition. Because the numerical age of the beds is not known, the mean will be used in subsequent calculations of Bermont age sea-level stands.

Adding this correction of 8.1 m to the surveyed depth relative to modern mean sea level (mmsl) of the karst beds gives a height of 3.7 m ($-4.4 + 8.1$) above mmsl for the lowermost packstone bed 6a and a height of 6.9 m ($-1.2 + 8.1$) above mmsl for uppermost packstone bed 2a. The mean height of these packstone beds is 5.3 m above mmsl. As previously discussed, the bivalve taxa indicate that the average water depth was 7.5 m. Therefore, the sea-level position, most likely representing peak highstand, during the formation of the unit was most likely an average of 12.8 m above the modern mean sea level, with a possible range from 11.2 m to 14.4 m. These relationships are summarized in Figure 20. A representative reconstruction of this sea level, based on modern elevations, is shown in Figure 4.

The key point is that sea levels during this period were higher than modern sea level. The value of 12.8 m above the modern mean sea level compares favorably with existing estimates of early Pleistocene sea levels. By synthesizing a variety of sources, Haq et al. (1987) calculate a highstand between 10 m and 20 m above mmsl between 1.1 Myr and 1.5 Myr. Based on paleoecological and topographic data, Dubar (1974) assigned a maximum sea level of “+ 50” feet (15 m) to the Bermont formation.

Malmgren and Berggren (1987) calculated a eustatic highstand approximately 15 m above mmsl during the early Pleistocene using $\delta^{18}\text{O}$ of benthic foraminifera.

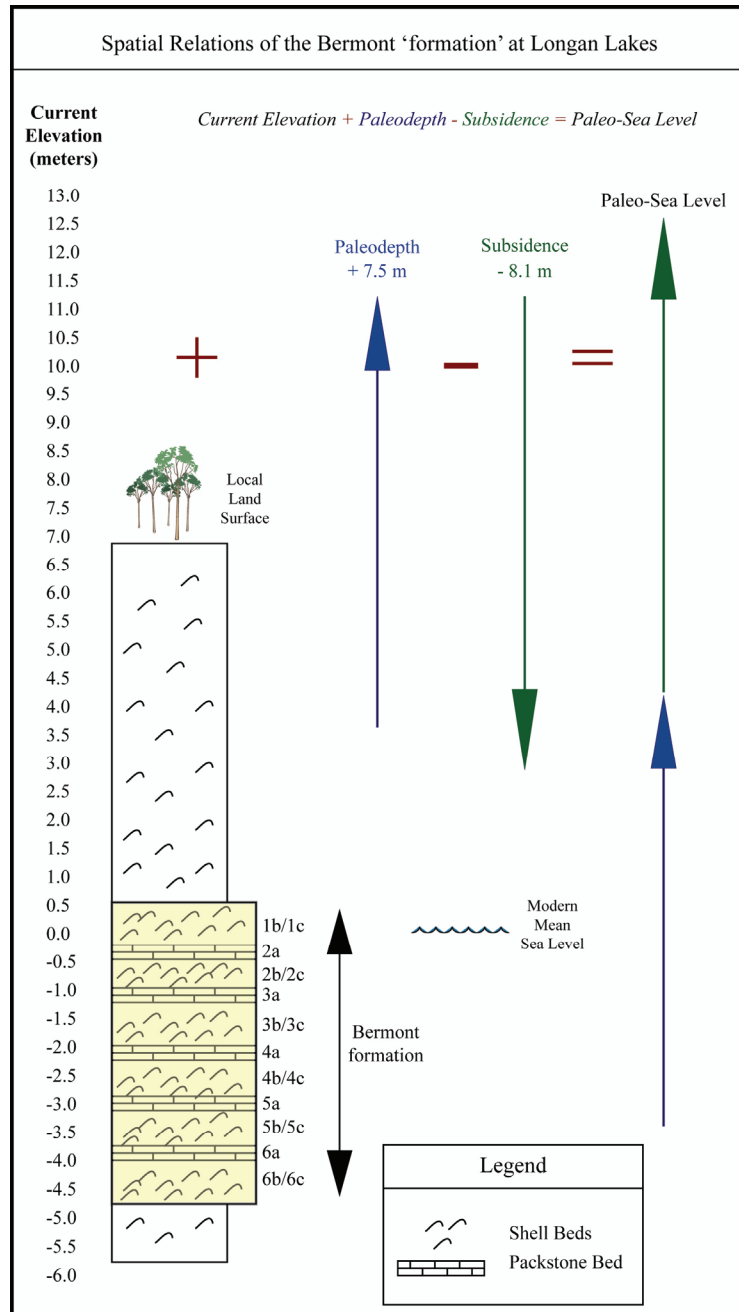


Figure 20. Spatial relations of the Bermont 'formation' at Longan Lakes. The early Pleistocene sea-level is the sum of the current elevation, the paleodepth, minus the subsidence (which adds because it is negative). Thus, the early Pleistocene sea level was approximately 13 m above the modern sea level.

However, if the previously discussed presence of in situ *Anodontia alba* is a more reliable indicator of a water depth than the average minimum depth of the most common taxa, then the sea level stand would instead only be 6.3 m above mmsl. If this lower sea level highstand is accurate, then it indicates that previous estimates of early Pleistocene msl are too high. A representative reconstruction of this sea level, based on modern elevations, is shown in Figure 21.

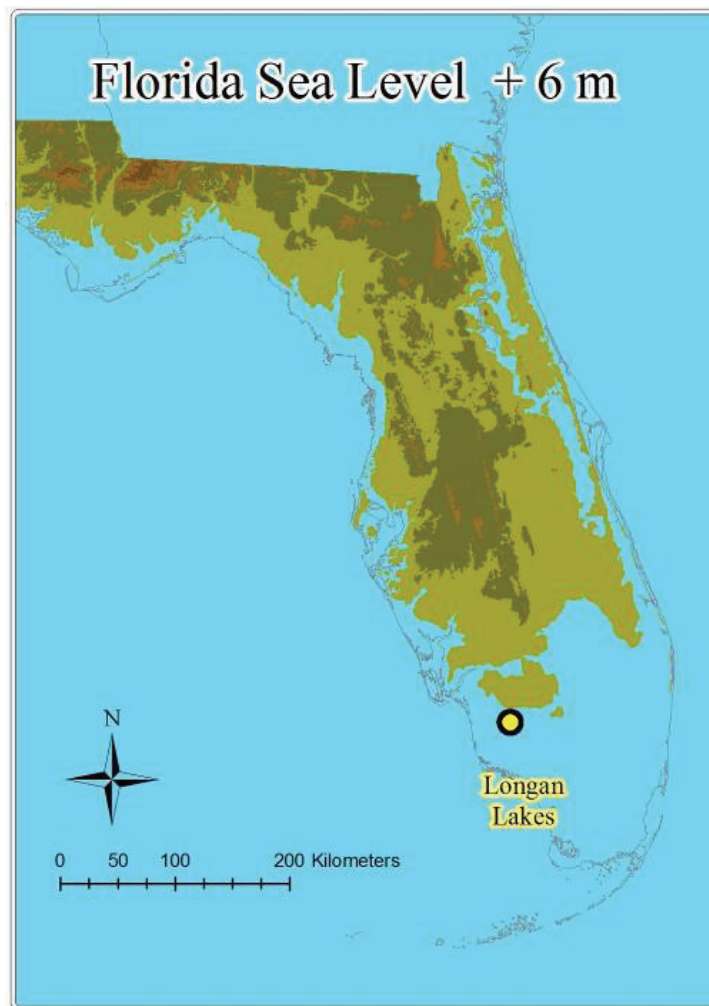


Figure 21. +6.3 m Pleistocene high sea level based on *Anodontia alba* (1.2 Ma).

Chapter Six

Conclusions

The early Pleistocene Bermont strata at Longan Lakes preserve extraordinarily unambiguous indicators of sea level fluctuations; a 6-m cyclothem-type set of beds consisting of six marine shell beds with five interbedded, diagenetically produced, packstone beds. The repetitive nature of the LL Bermont strata allows for additional tuning of Florida's sequence stratigraphic model and supports the hypothesis that the Bermont formation belongs within sequence cycle 3.8.

