UNIVERSITY OF ALBERTA

DEPOSITIONAL AND DIAGENETIC FEATURES OF THE MIDDLE MIOCENE CAYMAN FORMATION, ROGER'S WRECK POINT, GRAND CAYMAN, BRITISH WEST INDIES

by

Elizabeth Ann Willson ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

Department of Geology

Edmonton, Alberta
Fall 1998

0-612-34434-7

UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR: **ELIZABETH ANN WILLSON**

TITLE OF THESIS: **DEPOSITIONAL AND DIAGENETIC FEATURES OF THE MIDDLE MIOCENE CAYMAN FORMATION, ROGER'S WRECK POINT, GRAND CAYMAN, BRITISH WEST INDIES**

DEGREE: **MASTER OF SCIENCE**

YEAR THIS DEGREE GRANTED: **1998**

Elizabeth Willson

#205, 108-23rd Ave. S.W.
Calgary, Alberta
T2S 0J1

September 29, 1998

UNIVERSITY OF ALBERTA

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance a thesis entitled DEPOSITIONAL AND DIAGENETIC FEATURES OF THE MIDDLE MIOCENE CAYMAN FORMATION, ROGER'S WRECK POINT, GRAND CAYMAN, BRITISH WEST INDIES submitted by ELIZABETH ANN WILLSON in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

Dr. Brian Jones (Supervisor)

Dr. B. D. E. Chatterton

Dr. C.R. Stelck

Dr. D.A. Craig

Sept. 25, 1998

ABSTRACT

Core from the Middle Miocene Cayman Formation at Roger's Wreck Point (RWP#2, QHW#1), Grand Cayman encompasses the *Stylophora* Floatstone, the Rhodolite Finger Coral Floatstone, the Rhodolite Coral Fragment Rudstone-Grainstone, the *Porites Leptoseris Montastrea Stylophora*, and the *Leptoseris Montastrea* Floatstone facies. These five facies represent deposition in a shallow, photic paleoenvironment, with variable wave energy and sedimentation, most likely in a bank to bank-edge setting. Internal facies architecture of the Cayman Formation does not behave in a predictable manner at the study locale.

Five diagenetic zones, distinguished on the basis of various diagenetic fabrics (matrix dolomites, cements, cavity fills, porosity) are revealed within the succession at Roger's Wreck Point. Porosity (1.0-29.2%) development throughout the formation was multi-stage and episodic, resulting from eustatically-linked dissolution, cementation and internal sedimentation. The relative timing of diagenetic change in RWP#2 is reflected by eleven paragenetic stages, each associated with a different sea level stillstand.

ACKNOWLEDGMENTS

Well, the good part is... it's finished! The bad part is... what the heck do I do with all my spare time? I was even starting to like -30°C weather and frost on my eyelashes when I walked into school. Seriously, I will miss my life here, the friends I have made, and the great times I have spent with my fellow slappers, in the name of academic pursuit, personal growth, adding to the decor of the Next Act, procrastination, or the occasional caffeine refueling no self-respecting grad student can do without. I have been well prepared for the real life out there (perish the thought!) and how to expect the most from it. Even Dusty has come out a few I.Q. points higher!

Special thanks to my professor Dr. Brian Jones without whom my thesis would have run at least 100 pages longer and bordered on the line of incoherency at points. I will never forget the value of a well-placed diagram in explaining a difficult concept.

The recent establishment of a BWC chapter in Calgary will continue the legacy started during my time in Edmonton. Without these partners in crime (Kim, Mare, Astrid) along with honourary members Cathy, Andrea, Candice as well as the only man we love and can count on, Devo, life would have been very dull to say the least and who would I have drank G and T's with? And of course, you bring special meaning to the phrase "Call them!". You gave me a couch to sleep on, ears to listen, acted as freak police (goldfish anyone?) and provided unlimited moral support when I was down, in addition to the most important of all - fashion advice. I will never forget dancing in Glasgow during Hogmany, spray-painting foam flowers on campus in the dead of night, cooking dinner for 15 over a Coleman stove at Mount Edith Cavell, or those early morning trips to the Great Canadian Bagel for inspiration. Together, I think we have learned that being true to ourselves is the first step to fulfillment, in every aspect of life.

The infamous Carbonate Group with its rotating cast of thousands including Jen, Astrid, Dayve, Tex, Paul, along with past and present students of Brian's are thanked for setting a research standard to which I hope to compare. Through 3 office moves, squeeze cheese wars, and many nights burning the midnight oil (and brain cells) I have come to appreciate the need for both fun and dedication in my research. Particular thanks to Jen for making me feel instantly welcome in my new western home and showing me the departmental ropes.

My housemates Karen, Dayve, Matt, and Steve, are commended for their particular care and attention to my fur-bearing companion Dusty. While living in the geology grad house, Dusty blossomed into a 15+ pound force to be reckoned with. The consideration and camaraderie between all of us in the house with a kitchen space built for midgets should serve as proof that earth scientists from all disciplines can indeed co-exist and flourish.

Of course, my parents are thanked for their patience and support. This submission should serve as proof that I will not remain a student forever, and yes, I have finally broken down and gotten a "real" job (the haircut is optional). Without their high expectations and example I may never have gotten this far.

A general thank you to all EAS grads, I don't think any department here at U of A or in Canada can compare to your enthusiasm, technical expertise, and overall zest for life. Why else would outsiders crash our TGIF parties?

Thank you to my employer, Imperial Oil for both technical and financial support as well as understanding the time required to finish this up. Financial and logistical support was provided for this project by NSERC (grant A6090 to Jones), the Society of Professional Well Log Analysts (scholarship to Willson), the Water Authority of the Cayman Islands and the Natural Resources Unit (Department of the Environment), Grand Cayman. And a tip of my hat to our Cayman drilling crew (Brent, Tex, Jen, Ian, *et al.*) for fighting the mosquitoes to supply me with core.