The oxygen isotope record (Joyce, 1990; Mix et al., 1995a; Mix et al., 1995b) shows that frequent low-amplitude eustatic change dominates the sea-level record during the early Pleistocene; the LL Bermont strata provide strong circumstantial evidence that these rapid eustatic changes affected south Florida's lower Pleistocene stratigraphy. The strata indicate that early Pleistocene sea-levels fluctuated a minimum of 10 m between highstands and lowstands. The Bermont strata also provide evidence that supports a series of early Pleistocene eustatic highstands between + 6 m and + 13 m above Recent sea-levels. Furthermore, south Florida's 6 m/Myr subsidence rate, low but measurable, allows for preservation of strata that would otherwise be reworked during transgressive cycles across the low-gradient carbonate platform.

This study also indicates that it is likely that the Bermont strata at LL were deposited between approximately 1.3 and 1.1 Ma based on correlation with the sea-level

curve of Haq et al. (1987). Verification by better-constrained chronostratigraphic data between individual beds at LL will provide independent verification of the results and will allow further tuning of the model.

Finally, this study shows that it is likely that the deposits of the Bermont formation record an interval of at least 160 kyr during the early Pleistocene. The faunal package that identifies the assemblage therefore persisted for a significant amount of time and is consequently important to studies of Florida's early Pleistocene, particularly paleoecological studies that investigate the impact of sea level changes on marine fauna. Previous studies have shown relationships between sea level and species richness (Harries, 2003) as well as the independence of species richness from sea level (Valentine and Jablonski, 1991); the LL strata, a record of multiple highstand intervals, provide a ready-made workshop to study the effects of repetitive sea level changes on early Pleistocene fauna.

References Cited

- Abbott, R.T., Morris, P.A., National Audubon Society, National Wildlife Federation, and Peterson, R.T., 1995, *A Field Guide to Shells: Atlantic and Gulf Coasts and the West Indies*: Boston, Houghton Mifflin, 350 p.
- Adams, A.E., and MacKenzie, W.S., 1998, *A color atlas of carbonate sediments and rocks under the microscope*: New York, John Wiley & Sons, 180 p.
- Allmon, W.D., 1992, Whence southern Florida's Plio-Pleistocene shell beds?, *in* Scott, T.M., and Allmon, W.D., eds., *Florida Geological Survey Special Publication 36: The Plio-Pleistocene Stratigraphy and Paleontology of Southern Florida*.
- Allmon, W.D., 1996, Late Neogene oceanographic change along Florida's West coast: evidence and mechanisms: *The Journal of Geology*, v. 104, p. 143-162.
- Banasiak, R., Greene, S., Herbert, G.S., Harries, P.J., Portell, R., and Oches, E.A., 2006, Comparing gastropod guilds prior to and following a regional mass extinction: examples from the Plio-Pleistocene of Florida, *The Geological Society of America, 55th Annual Meeting: Southeastern Section*: Knoxville, TN.
- Berger, A., and Loutre, M.F., 1991, Insolation values for the climate of the last 10 million years: *Quaternary Science Reviews*, v. 10, p. 297-317.
- Blackwelder, B.W., 1981, Late Cenozoic stages and molluscan zones of the U.S. middle Atlantic Coastal Plain: *Memoir 12, The Paleontological Society*, 34 p.
- Blum, M.D., Misner, T.J., Collins, E.S., Scott, D.B., Morton, R.A., and Aslan, A., 2001, Middle Holocene sea-level rise and highstand at +2 M, Central Texas coast: *Journal of Sedimentary Research*, v. 71, p. 581-588.

- Bradley, R.S., 1999, *Paleoclimatology*: Amsterdam, Harcourt Academic Press, 613 p.
- Broecker, W.S., 1969, unpublished data.
- Budd, D.A., Gaswirth, S.B., and Oliver, W.L., 2002, Quantification of macroscopic subaerial exposure features in carbonate rocks: *Journal of Sedimentary Research*, v. 72, p. 917-928.
- Chappell, J., 1974, *Geology of Coral Terraces, Huon Peninsula, New Guinea; A Study of Quaternary Tectonic Movements and Sea-Level Changes*: *Geol Soc Am Bull*, v. 85, p. 553-570.
- Chappell, J., and Polach, H., 1991, Post-glacial sea-level rise from a coral record at Huon Peninsula, Papua New Guinea: *Nature*, v. 349, p. 147-149.
- Chelladurai, J., Harries, P.J., Herbert, G.S., Oches, E.A., and Portell, R., 2006, Community analysis of the bivalves in the early Pleistocene Bermont formation (poster), The Geological Society of America, 55th Annual Meeting, Southeastern Section: Knoxville, TN.
- Chen, E., and Gerber, J.F., 1990, *Climate*, in Myers, R.L., and Ewel, J.J., eds., *Ecosystems of Florida*: Orlando, University of Central Florida Press, p. 765.
- Choquette, P.W., and Trusell, F.C., 1978, A procedure for making the titan-yellow stain for Mg-calcite permanent: *Journal of Sedimentary Research*, p. 639-641.
- Coates, A.G., Collins, L.S., Aubry, M.-P., and Berggren, W.A., 2004, The Geology of the Darien, Panama, and the late Miocene-Pliocene collision of the Panama arc with northwestern South America: *Geological Society of America Bulletin*, p. 1327-1344.
- Coates, A.G., Jackson, J.B.C., Collins, L.S., Cronin, T.M., Dowsett, H.J., Bybell, L.M., Jung, P., and Obando, J.A., 1992, Closure of the Isthmus of Panama: the near-shore marine record of Costa Rica and western Panama: *Geological Society of America Bulletin*, p. 814-828.

- Coe, A.L., Bosence D.W.J., Church, K.D., Flint, S.S., Howell, J.A., Wilson, R.C.L., 2003, *The Sedimentary Record of Sea-Level Change*: Cambridge, Cambridge University Press.
- Compton, J.S., 1997, Origin and paleoceanographic significance of Florida's phosphorite deposits, *in* Randazzo, A.F., and Jones, D.S., eds., *The Geology of Florida*: Gainesville, University Press of Florida, p. 327.
- Cunningham, K.J., Bukry, D., Sato, T., Barron, J.A., Guertin, L.A., and Reese, R.S., 2001, Sequence stratigraphy of a south Florida carbonate ramp and bounding siliciclastics (Late Miocene-Pliocene), Florida Geological Survey, Special Publication 49, p. 35-66.
- Cunningham, K.J., McNeill, D.F., Guertin, L.A., Ciesielski, P.F., Scott, T.M., and de Verteuil, L., 1998, New Tertiary stratigraphy for the Florida Keys and southern peninsula of Florida: *Geological Society of America Bulletin*, v. 110, p. 231-258.
- Cunningham, K.J., Wacker, M.A., Robinson, E., Dixon, J.F., and Wingard, G.L., 2005, A cyclostratigraphic and borehole-geophysical approach to development of a three-dimensional conceptual hydrogeologic model of the karstic Biscayne Aquifer, southeastern Florida, U.S. Geological Survey.
- Davis, R.A., 1994a, Barrier island systems - a geologic overview, *in* Davis Jr., R.A., ed., *Geology of Holocene barrier island systems*: Berlin, Springer Verlag, p. 1-46.
- Davis, R.A., 1994b, Barriers of the Florida Gulf Peninsula, *in* Davis Jr., R.A., ed., *Geology of Holocene barrier island systems*: Berlin, Springer Verlag, p. 167-206.
- Denizman, C., and Randazzo, A.F., 2000, Post-Miocene subtropical karst evolution, lower Suwannee River basin, Florida: *Geological Society of America Bulletin*, v. 112, p. 1804-1813.
- DePratter, C.B., and Howard, J.D., 1981, Evidence for a sea level lowstand between 4500 and 2400 years B.P. on the southeast coast of the United States: *Journal of Sedimentary Petrology*, v. 51, p. 1287-1295.
- Diekmann, B., and Kuhn, G., 2002, Sedimentary record of the mid-Pleistocene climate transition in the southeastern South Atlantic (ODP Site 1090): *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 182, p. 241-258.

- Dodd, J.R., and Stanton, R.J.J., 1981, *Paleoecology, concepts and applications*: New York, John Wiley & Sons, 559 p.
- Dreybrodt, W., 1988, *Processes in karst systems*: Berlin, Springer-Verlag, 288 p.
- Driscoll, N.W., and Haug, G.H., 1998, A short circuit in thermohaline circulation: a cause for northern glaciation?: *Science*, v. 282, p. 436-438.
- Drummond, C.N., and Wilkinson, B.H., 1993, Carbonate cycle stacking patterns and hierarchies of orbitally forced eustatic sealevel change: *Journal of Sedimentary Petrology*, v. 63, p. 369-377.
- DuBar, J.M., 1962, Neogene biostratigraphy of the Charlotte Harbor area in southwestern Florida: *Florida Geological Survey Bulletin 43*, Florida Geological Survey.
- DuBar, J.R., 1974, Summary of the Neogene stratigraphy of southern Florida, *in* Oaks, R.Q.J., and Dubar, J.R., eds., *Post-Miocene stratigraphy Central and Southern Atlantic Coastal Plain*: Logan, Utah State University Press.
- Duncan, D.S., Locker, S.D., Brooks, G.R., Hine, A.C., and Doyle, L.J., 2003, Mixed carbonate-siliciclastic infilling of a Neogene carbonate shelf-valley system: Tampa Bay, West-Central Florida: *Marine Geology*, v. 200, p. 125-156.
- Dunham, R.J., 1962, Classification of carbonate rocks according to depositional texture, v. 1, p. 108-121, 7 Pls.
- Embry, A.F., and Klovan, J.E., 1972, Absolute water depth of late Devonian paleoecological zones, v. 61/2, p. 672-686.
- Emery, D., and Myers, K.J., 1996, *Sequence stratigraphy*: Oxford, Blackwell science, p. 297.
- Evans, M.W., 1989, Late Miocene to Quaternary seismic and lithologic sequence stratigraphy of the Charlotte Harbor area: Southwest Florida: Saint Petersburg, University of South Florida.

- Evans, M.W., and Hine, A.C., 1991, Late Neogene sequence stratigraphy of a carbonate-siliciclastic transition: Southwest Florida: Geological Society of America Bulletin, v. 103, p. 679-699.
- Fairbanks, R.G., 1989, A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation: Nature, v. 342, p. 637-642.
- Fairbanks, R.G., and Matthews, R.K., 1978, The marine oxygen isotope record in Pleistocene coral, Barbados, West Indies: Quaternary Research, v. 10, p. 181-196.
- Ferguson, T.W., and Davis, R.A.J., 2003, Post-Miocene stratigraphy and depositional environments of valley-fill sequences at the mouth of Tampa Bay, Florida: Marine Geology, v. 200, p. 157-170.
- Flügel, E., 2004, Microfacies of carbonate rocks: Berlin, Springer.
- Folk, R.L., 1973, The natural history of crystalline calcium carbonate: effect of magnesium content and salinity: Journal of Sedimentary Petrology, v. 44, p. 40-53.
- Friedman, G.M., 1959, Identification of carbonate minerals by staining methods: Journal of Sedimentary Petrology, v. 29, p. 87-97.
- Goldhammer, R.K., Dunn, P.A., and Hardie, L.A., 1990, Depositional cycles, composite sea-level changes, cycle stacking patterns, and the hierarchy of stratigraphic forcing: examples from Alpine Triassic platform carbonates: Geological Society of America Bulletin, v. 102, p. 535-562.
- Goldhammer, R.K., Harris, M.T., Dunn, P.A., and Hardie, L.A., 1993, Sequence stratigraphy and systems tract development of the Latemar Platform, Middle Triassic of the Dolomites (northern Italy): outcrop calibration keyed by cycle stacking patterns, *in* Loucks, R.G., and Sarg, J.F., eds., Carbonate sequence stratigraphy: recent developments and applications, AAPG Memoir 57: Tulsa, AAPG, p. 353-388.

- Greene, S., Banasiak, R., Chelladurai, J., Harries, P.J., Herbert, G.S., Oches, E.A., and Portell, R., 2006, An evenness study of the Pleistocene Bermont fauna of Florida (poster), The Geological Society of America, 55th Annual Meeting, Southeastern Section: Knoxville, TN.
- Griffiths, J.C., 1967, Scientific method in analysis of sediments: New York, McGraw-Hill Book Company, 508 p.
- Hallam, A., 1992, Phanerozoic sea-level changes: New York, Columbia university press, 266 p.
- Haq, B.U., Hardenbol, J., and Vail, P.R., 1987, The new chronostratigraphic basis of Cenozoic and Mesozoic sea level cycles, *in* Ross, C.A., and Haman, D., eds., Timing and depositional history of eustatic sequences: constraints on seismic stratigraphy, special publication no. 24: Houston, Cushman foundation for foraminiferal research, p. 7-13.
- Harries, P.J., 2003, Relationship between sea level and species richness, *in* Harries, P.J., ed., High resolution approaches in stratigraphic paleontology: Dordrecht, Kluwer academic publishers, p. 474.
- Harris, W.B., and Zullo, V.A., 1993, Problems in application of sequence stratigraphy to the Florida Neogene, *in* Zullo, V.A., Harris, W.B., Scott, T.M., and Portell, R.W., eds., Florida Geological Survey Special Publication 37: The Neogene of Florida and adjacent regions.
- Haug, G.H., and Tiedemann, R., 1998, Effect of the formation of the Isthmus of Panama on Atlantic Ocean thermohaline circulation: *Nature*, v. 393, p. 673-676.
- Hays, J.D., Imbrie, J., and Shackleton, N.J., 1976, Variations in the Earth's orbit: pacemaker of the Ice Ages: *Science*, v. 194, p. 1121-1132.
- Herbert, G.S., 2004, Biotic Evolution in Plio-Pleistocene Marine Environments of Tropical America: Systematic, Phylogenetic, and Stable Isotope Investigations of the Muricidae (Mollusca: Gastropoda): Unpublished Ph.D. dissertation, University of California, Davis.

- Hine, A.C., 1997, Structural and paleoceanographic evolution of the margins of the Florida Platform, *in* Randazzo, A.F., and Jones, D.S., eds., *The Geology of Florida*: Gainesville, University Press of Florida, p. 327.
- Hine, A.C., Brooks, G.R., Davis Jr., R.A., Doyle, L.J., Gelfenbaum, G., Locker, S.D., Twichell, D.C., and Weisberg, R.H., 2001, A summary of findings of the West-Central Florida Coastal Studies Project, United States Geological Survey, p. 41.
- Hine, A.C., Brooks, G.R., Davis Jr., R.A., Duncan, D.S., Locker, S.D., Twichell, D.C., and Gelfenbaum, G., 2003, The west-central Florida inner shelf and coastal system: a geologic conceptual overview and introduction to the special issue: *Marine Geology*, v. 200, p. 1-17.
- Hoefs, J., 2004, *Stable isotope geochemistry*: Berlin, Springer, 244 p.
- Hoerle, S.E., 1970, Mollusca of the "Glades" unit of southern Florida: Part II; list of molluscan species of the Belle Glade Rock Pit, Palm Beach County, Florida: *Tulane Stud. Geol. Paleont.*, v. 8, p. 56-68.
- Hulbert, R.C.J., and Morgan, G.S., 1989, Stratigraphy, paleoecology, and vertebrate fauna of the Leisey Shell Pit local fauna, early Pleistocene (Irvingtonian) of southwestern Florida.: *Papers in Florida Paleontology*, v. 2, p. 1-19.
- Imbrie, J., Berger, A., Boyle, E.A., Clemens, S.C., Duffy, A., Howard, W.R., Kukla, G., Kutzbach, J.E., Martinson, D.G., McIntyre, A., Mix, A.C., Molfino, B., Morley, J.J., Peterson, L.C., Pisias, N.G., Prell, W.L., Raymo, M.E., Shackleton, N.J., and Toggweiler, J.R., 1993, On the structure and origin of major glaciation cycles: 2. The 100,000-year cycle: *Paleoceanography*, v. 8, p. 699-735.
- Joyce, J.E., 1990, High-resolution planktic stable isotope record and spectral analysis for the last 5.35 m.y.: Ocean Drilling Program Site 625, northeast Gulf of Mexico: *Paleoceanography*, v. 5, p. 507-529.
- Kerans, C., and Tinker, S.W., 1997, Sequence stratigraphy and characterization of carbonate reservoirs: short course notes No. 40: Tulsa, Society for sedimentary geology.
- Kidwell, S.M., 1986, Models for fossil concentrations: paleobiologic implications: *Paleobiology*, v. 12, p. 6-24.