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION 1

1.1 INTRODUCTION 1

1.2 GEOLOGIC AND GEOGRAPHIC SETTING 4

1.2.1 Geography of the Cayman Islands 4

1.2.2 Tectonic Setting 5

1.3 STRATIGRAPHIC FRAMEWORK OF THE CAYMAN ISLANDS 8

1.3.1 The Historical Development of Stratigraphic Nomenclature 8

1.3.2 Stratigraphic Architecture 10

1.4 STUDY AREA 12

1.5 OBJECTIVES 14

1.6 METHODS AND MATERIALS 17

1.6.1 Core Retrieval and Logging 17

1.6.2 Outcrop Analysis 18

1.6.3 Thin Section Petrography 18

CHAPTER TWO: FACIES OF THE CAYMAN FORMATION 19

2.1 INTRODUCTION 19

2.2 FACIES OF THE CAYMAN FORMATION 21

2.3 CORAL BIOFACIES 26

2.4 DISCUSSION 27

2.5 SUMMARY 28

CHAPTER THREE: DEPOSITIONAL FRAMEWORK OF THE CAYMAN FORMATION 29

3.1 FACIES ARCHITECTURE 29

3.2 PALEOENVIRONMENTAL RECONSTRUCTION 29

3.2.1 General Environmental Setting 29

3.2.2 Discussion 34

3.2.3 Facies-Related Paleoenvironments 34

3.3 DEPOSITIONAL MODEL FOR THE CAYMAN FORMATION 41

3.3.1 Proposed Model 41

3.3.2 Discussion 43

3.3.3 Summary 46

CHAPTER FOUR: DIAGENESIS OF THE CAYMAN FORMATION 47

4.1 INTRODUCTION 47

4.2 DIAGENETIC FEATURES 47

4.3 DIAGENETIC ZONES 56

4.4 INTERPRETATIONS 60

4.4.1 Matrix Dolomites 60

4.4.2 Cavity Fills 62

4.4.3 Cements 63

4.4.4 Porosity 67

4.5 PARAGENETIC SEQUENCE 68

4.6 SUMMARY 74

CHAPTER FIVE: EUSTATIC CHANGE AND THE CAYMAN FORMATION 75

5.1 INTRODUCTION 75

5.2 EUSTATIC CORRELATION 75

5.2.1 Background 75

5.2.2 Tectonic Concerns 76

5.2.3 Eustatic Curves Compared 77

5.2.4 Haq's Curve and Cayman Stratigraphy 81

5.2.5 Termination of Cayman Formation Deposition 83

5.3 DIAGENESIS AND EUSTASY 86

5.3.1 Absolute Timing of Diagenesis 86

5.3.2 Discussion 91

CHAPTER SIX: CONCLUSIONS 93

REFERENCES 95

LIST OF TABLES

TABLE

2.1 Facies of the Cayman Formation in RWP#2 22

2.2 Biofacies-Facies Comparison 26

3.1 Depositional Setting Parameters, Roger's Wreck Point 35

4.1 Matrix Dolomite Features 48

4.2 Cavity Fill Features 48

4.3 Cement Types 49

4.4 Depth Variance in Lithological Features of RWP#2 58

4.5 Comparison of Cements Described for the Cayman Formation 66

4.6 Key Diagenetic Features of the Paragenetic Stages for RWP#2 69

5.1 Comparison of Eustatic Event-Paragenetic Stage Matches 85

5.2 Eustatic Events and Paragenetic Stages for RWP#2 88

List of Figures

Figure

1.1 Caribbean Map 2

1.2 Cayman Islands Maps 3

1.3 Caribbean Tectonic Map 6

1.4 Generalized Stratigraphic Column for the Cayman Islands 9

1.5 Map of Grand Cayman with Detail Map of Study Area 13

1.6 Generalized Stratigraphic Strip Log for RWP#2, QHW#1 15

3.1 Facies Strip Log, RWP#2 30

3.2 Biota Strip Log, RWP#2 32

3.3 Depositional Environment Model, Cayman Formation, Roger's Wreck Point 42

4.1 Diagenetic Zones in RWP#2 50

4.2 Porosity Features of RWP#2 Diagenetic Zones 57

4.3 Diagenetic Environments Affecting RWP#2 70

5.1 Eustatic Curve Comparison 79

5.2 Miocene-Pleistocene Portion of Haq *et al.* (1987) Eustatic Curve 80

5.3 Stillstand Positions which affected the Cayman Formation in RWP#2 87

List of Plates

Plate

I	Thin Section Photographs of Matrix Dolomites	51
II	Thin Section Photographs of Cements A, B, E	52
III	Thin Section Photographs of Cement D	53
IV	Thin Section Photographs of Hardground and Cement C	54

CHAPTER ONE: INTRODUCTION

1.1 INTRODUCTION

Accurately reconstructing the depositional and diagenetic histories of highly-altered carbonate strata remains an area of geological expertise in need of improvement. Our understanding of ancient sedimentary environments, especially their controlling mechanisms, has been heightened significantly through the study of modern analogues. Analysis of depositional textures, faunal content and condition, facies architecture, and the type and distribution of diagenetic fabrics provide the details required to interpret depositional paleoenvironments and their subsequent diagenetic changes. Examination and documentation of this information allow it to be used in the interpretation of broad-scale geological processes including the impact and results of eustatic change as well as the chemical reactions associated with rock-water equilibration.

In this study, the depositional and diagenetic character of the Cayman Formation at Roger's Wreck Point, Grand Cayman is examined and interpreted. The strata of this formation provide a unique opportunity for observing and documenting textural changes resulting from slight variation in the depositional environment. The impact of fluctuating sea level on the distribution of diagenetic fabrics is also investigated. Athough these strata are highly-altered, the fabric retentive nature of dolomitization as well as the relative tectonic stability of Grand Cayman Island eliminates some of the uncertainty inherent to interpretations of this kind. The intent of this research is also to provide a new window into the geological character of the formation as a whole. In addition, insight may be gained as to how diagenetic fabrics (*i.e.* porosity development) can be used to assess relative sea level change.