- Land, L.S., 1970, Phreatic versus vadose meteoric diagenesis of limestones: evidence from a fossil water table: *Sedimentology*, v. 14, p. 175-185.
- Le Roux, J.P., Gómez, C., Fenner, J., and Middleton, H., 2004, Sedimentological processes in a scarp-controlled rocky shoreline to upper continental slope environment, as revealed by unusual sedimentary features in the Neogene Coquimbo Formation, north-central Chile: *Sedimentary Geology*, v. 165, p. 67-92.
- Longman, M.W., 1980, Carbonate diagenetic textures from nearsurface diagenetic environments: *AAPG Bulletin*, v. 64, p. 461-487.
- Lyons, W.G., 1991, Post-Miocene species of *Latirus* Montfort, 1810 (Mollusca: Fasciolarriidae) of southern Florida, with a review of regional marine biostratigraphy: *Bulletin of the Florida Museum of Natural History*, v. 35, p. 131-208.
- Lyons, W.G., 1992, Caloosahatchee-age and younger molluscan assemblages at APAC mine, Sarasota county, Florida, in Scott, T.M., and Allmon, W.D., eds., *Florida Geological Survey Special Publication 36: The Plio-Pleistocene Stratigraphy and Paleontology of Southern Florida*.
- MacFadden, B.J., 1997, Fossil mammals of Florida, in Randazzo, A.F., and Jones, D.S., eds., *The Geology of Florida*: Gainesville, University Press of Florida, p. 327.
- Mallinson, D.J., and Compton, J.S., 1995, Mixed carbonate-siliciclastic sequence stratigraphy utilizing strontium isotopes: deciphering the Miocene sea-level history of the Florida Platform, in Haq, B.U., ed., *Sequence stratigraphy and depositional response to eustatic, tectonic and climatic forcing*: Dordrecht, Kluwer Academic Publishers, p. 381.
- Malmgren, B.A., and Berggren, W.A., 1987, Evolutionary changes in some late Neogene planktonic foraminiferal lineages and their relationships to paleoceanographic changes: *Paleoceanography*, v. 2, p. 445-456.
- McCartan, L., Owens, J.P., Blackwelder, B.W., Szabo, B.J., Belknap, D.F., Kriaušakul, N., Mitterer, R.M., and Wehmiller, J.F., 1982, Comparison of amino acid racemization geochronology with lithostratigraphy, biostratigraphy, uranium-series coral dating, and magnetostratigraphy in the Atlantic coastal plain of the southeastern United States: *Quaternary Research*, v. 18, p. 337-359.

- Miller, G.H., and Brigham-Grette, J., 1989, Amino acid geochronology: resolution and precision in carbonate fossils: *Quaternary International*, v. 1, p. 111-128.
- Missimer, T.M., 1992, Stratigraphic relationships of sediment facies within the Tamiami Formation of southwest Florida: proposed intraformational correlations, *in* Scott, T.M., and Allmon, W.D., eds., *Florida Geological Survey Special Publication 36: The Plio-Pleistocene Stratigraphy and Paleontology of Southern Florida*.
- Mitterer, R.M., 1974, Pleistocene stratigraphy in southern Florida based on amino acid diagenesis in fossil *Mercenaria*: *Geology*, v. 2, p. 425-428.
- Mitterer, R.M., 1975, Ages and diagenetic temperatures of Pleistocene deposits of Florida based on isoleucine epimerization in *Mercenaria*: *Earth and Planetary Science Letters*, v. 28, p. 275-282.
- Mix, A.C., Le, J., and Shackleton, N.J., 1995a, Benthic foraminiferal stable isotope stratigraphy of Site 846: 0-1.8 Ma, *in* Pisias, N.G., Mayer, L., Janecek, T., Palmer-Julson, A., and Van Andel, T.H., eds., *Proceedings of the Ocean Drilling Program, Scientific Results 138*, p. 839-854.
- Mix, A.C., Pisias, N.G., Rugh, W., Wilson, J., Morey, A., and Hagelberg, T., 1995b, Benthic foraminiferal stable isotope record from Site 849, 0-5 Ma: local and global climate changes., *in* Pisias, N.G., Mayer, L., Janecek, T., Palmer-Julson, A., and Van Andel, T.H., eds., *Proceedings of the Ocean Drilling Program, Scientific Results 138*, p. 371-412.
- Muhs, D.R., Szabo, B.J., McCartan, L., Maat, P.B., Bush, C.A., and Halley, R.B., 1992, Uranium-series age estimates of corals from Quaternary marine sediments of southern Florida, *in* Scott, T.M., and Allmon, W.D., eds., *Florida Geological Survey Special Publication 36: The Plio-Pleistocene Stratigraphy and Paleontology of Southern Florida*.
- Mullins, H.T., Gardulski, A.F., Hine, A.C., Melillo, A.J., Sherwood, W.W.J., and Applegate, J., 1988, Three-dimensional sedimentary framework of the carbonate ramp slope of central west Florida: a sequential seismic stratigraphic perspective: *Geological Society of America Bulletin*, v. 100, p. 514-533.
- Mullins, H.T., and Neumann, A.C., 1979, Geology of the Miami terrace and its paleoceanographic implications: *Marine Geology*, v. 30, p. 205-232.

- NACSN, N.A.C.o.S.N., 2005, North American stratigraphic code: AAPG Bulletin, v. 89, p. 1547-1591.
- Naish, T., and Kamp, P.J.J., 1997, Sequence stratigraphy of sixth-order (41 k.y.) Pliocene-Pleistocene cyclothems, Wanganui Basin, New Zealand; a case for the regressive systems tract: Geological Society of America Bulletin, v. 109, p. 978-999.
- Oches, E.A., and McCoy, W.D., 1995, Aminostratigraphic evaluation of conflicting age estimates for the "Young Loess" of Hungary: Quaternary Research, v. 44, p. 160-170.
- Olsson, A.A., 1964, The geology and stratigraphy of south Florida
in Olsson, A.A., and Petit, R.E., eds., Some Neogene mollusca from Florida and the Carolinas: Bulletin of American Paleontology, Volume 47, p. 511-526.
- Opdyke, N.D., Spangler, D.P., Smith, D.L., Jones, D.S., and Lindquist, R.C., 1984, Origin of the epeirogenic uplift of Plio-Pleistocene beach ridges in Florida and development of the Florida karst: Geology, v. 12, p. 226-228.
- Perkins, R.D., 1977, Depositional framework of Pleistocene rocks in south Florida: Geological Society of America Memoir, v. 147, p. 131-198.
- Petuch, E.J., 1993, Patterns of gastropod extinction in the Plio-Pleistocene Okeechobean Sea of southern Florida, *in* Zullo, V.A., Harris, W.B., Scott, T.M., and Portell, R.W., eds., Florida Geological Survey Special Publication 37: The Neogene of Florida and adjacent regions.
- Petuch, E.J., 2003, Cenozoic seas: the view from eastern North America: Boca Raton, CRC Press, 318 p.
- Posamentier, H.W., and Allen, G.P., 1999, Siliciclastic sequence stratigraphy - concepts and applications: Tulsa, Society for sedimentary geology, 210 p.
- Prothero, D.R., and Schwab, F., 1996, Sedimentary geology: an introduction to sedimentary rocks and stratigraphy: New York, W.H. Freeman and Company.

- Read, J.K., and Goldhammer, R.K., 1988, Use of Fischer plots to define third-order sea-level curves in Ordovician peritidal cyclic carbonates, *Appalachians: Geology*, v. 16, p. 895-899.
- Redfern, C., 2001, Bahamian seashells: a thousand species from Abaco, Bahamas: Boca Raton, BahamianSeashells.com, Inc., 280 p.
- Richmond, G.M., and Fullerton, D.S., 1986, Summary of Quaternary glaciations in the United States of America: *Quaternary Science Reviews*, v. 5, p. 183-196.
- Roof, S.R., Mullins, H.T., Gartner, S., Huang, T.C., Joyce, E., Prutzman, J., and Tjalsma, L., 1991, Climatic forcing of cyclic carbonate sedimentation during the last 5.4 million years along the west Florida continental margin: *Journal of Sedimentary Petrology*, v. 61, p. 1070-1088.
- Rosenberg, G., 2005, *Malacolog 4.0: A database of Western Atlantic marine mollusca*. [WWW database (version 4.0.2)].
- Ruddiman, W.F., 2001, *Earth's climate: past and future*: New York, W. H. Freeman and Company, 465 p.
- Rutter, N.W., Crawford, R.J., and Hamilton, R.D., 1985, Amino acid racemization dating, *in* Rutter, N.W., ed., *Dating methods of Pleistocene deposits and their problems*: Toronto, Geological Association of Canada.
- Sadler, P.M., Osleger, D.A., and Montañez, I.P., 1993, On the labeling, length, and objective basis of Fischer plots: *Journal of Sedimentary Petrology*, v. 63, p. 360-368.
- Sanford, P.K., Bourn, T., Oches, E.A., Harries, P.J., Herbert, G.S., and Portell, R., 2006, Stratigraphy and sea-level fluctuation in southern Florida: an aminostratigraphic approach, The Geological Society of America, 55th Annual Meeting: Southeastern Section: Knoxville, TN.
- Schlager, W., 2005, *Carbonate sedimentology and sequence stratigraphy*: Tulsa, Society for sedimentary geology, 200 p.

- Schmidt, W., 1997, Geomorphology and physiography of Florida, *in* Randazzo, A.F., and Jones, D.S., eds., The Geology of Florida: Gainesville, University Press of Florida, p. 327.
- Scholle, P.A., 1978, Memoir 27: A color illustrated guide to carbonate rock constituents, textures, cements, and porosities: Tulsa, The American Association of Petroleum Geologists, 241 p.
- Schwarcz, H.P., and Blackwell, B., 1985, Uranium-series disequilibrium dating, *in* Rutter, N.W., ed., Dating methods of Pleistocene deposits and their problems: Toronto, Geological Association of Canada.
- Schwarzacher, W., 1993, Cyclostratigraphy and the Milankovitch theory: Amsterdam, Elsevier, 225 p.
- Scott, T.M., 1992, Coastal plains stratigraphy: The dichotomy of biostratigraphy and lithostratigraphy - a philosophical approach to an old problem, *in* Scott, T.M., and Allmon, W.D., eds., Florida Geological Survey Special Publication 36: The Plio-Pleistocene Stratigraphy and Paleontology of Southern Florida.
- Scott, T.M., 1997, Miocene to Holocene history of Florida, *in* Randazzo, A.F., and Jones, D.S., eds., The Geology of Florida: Gainesville, University Press of Florida, p. 327.
- Selley, R.C., 2000, Applied sedimentology: San Diego, Academic Press, 523 p.
- Smith, D.L., and Lord, K.M., 1997, Tectonic evolution and geophysics of the Florida basement, *in* Randazzo, A.F., and Jones, D.S., eds., The Geology of Florida: Gainesville, University Press of Florida, p. 327.
- Stanley, S.M., 1986, Anatomy of a regional mass extinction; Plio-Pleistocene decimation of the western Atlantic bivalve fauna: *Palaios*, v. 1, p. 17-36.
- Taylor, D.W., 1966, Summary of North American Blancan non-marine mollusks: *Malacologia*, v. 4, p. 1-172.

- Vail, P.R., Audemard, F., Bowman, S.A., Eisner, P.N., and Perez-Cruz, G., 1991, The stratigraphic signature of tectonics, eustasy, and sedimentation, *in* Einsele, G., Ricken, W., and Seilacher, A., eds., *Cycles and events in stratigraphy*: Berline, Springer, p. 617-659.
- Valentine, J.W., and Jablonski, D., 1991, Biotic effects of sea level change; the Pleistocene test: *Journal of Geophysical Research*, v. 96, p. 6873-6878.
- Van Wagoner, J.C., Mitchum, R.M., Campion, K.M., and Rahmanian, V.D., 1990, Siliciclastic sequence stratigraphy in well logs, cores, and outcrops: concepts for high-resolution correlation of time and facies: Tulsa, American Association of Petroleum Geologists, 55 p.
- Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S., and Hardenbol, J., 1988, An overview of the fundamentals of sequence stratigraphy and key definitions: *Sea-Level Changes - An Integrated Approach*, SEPM Special Publication No. 42, p. 39-45.
- Visher, G., 1969, Grain size distributions and depositional processes: *Journal of Sedimentary Petrology*, v. 39, p. 1074-1106.
- Vokes, E.H., 1963, Cenozoic muricidae of the western Atlantic region. Part I *Murex sensu stricto*: *Tulane Stud. Geol.*, v. 1, p. 93-123.
- Waller, T.R., 1969, The evolution of the *Argopecten gibbus* stock (mollusca: bivalvia), with emphasis on the Tertiary and Quaternary species of eastern North America: *J. Paleont.*, v. 43, p. 1-124.
- Warzeski, E.R., Cunningham, K.J., Ginsberg, R.N., Anderson, J.B., and Ding, Z.-D., 1996, A Neogene mixed siliciclastic and carbonate foundation for the Quaternary carbonate shelf, Florida Keys: *Journal of Sedimentary Research*, v. 66, p. 788-800.
- Webb, S.D., Morgan, G.S., Hulbert, R.C.J., Jones, D.S., MacFadden, B.J., and Mueller, P.A., 1989, Geochronology of a rich early Pleistocene vertebrate fauna, Leisey Shell Pit, Tampa Bay, Florida: *Quaternary Research*, v. 32, p. 96-110.

- Wehmiller, J.F., and Belknap, D.F., 1978, Alternative kinetic models for the interpretation of amino acid enantiomeric ratios in Pleistocene mollusks: examples from California, Washington, and Florida: *Quaternary Research*, v. 9, p. 330-348.
- White, W.A., 1970, The geomorphology of the Florida Peninsula, *Geological Bulletin* No. 51, *in* Survey, F.G., ed., Florida Geological Survey.
- Wilson, J.L., 1975, *Carbonate facies in geologic history*: Berlin, Springer-Verlag, 471 p.
- Wornardt, W.W., Jr., 1999, Revision of sequences boundaries and maximum flooding surfaces: Jurassic to Recent, Offshore Technology Conference: Houston, p. 18.
- Wornardt, W.W., and Vail, P.R., 1991, Revision of the Plio-Pleistocene cycles and their application to sequence stratigraphy and shelf and slope sediments in the Gulf of Mexico: *Transactions-Gulf Coast Association of Geological Societies*, v. 41, p. 719-745.
- Wright, V.P., 1982, The recognition and interpretation of paleokarsts: two examples from the Lower Carboniferous of South Wales: *Journal of Sedimentary Petrology*, v. 52, p. 83-94.
- Zachos, J., Pagani, M., Sloan, L., Thomas, E., and Billups, K., 2001, Trends, rhythms, and aberrations in global climate 65 Ma to present: *Science*, v. 292, p. 686-693.
- Zullo, V.A., and Harris, W.B., 1992, Sequence stratigraphy of marine Pliocene and lower Pleistocene deposits in southwestern Florida: preliminary assessment, *in* Scott, T.M., and Allmon, W.D., eds., *Florida Geological Survey Special Publication 36: The Plio-Pleistocene Stratigraphy and Paleontology of Southern Florida*.

Appendices

Appendix A: Lithologic Data

Descriptions of the individual beds each contain descriptions of the lithology and an overview of the biota.