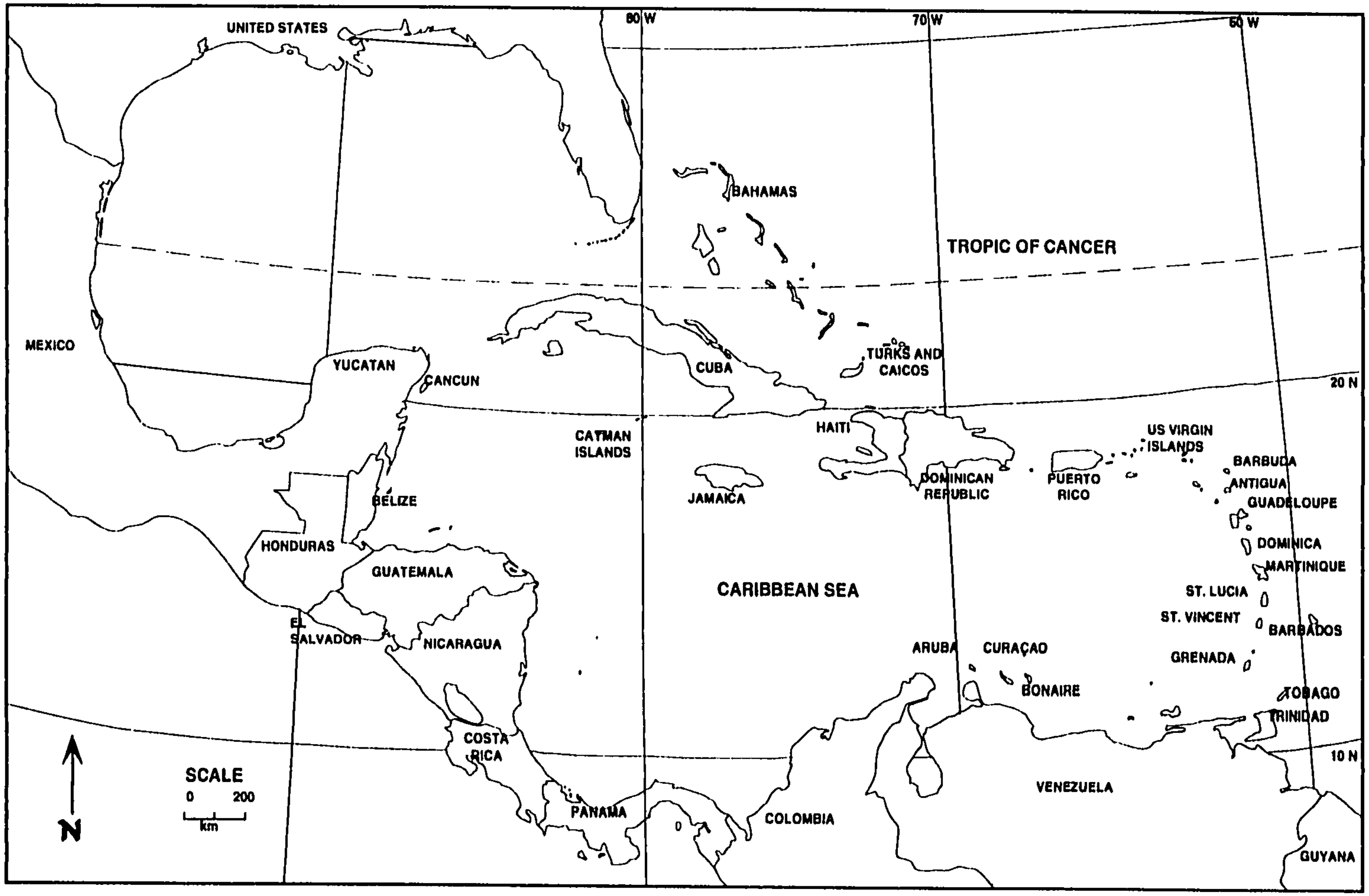


Figure 1.1 Location of the Cayman Islands within the Caribbean.

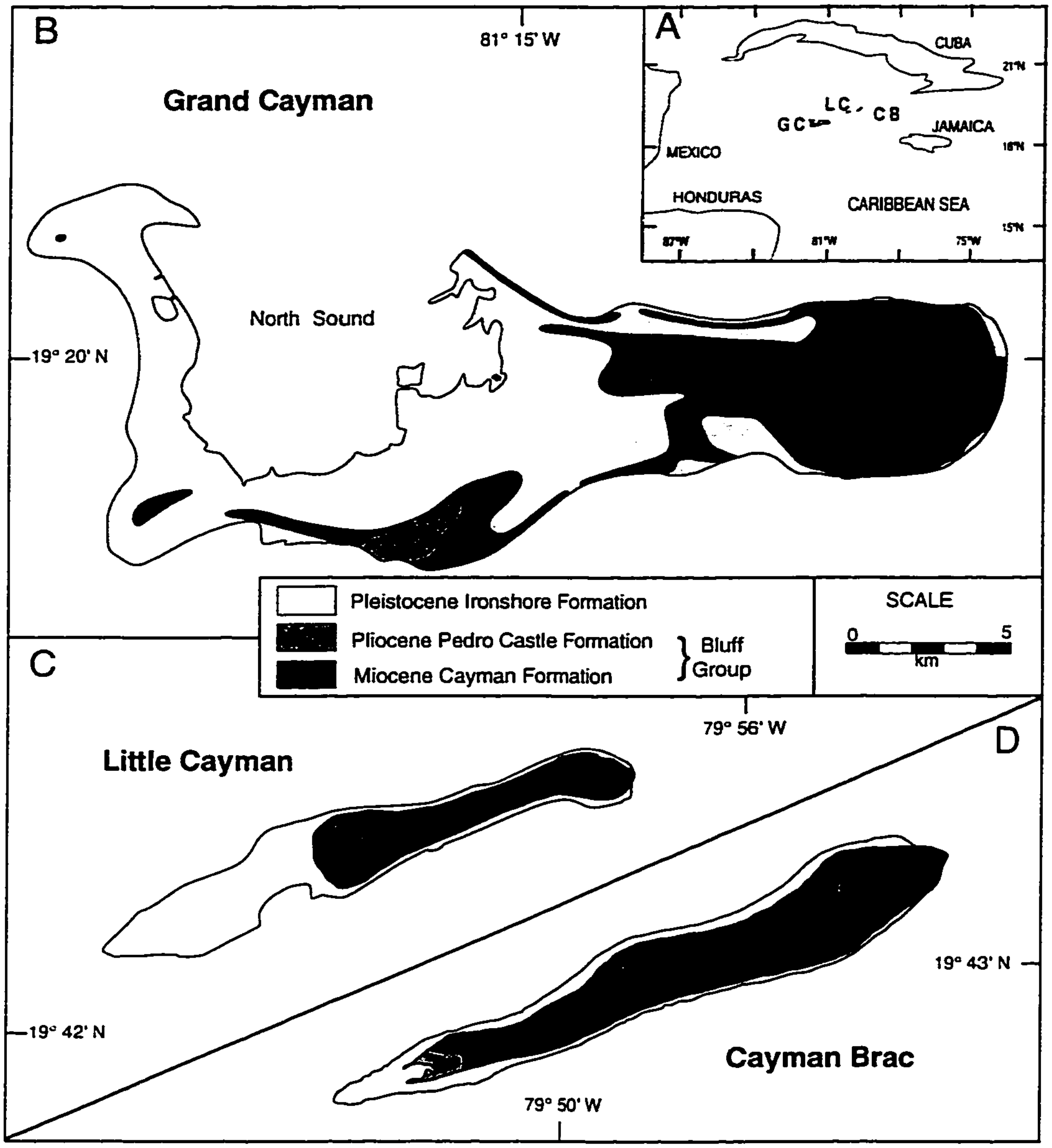


Figure 1.2 A) Location map showing the Cayman Islands; Grand Cayman (**GC**), Little Cayman (**LC**), and Cayman Brac (**CB**). B), C), D) Outcrop maps of Grand Cayman, Little Cayman and Cayman Brac (Modified from Jones *et al.*, 1994a).

1.2 GEOLOGIC AND GEOGRAPHIC SETTING

1.2.1 Geography of the Cayman Islands

The Cayman Islands are situated in the northwestern portion of the Caribbean Sea, approximately 300 km south of Cuba and 300 km west of Jamaica (Figure 1.1). Grand Cayman, the largest of the islands, has an areal extent of 196 km^2 and dimensions of approximately 35 km east-west and 8 km north-south (Figure 1.2). Referred to as the "Lesser Islands" due to their smaller size, Little Cayman and Cayman Brac are located 130 km northwest of Grand Cayman and 7 km from each other.

Topographic relief on Grand Cayman is subdued. The Mountain, at ~18 m above sea level (asl), defines the highest point whereas the rest of the island rarely exceeds 4 m asl. A narrow peripheral ridge (>6 m asl) borders the eastern, southern and northern coasts along with minor continuations near the Mountain and Pedro Castle (Ng and Beswick, 1994).