Bed 1b 453-505

Moderately sorted silt to fine creamy white sands. Poorly defined fining upwards of grains. Over 50% bioclast material consisting of medium to small-cobble sized shells and shell fragments. No major preferred orientation, over 25% of shells are concave downward. Some coral fragments (*Manicina sp.*) are present. Fossils include *Anadontia sp.*, *Chione elevata*, *Turritella*, Lucinidae, and Pectinidae. Some Tellinidae are still articulated. Some *Anadontia sp.* are present in life position. Some *Chione elevata* are still articulated.

Bed 1c 435-453

Poorly sorted silt to cobble size white sediment and shelly bioclast material. Sediments fine upwards into Bed 1b. Over 75% bioclast material consists of medium to cobble sized shells and shell fragments. Some preference in position of shells is displayed, with over 25% of shells lying concave upward. Rare (< 1%) signs of predatory gastropod boring. Fewer than 10% of bivalves are articulated. Shelly material includes Veneridae (*Chione elevata*), *Turritella*, Lucinidae, Pectinidae, and *Conus sp.* Over 50% of shells are *Chione elevata*. Some Tellinidae are still articulated. Some *Anadontia sp.* are present in life position. Some *Chione elevata* are still articulated. Also noted *Busycon spiratum* (up to 9 cm), *Anomia sp.*, Ostreidae, and *Crepidula sp.*

Appendix A (Continued)

Bed 2a 425-435

Moderately sorted fine tan cemented sand and some shelly bioclast material classified as a packstone. Visible signs of weathering (e.g. vugs). Approximately 75% of shells are fragmented. Vertical breaks approximately 10 cm wide penetrate through Bed 2a every 1 to 2 meters allow sediments to penetrate from Bed 1c to Bed 2b. Freshwater gastropods (Planorbidae) present near top of bed.

Bed 2b 415-425

Dark grey to brown fossiliferous to sparsely fossiliferous packed biosparite, crystallized/lithified around sand to pebble sized bioclasts. Boring and burrowing traces (< 25%) are present. Very fine white sand is lodged between cracks and voids in the rock. Unit thickness ranges from 10 cm to 20 cm. Upper bedding plane is burrowed and pitted. Cracks in rock (approximately one 10 cm break every 1 to 2 meters) allow collapse and intrusion of material from Bed 1c. Bryozoan encrustation and trace yellow carbonate crystallization present within void cavities. Bioclasts include *Chione elevata*, *Diodora sp.*, and Olividae.

Wavy contact with Bed 2c fluctuates over 15 cm vertically

Bed 2c 392-415

Poorly sorted silt to cobble size white sediment and shelly bioclast material. Over 60% bioclast material consists of medium to cobble sized shells and shell fragments. Over 60% of disarticulated shells are concave upward. Sediments fine upwards in upper 5

Appendix A (Continued)

cm of bed. Rare (< 1%) signs of predatory boring, less than 10% of bivalves are articulated. Shelly material includes Veneridae (*Chione elevata*), *Turritella*, Lucinidae, and Pectinidae. Some Tellinidae are still articulated. Some *Anadontia sp.* are present in life position. Some *Chione elevata* are still articulated. Also noted *Busycon spiratum* (up to 9cm), *Anomia sp.*, Ostreidae, and *Crepidula sp.*

Abrupt contact, bottom of Bed 2c undulates 5 cm vertically over a 2 meter lateral distance.

Bed 3a 382-392

Dark grey to brown fossiliferous to sparsely fossiliferous micrite, crystallized/lithified around pebble sized bioclasts and classified as a packstone. Boring and burrowing traces (< 25%) are present. Very fine sand is lodged between cracks and voids in the rock. Unit is 10 to 20 cm thick. Bioclasts include *Chione elevata*, *Diodora sp.*, and Olividae. Bryozoan encrustation and trace yellow carbonate crystallization present within void cavities.

Abrupt contact, bottom of Bed 3a undulates 3 cm vertically over 2 meter lateral distance.

Bed 3b 345-382

Moderately sorted silt to fine creamy white sands. Over 40% bioclast material consisting of medium to small cobble sized shells and shell fragments. Fining upwards

Appendix A (Continued)

but bioclast content up to 70% at top of bed. No major preferred orientation, over 25% of shells are concave downward. Fossils include *Chione elevata*, *Turritella*, *Brachiodontes* *sp.*, *Conus* *sp.*, Lucinidae, and Pectinidae. Some Tellinidae are still articulated. Some *Anadontia* *sp.* are present in life position. Some *Chione elevata* are still articulated. Some coral fragments (*Manicina* *sp.*) present.

Gradual, diffuse contact with over 5 cm relief.

Bed 3c 326-345

Poorly sorted silt to cobble size white sediment and shelly bioclast material. Over 60% bioclast material consisting of medium to cobble sized shells and shell fragments. No major preferred orientation, over 25% of shells are concave downward. Sediments fine upwards in upper 5 cm of bed. Rare (< 1%) signs of predatory boring, less than 10% of bivalves are articulated. Shelly material includes Veneridae (*Chione elevata*), *Turritella*, Lucinidae, and Pectinidae. Some Tellinidae are still articulated. Some *Anadontia* *sp.* are present in life position. Some *Chione elevata* are still articulated. Also noted *Busycon spiratum* (up to 9cm), *Anomia* *sp.*, Ostreidae, and *Crepidula* *sp.*

Wavy contact, top of Bed 4a weathered, contains boreholes and burrows with relief up to 25 cm.

Appendix A (Continued)

Bed 4a 280-326

Moderately sorted silt to fine creamy white sands. Grains are cemented with scattered friable areas that have a higher concentration of bioclastic debris, all classified as a packstone. Over 40% bioclast material consisting of medium to small cobble sized shells and shell fragments. Fining upwards. No major preferred orientation, over 25% of shells are concave downward. Fossils include *Chione elevata*, *Turritella*, Lucinidae, and Pectinidae. Some Tellinidae are still articulated. Some *Chione elevata* are still articulated. Some coral fragments (*Manicina sp.*) present.

Bed 4b 250-280

Moderately sorted silt to fine creamy white sands. Over 40% bioclast material consisting of medium to small cobble sized shells and shell fragments. Fining upwards. No major preferred orientation, over 25% of shells are concave downward. Fossils include *Chione elevata*, *Turritella*, Lucinidae, and Pectinidae. Some Tellinidae are still articulated. Some *Anadontia sp.* is present in life position. Some *Chione elevata* are still articulated. Some coral fragments (*Manicina sp.*) present.

Bed 4c 220-250

Poorly sorted silt to fine creamy white sands. Over 60% bioclast material consisting of medium to cobble sized shells and shell fragments. Fining upwards. No major preferred orientation, over 25% of shells are concave downward. Fossils include *Chione elevata*, *Conus sp.*, *Turritella*, Lucinidae, and Pectinidae. Some Tellinidae are still articulated. Some *Anadontia sp.* is present in life position. Some *Chione elevata* are still articulated.

Appendix A (Continued)

Flat linear contact with few dips.

Bed 5a 170-220

Dark grey to brown fossiliferous to sparsely fossiliferous micrite, crystallized/lithified around pebble sized bioclasts and classified as a packstone. Very fine sand is lodged between cracks and voids in the rock. Bottom of bed has 10% burrows (mm scale) and rhizolith (root) traces consisting of primarily vertical cylindrical tubes (mm scale) containing wood fragments. Some oxidation present near base of bed. Boring and burrowing traces (< 25%) are present. Bioclasts include *Chione elevate*, *Diodora sp.*, and Olividae. Bryozoan encrustation and trace yellow carbonate crystallization present within void cavities.

Bed 5b 150-170

Silty sand, moderately well-sorted with sand to gravel size bivalve and gastropod shells and shell fragments. Coral fragment of *Solenastrea hyades* > 15 cm diameter embedded in sediment, visible traces of other 5 to 10 cm spheres.

Bed 5c 110-150

Poorly sorted silty to fine creamy white sands. Over 60% bioclast material consisting of medium to cobble sized shells and shell fragments. Fining upwards. Over 25% of shells are concave upwards. Fossils include *Chione elevata*, *Turritella*, Lucinidae, and Pectinidae. Some Tellinidae are still articulated. Some *Anadontia sp.* are present in life position. Over 25 % of *Chione elevata* are still articulated.

Appendix A (Continued)

Bed 6a 90-110

Dark grey to brown fossiliferous to sparsely fossiliferous micrite, crystallized/lithified around pebble sized bioclasts and classified as a packstone. Orange “rust” oxidation present on over half of material. Very fine sand is lodged between cracks and voids in the rock. Boring and burrowing traces (< 25%) are present. Bioclasts include *Chione elevata*, *Diodora sp.*, and Olividae. Bryozoan encrustation and trace yellow carbonate crystallization present within void cavities.

Bed 6b 20-90

Poorly sorted silty to fine creamy white sands. Over 60% bioclast material consisting of medium to cobble sized shells and shell fragments. Over 25% of shells are concave upwards. Sediments coarsen upwards. Fossils include *Chione elevata*, *Turritella*, Lucinidae, and Pectinidae. Some Tellinidae are still articulated. Some *Anadontia sp.* are present in life position. Over 25 % of *Chione elevata* are still articulated.

Bed 6c 0-20

Moderately well-sorted fine clayey-silty sand with fine gravel sized shells including bivalves, barnacles, and shell fragments. Fossils include *Chione elevata*, Lucinidae, and Pectinidae.

Appendix B: Grain Size Data

Table 5. Summary of Grain Size Analysis.

[illegible]

Appendix B (Continued)

Table 6. Sorting Coefficient by Bed.

Bed	<i>Sorting Coefficient</i>			
6c	84	16	95	5
	3	4		1 5
	4		6.6	
	-0.25	-0.606060606		-0.856060606
5c	84	16	95	5
	2	4	0	5
	4		6.6	
	-0.5	-0.757575758		-1.257575758
4c	84	16	95	5
	2	4	0	4
	4		6.6	
	-0.5	-0.606060606		-1.106060606
3c	84	16	95	5
	2	4	0	4
	4		6.6	
	-0.5	-0.606060606		-1.106060606
2c	84	16	95	5
	1	4	0	4
	4		6.6	
	-0.75	-0.606060606		-1.356060606
1a	84	16	95	5
	0	4	-1	4
	4		6.6	
	-1	-0.757575758		-1.757575758

Appendix B (Continued)

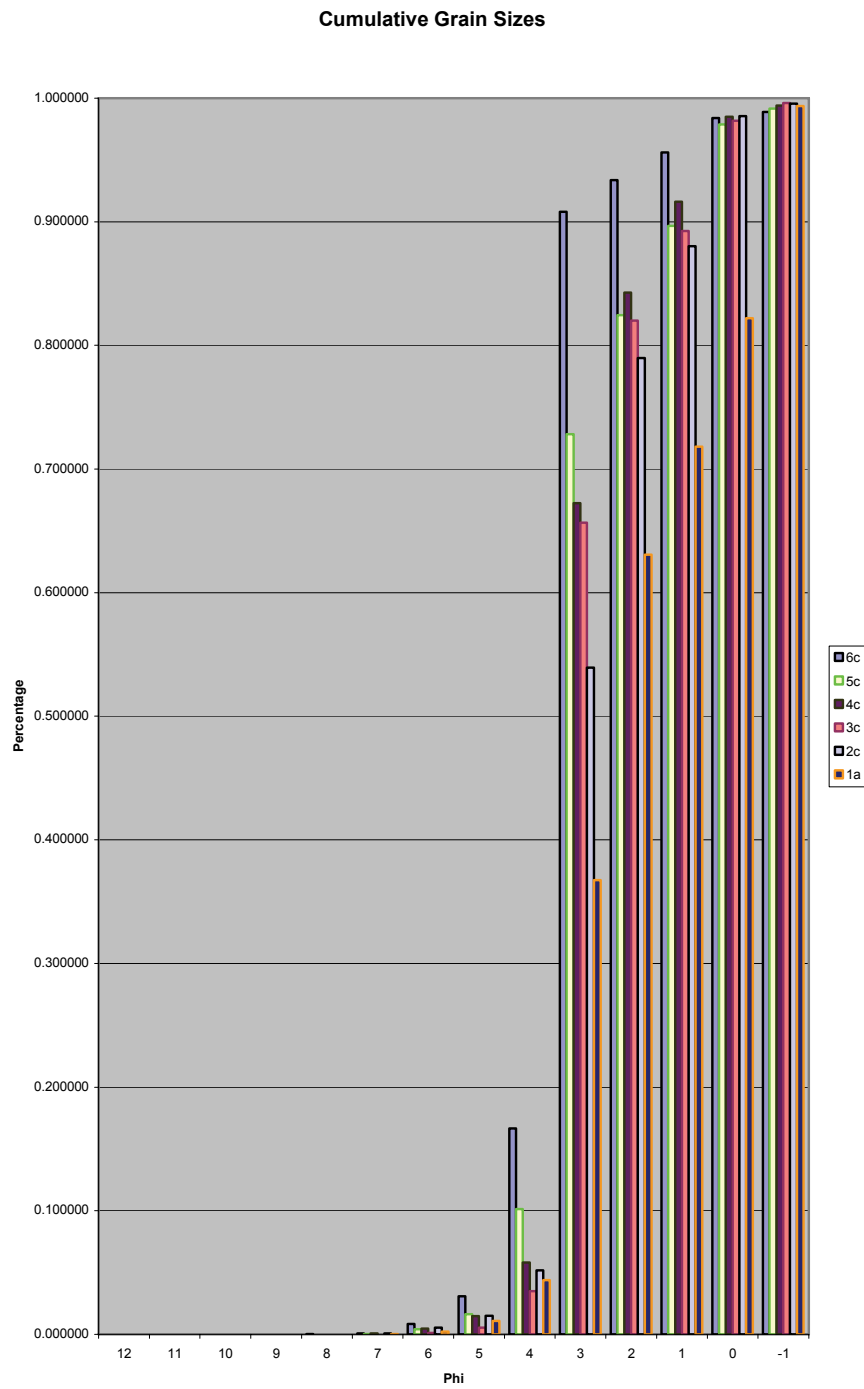


Figure 22. Cumulative grain sizes.

Appendix B (Continued)