Caymanian terrain reveals a distinct zonation that is controlled by bedrock lithology. Coastal areas are characterized by sharp karst exposures developed on relatively competent dolomitic strata or broad, flat carbonate sand beaches, created by the weathering of less indurated limestones. Further inland, thin terra rossa soils support a dense semi-tropical to tropical vegetation that is especially lush on the western end of the island (Jones and Smith, 1988). The interior regions and the coast bordering North Sound consist of widespread mangrove swamps and impenetrable brush. An intricate system of man-made dykes constructed by the Mosquito Research and Control Unit dissect these areas in an attempt to enhance water circulation as a means of combating an overwhelming indigenous mosquito population (Conyers, 1990).

Temporal and spatial variations in rainfall distribution on Grand Cayman are caused by prevailing winds associated with the Caribbean climate. From May to October, easterly trade winds dominate, bringing frequent rains and the occasional hurricane. The winter season is often dry and is characterized by northwesterly winds which bring only sporadic precipitation. Rainfall levels range from 900 to 1600 mm over Grand Cayman with the eastern half and northwestern extension being the most arid regions on the island (Ng *et al.*, 1992).

Recognized as a world class vacation destination for its beautiful sandy beaches, warm sunny weather and welcoming locals, Grand Cayman is also renowned as a snorkeler's and diver's paradise. Less than 1 km from the coastline, following the inner shelf margin, lies a well-developed and robust fringing reef complex which provides spectacular views of modern Caribbean reef biota. Although the south, east and north coasts support a flourishing reef community (*i.e.* Rigby and Roberts, 1976; Blanchon *et al.*, 1997) the western leeward margin is characterized by patch reefs and scattered corals. Reef morphology and zonation vary locally and are controlled by the orientation of the shelf, degree of hurricane impact, as well as the normal daily levels of wind and wave exposure (Blanchon and Jones, 1995; Blanchon *et al.*, 1997). In most locations the shelf is divided into upper (0-15 m subsea) and lower (20-25 m subsea) terraces by a mid-shelf scarp (Blanchon and Jones, 1995).

Small patch reefs flourish in protected lagoons behind the fringing reef where water depth rarely exceeds 3 m. North Sound is the largest lagoon, being about 10 km in diameter, averaging 5 m in water depth, and covering most of west-central portion Grand Cayman (Roberts, 1976). It opens to the windward margin to the north of the island and has become famous with sightseers for its large population of stingrays.

1.2.2 Tectonic Setting

Seismic imaging indicates that each of the Cayman Islands is situated upon separate fault blocks which form isolated highs along the submerged Cayman Ridge (Falquist and Davies, 1971; Dillon *et al.*, 1972) (Figure 1.3). Likened to a subterranean mountain range, the ridge marks the southern limit of the North American Plate and extends westward from the Sierra Maestra in Cuba to within 100 km of Belize's continental shelf (Falquist and Davies, 1971).

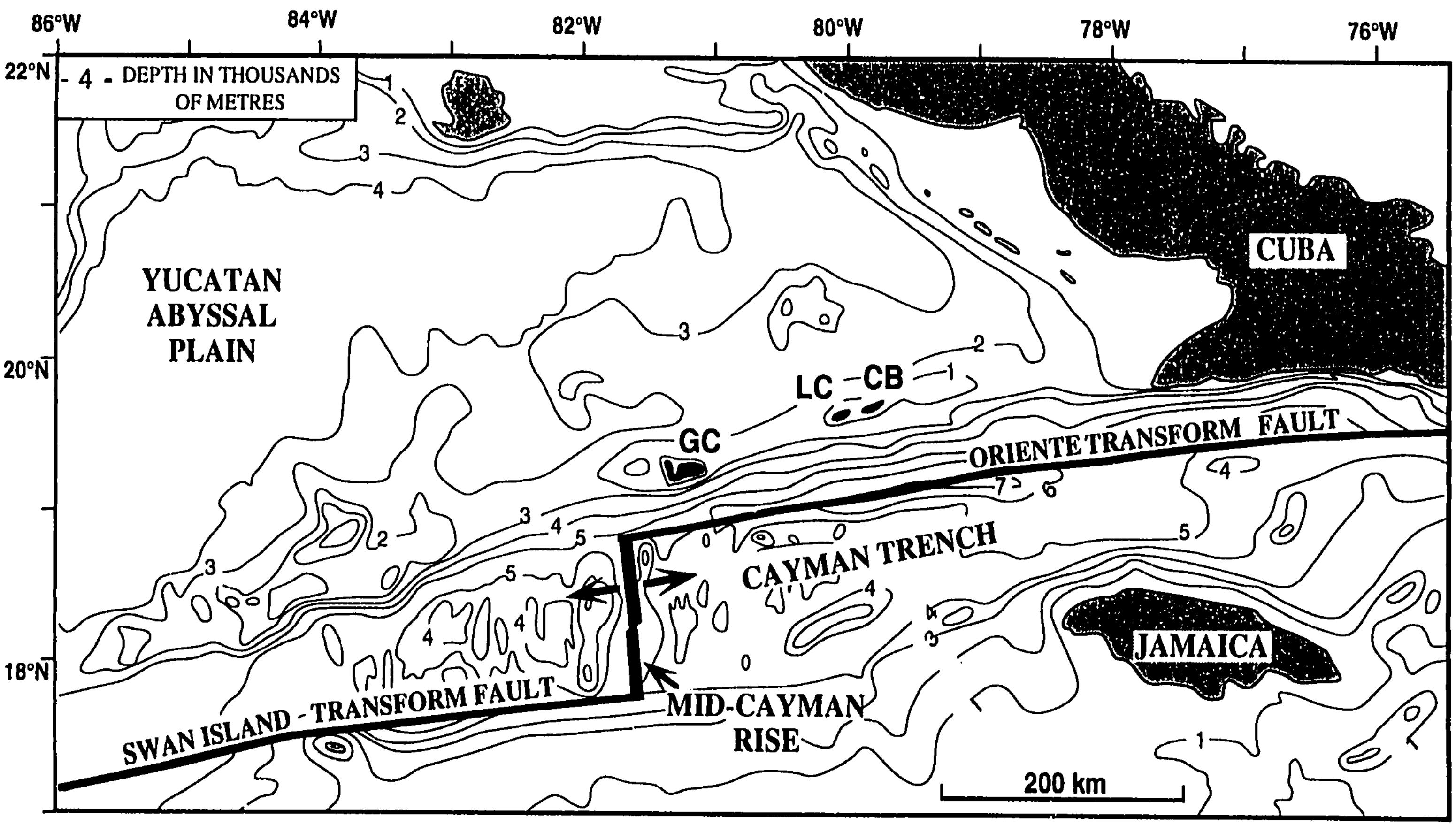


Figure 1.3 Structure map of the Caribbean Sea showing bathymetry and the location of Grand Cayman (GC), Cayman Brac (CB), and Little Cayman (LC) relative to the key structural elements of the region. (Modified from Jones, 1994).

South of the Cayman Ridge lies the Cayman Trough, 100 to 150 km wide (Rigby and Roberts, 1976) and up to 6000 m deep (Stoddart, 1980). Southwest of Grand Cayman is an active north-south trending spreading centre known as the Cayman Rise. Extending eastward from the north end of the Cayman Rise is the Oriente Transform Fault whereas the Swan Island Transform Fault extends westward from the southern extremity of the same spreading centre. Recent monitoring of seismic activity along both transform faults and the Cayman Rise has revealed that all three structural features are geologically active (MacDonald and Holocombe, 1978; Leroy *et al.*, 1996).

The basement blocks upon which each island became established probably consist of granodiorite, the most common rock type outcropping subaqueously along the Oriente slope (Emery and Milliman, 1980; Stoddart, 1980). These igneous rocks were covered by a thin basaltic veneer that provided a base for the growth of reef biota. Tertiary carbonates containing diverse faunal and floral components were the product of this bank community. Development of the Cayman Trench commenced during Eocene time, with a crustal accretion rate of 0.4 cm/yr along the Mid-Cayman Rise (Perfit and Heezen, 1978). A shallow carbonate bank flourished on the ridge until the early Miocene when subsidence, at an average rate of 6 to 10 cm/1000 yr lowered the bank below the photic zone and halted its growth (Perfit and Heezen, 1978; Emery and Milliman, 1980). Subsequent uplift which began in the Middle Miocene affected the Cayman Islands, south Cuba, Jamaica, Central America and the Swan Islands and helped re-establish reef organisms on top of the previous carbonate bank. Continued slow elevation of the bank above sea level exposed the resultant Oligocene-Pliocene carbonate sequences which now outcrop as bedrock on the Caymans (Perfit and Heezen, 1978). Although the thickness of the entire bank sequence remains uncertain, drilling in central Grand Cayman continued to penetrate Oligocene carbonates at 401 m subsurface (Emery and Milliman, 1980).

Four minor highstand events linked to major Pleistocene sea level rises are responsible for the deposition of the Ironshore Formation and its four constituent members

(Vézina, 1997). This formation unconformably onlaps the Tertiary deposits along the coastal regions of Grand Cayman (Jones and Hunter, 1990).

1.3 STRATIGRAPHIC FRAMEWORK OF THE CAYMAN ISLANDS

1.3.1 The Historical Development of Stratigraphic Nomenclature

Matley (1926) was the first geologist assigned the task of exploring, documenting and mapping the geology of the Cayman Islands for the British government. The hard Tertiary carbonates he encountered in sheer cliffs along the coasts of Cayman Brac and Little Cayman were appropriately named the "Bluff Limestones" (Matley, 1924a; 1924b; 1926). As further research (Jones *et al.*, 1984; Pleydell and Jones, 1988) revealed that most of the Tertiary succession consisted of dolostones, it was renamed the Bluff Formation (Jones *et al.*, 1994b). A type section of this formation was designated at Pedro Castle Quarry, Grand Cayman, with the constituent units named as the Cayman and Pedro Castle members (Jones and Hunter, 1989).

Extensive collection of outcrop data on Cayman Brac in 1994 lead to further revision of Caymanian stratigraphy (Jones *et al.*, 1994a). As a result, the Bluff Formation was elevated to group status with three constituent formations (Figure 1.4). The separation of the Brac, Cayman, and Pedro Castle formations was justified by lithological differences. Considerable time gaps between these formations are evident as disconformities and unconformities (Jones *et al.*, 1994a; 1994b). On Grand Cayman, however, only the Pedro Castle and Cayman formations have been found, despite drilling in 1997 that reached a depth of 156 m subsea (Jones and Hunter, 1989; Jones, 1998 *pers. comm.*).

The Tertiary strata of the Cayman Islands can be correlated with other Tertiary Caribbean carbonate successions. The Cayman Formation is correlated with the Paso Real Formation of Cuba, the Los Puertos and Aymamon limestones of Puerto Rico, and the Buff Bay Formation of north-central Jamaica (Jones *et al.*, 1994a).

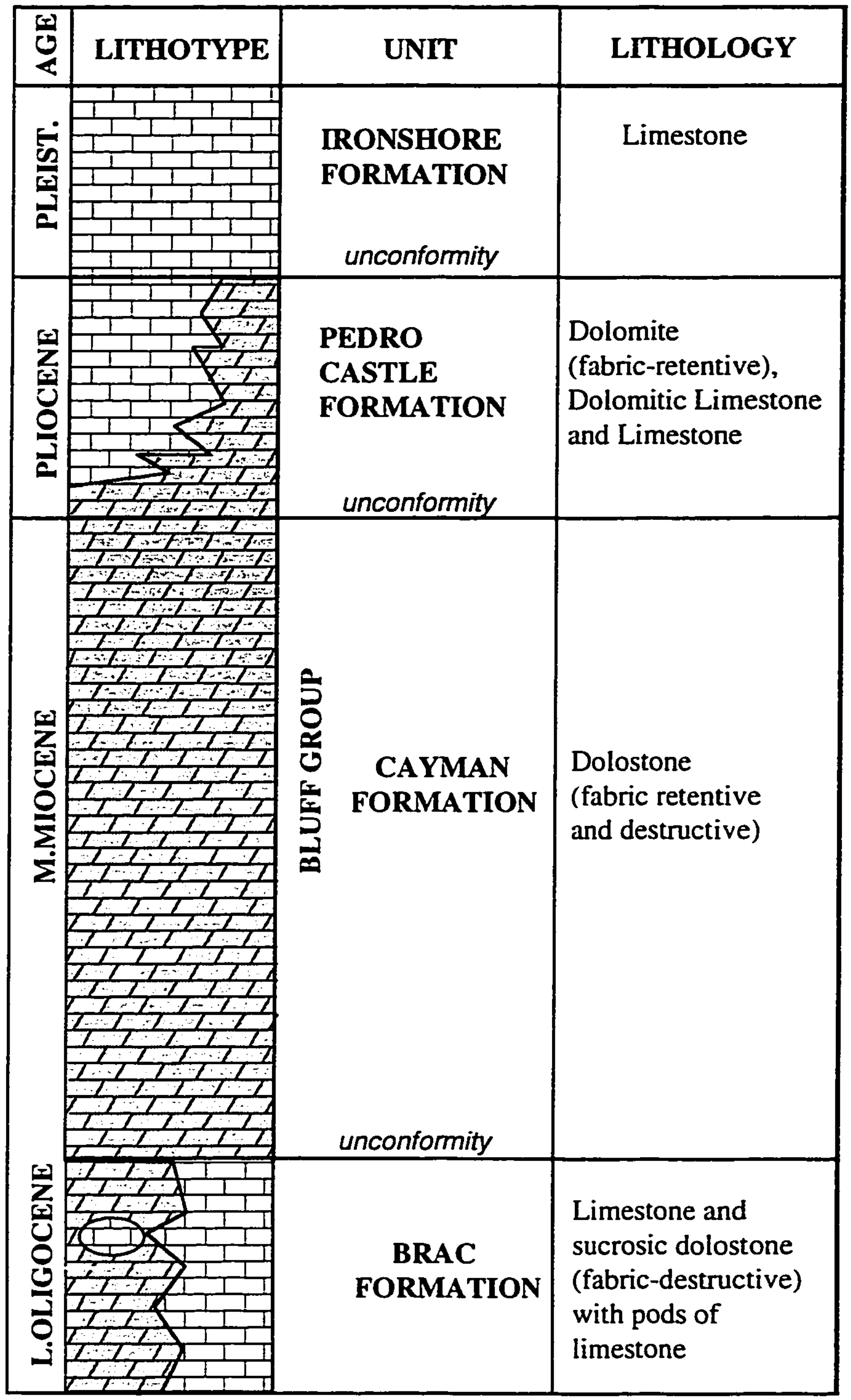


Figure 1.4 Stratigraphic column for the Cayman Islands (modified from Jones *et al.*, 1994b).