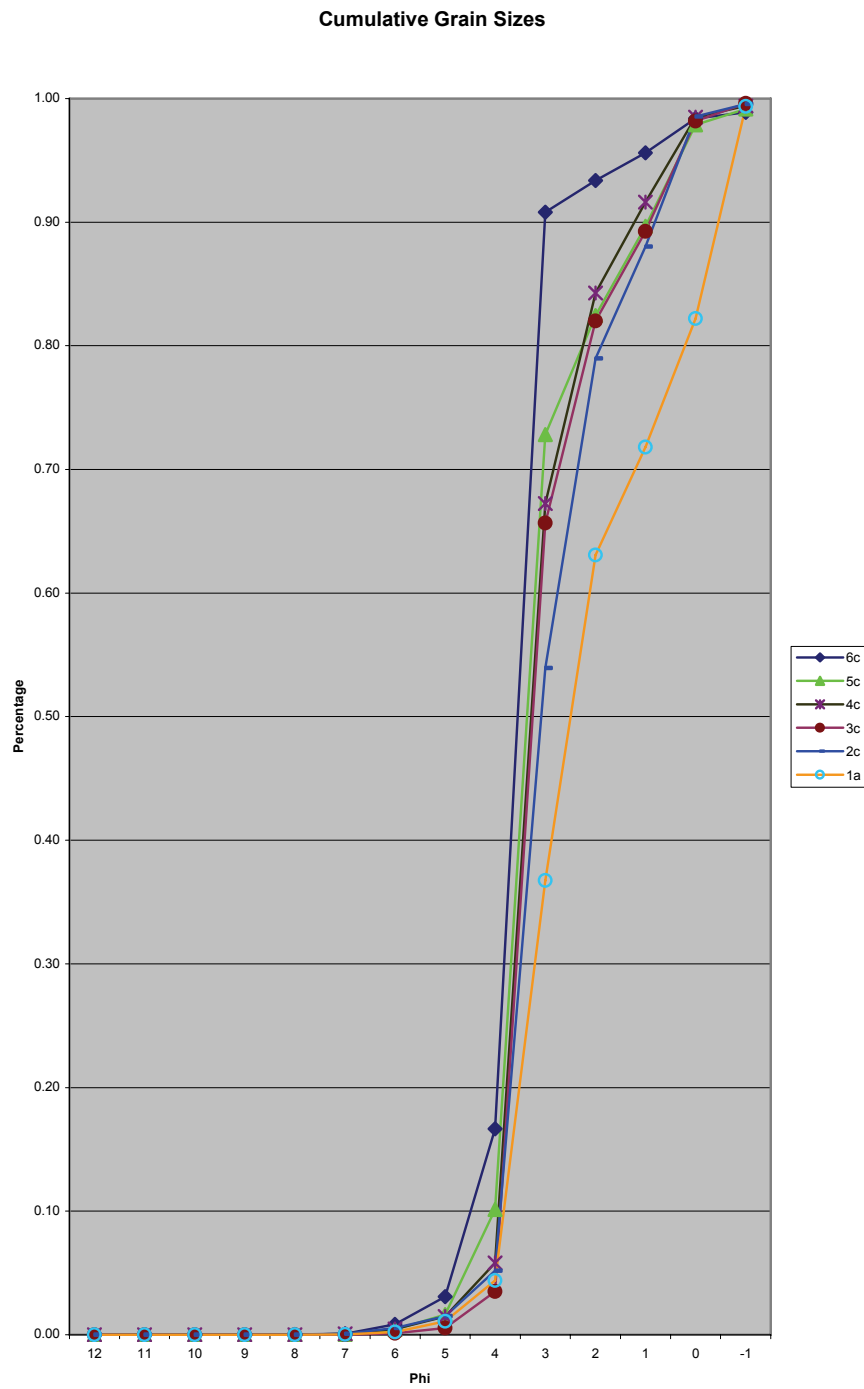


Figure 23. Cumulative grain sizes.

Appendix C: Bivalve Data

Table 7. Weighted Average Bivalve Depth in Meters for Representative Beds from LL.

Average Depth, Unweighted (m)		Bed 2c			Bed 3c			Bed 4c			Bed 5c			Bed 6b		
Min	Max	n	Wt Min	Wt Max	n	Wt Min	Wt Max	n	Wt Min	Wt Max	n	Wt Min	Wt Max	n	Wt Min	Wt Max
6	66	2649	4.7	11.2	1504	5.1	11.1	2592	5.5	15.5	3280	3.7	10.9	3571	1.9	10.8

Appendix C (Continued)

Table 8. Weighted Average Bivalve Depth per Cycle.

Species	Depth (m)	max	n	%	Bed 2c	Bed 3c	Bed 4c	Bed 5c	Bed 6b	WM Max	WM Min	n	%	WM Max	WM Min	n	%	WM Max	WM Min	n	%	WM Max	WM Min	n	%
<i>Azara equisetis</i>	7	11	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00
<i>Asplenium platyneuron</i>	0	20	9	0.00	0.00	0.07	20	0.01	0.00	0.27	18	0.01	0.00	0.14	20	0.01	0.00	0.12	85	0.02	0.00	0.00	0.00	0.00	0.48
<i>Asplenium platyneuron</i>	3.6	9	4	0.00	0.01	0.01	0	0.00	0.00	0.00	0.00	3	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0	10	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0	10	0	0.00	0.00	0.00	1	0.00	0.00	0.00	40	0.02	0.02	0.02	0	0.00	0.00	0.00	0.00	35	0.01	0.01	0.01	0.01	0.01
<i>Asplenium platyneuron</i>	0	0.3	4	0.00	0.00	0.00	1	0.00	0.00	0.00	0	0.00	0.00	0.00	4	0.00	0.00	0.00	0.00	4	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	1	11	11	0.00	0.00	0.05	37	0.02	0.02	0.27	46	0.02	0.02	0.20	12	0.00	0.00	0.04	54	0.02	0.02	0.17	0.02	0.17	0.02
<i>Asplenium platyneuron</i>	0	140	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	6	73	0	0.00	0.00	0.00	0	0.00	0.00	0.00	1	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	68	0.02	0.12	0.12	0.12	0.12
<i>Asplenium platyneuron</i>	0	80	3	0.00	0.00	0.00	15	0.01	0.00	0.80	22	0.01	0.00	0.68	38	0.01	0.00	0.93	4	0.00	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	8	48	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	3	0.00	0.01	0.04	0.04	
<i>Asplenium platyneuron</i>	5.4	10.8	9	0.00	0.02	0.04	25	0.02	0.09	0.18	95	0.04	0.20	0.40	28	0.01	0.00	0.09	23	0.01	0.03	0.07	0.03	0.07	0.03
<i>Asplenium platyneuron</i>	0.13	28	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0	13	97	0.04	0.04	0.07	35	0.02	0.02	0.08	7	0.00	0.00	0.00	55	0.02	0.00	0.00	0.00	70	0.02	0.02	0.02	0.02	0.02
<i>Asplenium platyneuron</i>	11	11	13	0.00	0.05	0.05	1	0.00	0.01	0.01	7	0.00	0.03	0.03	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0.6	9	1302	0.49	0.29	4.42	367	0.24	0.15	2.20	430	0.17	0.10	1.49	1850	0.56	0.34	5.08	2338	0.65	0.39	5.89	0.65	0.39	5.89
<i>Asplenium platyneuron</i>	5	56	2	0.00	0.00	0.04	0	0.00	0.00	0.00	3	0.00	0.01	0.06	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0.1	2	0	0.00	0.00	0.00	0	0.00	0.00	0.00	2	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0.9	1	2	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0.1	1	2	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	4	183	65	0.02	0.10	4.49	1	0.00	0.00	0.12	31	0.01	0.05	2.19	4	0.00	0.00	0.22	4	0.00	0.00	0.22	4	0.00	0.20
<i>Asplenium platyneuron</i>	7	11	0	0.00	0.00	0.00	6	0.00	0.03	0.04	7	0.01	0.03	0.19	30	0.01	0.04	0.06	1	0.00	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0	11	18	0.00	0.00	0.00	0	0.00	0.00	0.00	16	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	9	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	4	7	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0.3	7	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0	100	25	0.01	0.00	0.34	69	0.04	0.00	3.92	56	0.02	0.00	2.16	35	0.01	0.00	1.07	12	0.00	0.00	0.34	0.34	0.34	0.34
<i>Asplenium platyneuron</i>	0	0.3	21	0.01	0.00	0.00	12	0.01	0.00	0.00	59	0.04	0.00	0.01	65	0.02	0.00	0.01	29	0.01	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0	13	0	0.00	0.00	0.00	0	0.00	0.00	0.00	9	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	6	73	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	7	11	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	7	9	0	0.00	0.00	0.00	3	0.00	0.01	0.02	8	0.00	0.02	0.03	4	0.00	0.00	0.02	0.03	4	0.00	0.01	0.01	0.01	0.01
<i>Asplenium platyneuron</i>	1	9	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0	90	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	7	11	6	0.00	0.02	0.02	2	0.00	0.01	0.01	6	0.00	0.02	0.03	0	0.00	0.00	0.00	0.00	6	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0	5.5	27	0.01	0.00	0.00	3	0.00	0.00	0.00	4	0.00	0.00	0.01	9	0.00	0.00	0.02	9	0.00	0.00	0.02	9	0.00	0.00
<i>Asplenium platyneuron</i>	11	11	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0	170	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	6	6	27	0.01	0.06	0.06	275	0.18	0.10	1.00	18	0.01	0.04	0.04	33	0.01	0.06	0.06	16	0.00	0.03	0.03	0.03	0.03	0.03
<i>Asplenium platyneuron</i>	7	8	155	0.06	0.41	0.47	49	0.03	0.23	0.26	240	0.09	0.66	0.74	64	0.02	0.14	0.16	119	0.03	0.23	0.27	64	0.02	0.20
<i>Asplenium platyneuron</i>	0.3	7	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	7	100	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0	100	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0	0.3	18	0.01	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	0.3	7	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	55	82	7	0.00	0.00	0.00	3	0.00	0.01	0.02	139	0.05	0.38	0.43	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	7	8	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	55	30	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	7	11	0	0.00	0.00	0.00	1	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
<i>Asplenium platyneuron</i>	6	20	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.												