1.3.2 Stratigraphic Architecture

The only known exposure of the Brac Formation crops out in the sheer cliffs at North East Point on Cayman Brac. A minimum thickness of 33 m and regional dip of 0.5° to the west has been proposed for this unit (Jones *et al.*, 1994a). Described as a pure limestone or sucrosic dolostone with isolated pods of limestone, this formation varies in texture from mudstone to grainstone (Jones and Hunter, 1994a). By correlating constituent *Lepidocylina* to the foraminifera associations of Vaughan (1926) and using $\partial Sr^{87}/Sr^{86}$ isotopes to date samples, the Brac Formation was assigned a late Lower Oligocene age (Jones *et al.*, 1994a). The upper surface of the Brac Formation is a bounding disconformity that dips 0.5-2° to the west with minor undulatory topography (Jones *et al.*, 1994a). Features associated with this contact indicate considerable subaerial exposure, followed by erosion and finally, lithification.

Most bedrock exposures on Cayman Brac and Grand Cayman consist of Cayman Formation dolostones. Constituent amphistegenid and miliolid foraminifera of these strata correlate to established Caribbean foraminifera distributions for this time period (Iturralde-Vinent, 1969). As a result, a Lower to Middle Miocene age for the Cayman Formation has been proposed (Jones and Hunter, 1989; Jones *et al.*, 1994a). On Cayman Brac, the Cayman Formation is estimated to be 102 m thick, a value surpassed by the retrieval of 152 m of Cayman core in 1997 from the Lower Valley well (LVR#2) on Grand Cayman (Jones, 1998 *pers. comm.*). The contact between the Cayman Formation and overlying Pedro Castle Formation is marked by an unconformity with variable regional relief (up to 40 m) on Grand Cayman (Jones and Hunter, 1994a). At Pedro Castle Quarry, the unconformity is penetrated by several varieties of sponge, worm, and bivalve borings (Jones and Hunter, 1989). The Cayman Unconformity developed as a result of subaerial exposure during the Messinian lowstand event (Jones and Hunter, 1989; Jones and Hunter, 1994b). Paleocaves and paleosinkholes that are connected to this unconformity indicate that exposure and dissolution predated deposition of the overlying Pedro Castle Formation (Jones and Hunter, 1994b).

The Pedro Castle Formation consists of gray to cream-coloured limestones, fabric-retentive dolostones, and dolomitic limestones. Its type section in Pedro Castle Quarry, is 2.5 m thick and contains numerous free-living corals, foraminifera, and rhodolites (Jones *et al.*, 1994a). The reference section, designated in well SH#3 at Safe Haven, is 32 m thick. These strata cannot be younger than Pliocene in age because they contain *Stylophora*, a coral that became extinct in the Caribbean following the Pliocene (Frost and Langenheim, 1974; Frost, 1977). This biostratigraphic date is supported by $\partial Sr^{87}/Sr^{86}$ isotope values that indicate a minimum age of 2 million years for the Pedro Castle Formation (Jones *et al.*, 1994a). The thickness and distribution of this formation is extremely variable due to differential erosion and paleorelief on the Cayman Unconformity. Core containing 40.1 m of Pedro Castle Formation (paleosinkhole fill) was retrieved from northeast Grand Cayman (QHW#1) (Jones and Hunter, 1989). At Paul Bodden's Quarry south of Georgetown, however, the Pleistocene Ironshore Formation directly overlies the Cayman Formation (Jones and Hunter, 1994). Since the Cayman Unconformity is preserved on the upper surface of the Cayman Formation at this location, erosion apparently removed the Pedro Castle Formation before Pleistocene deposition.

The Ironshore Formation (Pleistocene), which is generally less than 9 m thick (Shourie, 1993), onlaps Tertiary carbonates along the coastal regions of Grand Cayman (Jones and Hunter, 1990). A maximum thickness of ~ 21 m for these strata is found to the northeast of the island at Roger's Wreck Point (Vézina, 1997). Facies identified in this formation include patch reef, lagoon interior and foreshore beach deposits (Brunt *et al.*, 1973; Jones and Hunter, 1990). Ur/Th dating of core from Roger's Wreck Point has helped divide the Ironshore Formation into four unconformity-bound members, ranging in age from 131 to 400 ka (Vézina, 1997). Each consists of limestone which varies texturally and compositionally from mudstone and coral framestone to friable cross-bedded oolitic grainstone. The combination of allochem diversity (*i.e.* abundant corals, bivalves, rhodolites and gastropods) and textural variety observed in these carbonates reflects widely fluctuating depositional conditions.

1.4 STUDY AREA

Roger's Wreck Point is a minor coastline projection encompassing Spotter Bay on the northeast corner of Grand Cayman (Figure 1.5). It occupies a coastal setting with an area roughly 900 x 300 m and is bound to the southwest by Queen's Highway. Road access is achieved from the highway by an old abandoned sand and gravel track. The entire area is relatively flat-lying (< 4m) and gently slopes towards the sea with the exception of a storm ridge, which parallels the coast, approximately 50-75 m from shore. This ridge is composed of unconsolidated rubble and achieves an elevation up to 4.5 m asl. Ground cover consists of scattered patches of dense vegetation, carbonate sand, exposed bedrock, and caliche crusts. This terrain has developed upon Pleistocene limestones exposed as a broad shallow karsted terrace along the shore.

Further inland the Ironshore Formation terminates against the base of a cliff (5-7 m high) consisting of Cayman Formation dolostones. Locally, this cliff reveals a pronounced erosional notch at ~6 m asl, which was most likely created during the Sangamon Highstand (Hunter and Jones, 1988). The timing of this feature is contemporaneous with deposition of the upper member of the Ironshore Formation, approximately 125 ka before present (Vézina, 1997).

The Roger's Wreck Point location was chosen as a drilling and coring site because 1) local relief was minimal allowing for simple drill set-up, 2) strata belonging to the Cayman Formation were assumed to be close to the surface, and 3) local ponds provided a suitable drilling fluid. Minor clearing of vegetation was necessary to prepare the site before drilling started.

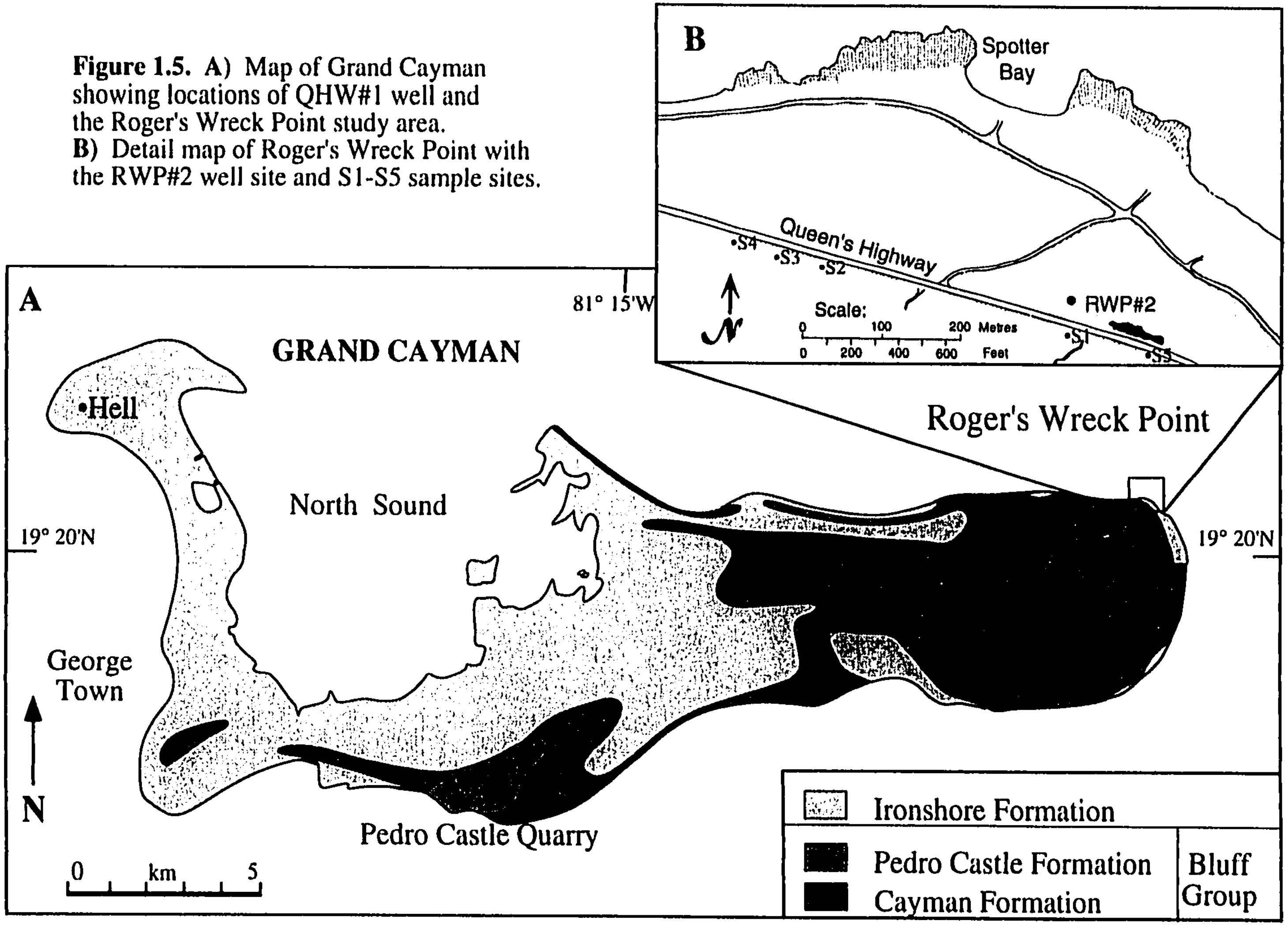


Figure 1.5. A) Map of Grand Cayman showing locations of QHW#1 well and the Roger's Wreck Point study area. **B)** Detail map of Roger's Wreck Point with the RWP#2 well site and S1-S5 sample sites.

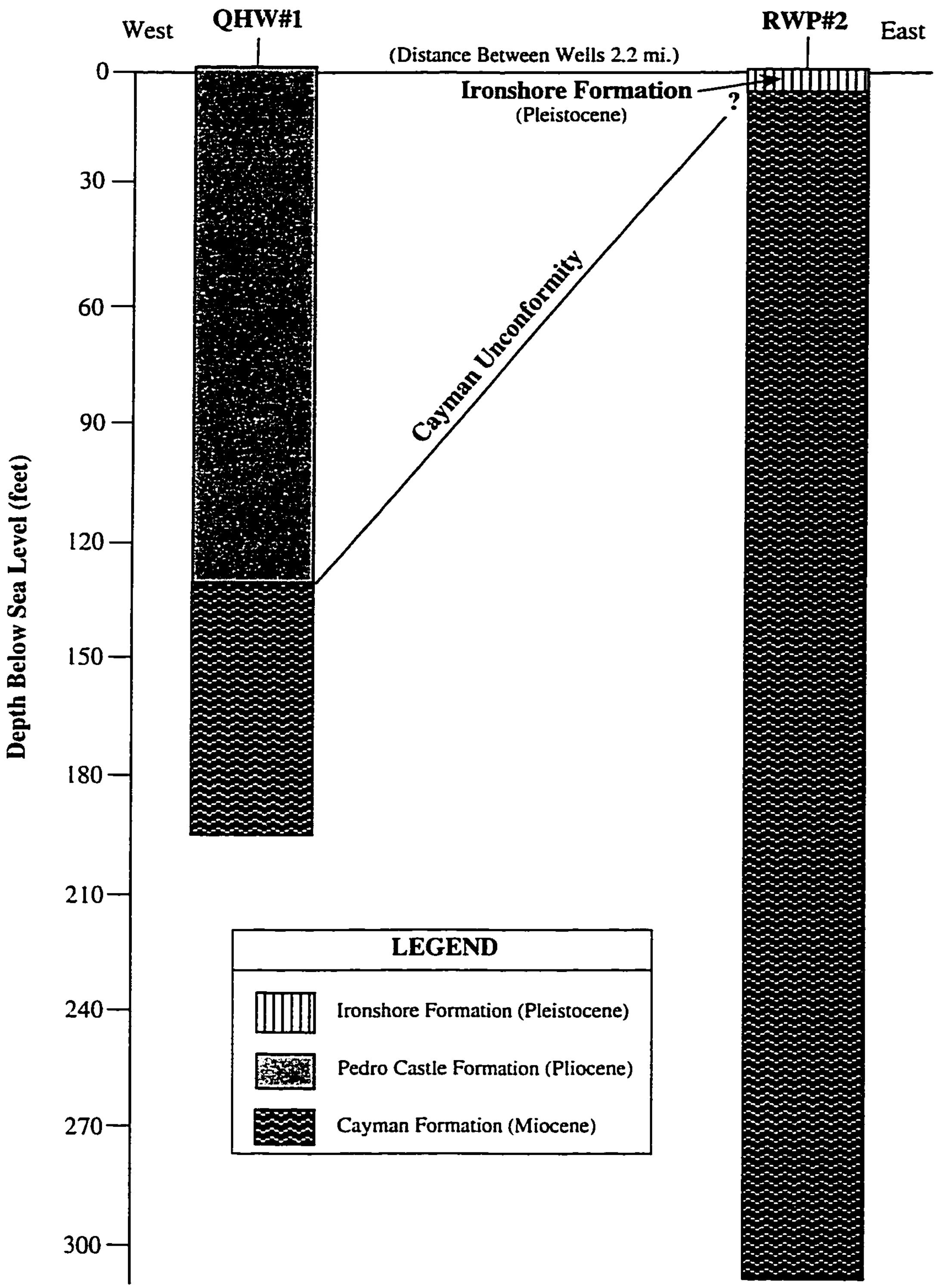
Drilling of RWP#2 was initiated at 9" (22.8 cm) above sea level and penetrated the base of the Ironshore Formation at 6'9" (2.1 m) subsea. The Cayman Formation was cored from 6'9" (2.1 m) to 309'10" (94.4 m) subsea. Mechanical breakdown of the drill terminated coring, thus suspending operations short of the Cayman Formation base. The upper contact of the Cayman Formation represents post-Pliocene erosion that removed the Pedro Castle Formation along with an unknown thickness of the Cayman Formation. Therefore, the exact stratigraphic position of the Cayman Formation sequence in RWP#2 remains uncertain but it is assumed that the top of the core is near the top of the formation.

Drilling at Queen's Highway yielded an additional set of Cayman core (QHW#1) that is incorporated in this project. The well site is located 3.5 km west of Roger's Wreck Point in a farmland setting. Coring was initiated at the base of a water-filled depression north of Queen's Highway and penetrated the Pliocene Pedro Castle Formation until encountering the Cayman Formation at 128'1" (39.0 m) subsea (Figure 1.6). Water in the sinkhole provided *in situ* lubrication for the drill apparatus. In this well, the Cayman Unconformity is marked by ~ 1 cm of relief. It is overlain by rhodolites, *Porites*, foraminifera rubble, and clasts of Cayman Formation dolostones. Coring of the Cayman Formation terminated at 194'5" (59.3 m) subsea due to breakage of the drill bit. The basal contact of the formation was not found. Although the Cayman Unconformity is preserved in this well at 128'1" (39.0 m), Cayman Formation strata are exposed in outcrop around the sinkhole. A minimum 128' (39.0 m) of relief has developed on the Cayman Unconformity in this area, which positions the top of the Cayman Formation in the QHW#1 core at least 128' (39.0 m) below the true formation top.

1.5 OBJECTIVES

To date, our geological understanding of the Cayman Formation on Grand Cayman is limited by the combined effects of low dip angle and minimal relief, limited core retrieval, and extensive surficial karst. Recent drilling and coring operations focusing in

Figure 1.6 Sketch showing stratigraphic units found in wells QHW#1 and RWP#2.



the northeast corner of the island have yielded two of the most complete sections through the Cayman Formation (RWP#2, QHW#1) which may improve this situation. As a combined set, these cores provide an unparalleled view into the vertical and spatial variability of this unit to a depth not previously possible. The lack of data on the Cayman Formation from this area of Grand Cayman makes the information gathered from both cores important to future research. As such, a comprehensive description and interpretation of their sedimentary and diagenetic fabrics has the potential to become a reference standard for future studies. It may also reveal new, more specific details as to the paleoenvironmental conditions prevalent during the Miocene, perhaps with wider implications for Caribbean geological history. As a result, all pertinent geological literature, drill core (wells RWP#2 and QHW#1), and samples collected during field work are reviewed and analyzed with the following objectives in mind.

(a) To describe and document the sedimentological textures and features in the Cayman Formation. This will result in the definition of depositional facies.

(b) To analyze and interpret paleoenvironmental conditions (salinity, wave energy, bathymetry and temperature) *via* examination of lithological and biological indicators. Such data are used to assess the impact of various extrinsic influences on the biotic and abiotic components of the sediment and the resultant depositional architecture.

(c) To summarize the observed sedimentary features and facies into a depositional model for the Cayman Formation.

(d) To describe the constituent diagenetic features and patterns. This will lead to an interpretation of the causes and development of diagenetic events and help establish a paragenetic sequence linked to sea level history.

(e) To propose the described RWP#2 succession of Cayman Formation core be accepted as a reference section for the formation.

Only by striving to understand the influence that eustatic change exerts on the creation and modification of the sedimentary rock record, during deposition and diagenesis, will a complete picture of carbonate depositional dynamics evolve. The interplay between relative sea-level variation and tectonism holds important implications for the composition of faunal assemblages, sedimentary textures, and the distribution of facies. Both the magnitude and frequency of eustatic changes during and following deposition can mediate a multitude of diagenetic features which commonly obscure primary rock fabrics. Therefore, creation of a suitable depositional and diagenetic model for a complex lithological package such as the Cayman Formation requires intimate knowledge of both sea level history and the effects it can manifest in carbonate rocks.

1.6 METHODS AND MATERIALS

1.6.1 Core Retrieval and Logging

The Cayman drilling and coring program of Dr. Brian Jones and his graduate students has been operating since 1991 and employs a J.K.S. Boyles' Winkie drill. This mobile system facilitates continuous coring and comes equipped with a diamond bit and 1.375" (3.5 cm) diameter, 10' (3.05 m) foot long coring barrel. A water pump and compressor set-up are used to draw water to lubricate the drill *via* circulation down the hole.

Preparation of 110 m of core for examination involved the slabbing, logging and cutting of plugs for thin sectioning. Particular care was taken to leave one half of each slab intact. The missing thickness from portions with less than 100% recovery were assigned to the base of that 10' core barrel interval. As the focus of this study was to define and delineate the facies and examine the distribution of diagenetic features, careful attention was paid to textural description, allochem identification, mineralogy, sedimentary and biogenic structures and the nature of dissolution features and how they relate to the original depositional material. The challenge of Miocene coral identification was accomplished with the aid of photographs and descriptions provided by Frost and Langenheim (1974), Frost (1977), and Hunter (1994). Rock names were assigned using the textural criteria of Embry and Klovan (1971).

Helium-injection porosity analysis was performed on 59 core plugs from RWP#2 sampled in 5' (127 cm) spacings in order to define the range in porosity and its variation with depth. This lab work was performed by Core Laboratories of Calgary along with measurements of grain density. Porosity type and distribution were described from the core and thin sections and interpreted in conjunction with the measured laboratory data.

1.6.2 Outcrop Analysis

Five outcrop locations were sampled along the coastal ridge, southwest of Roger's Wreck Point. Four of these are situated to the west of Queen's Highway (S1, S2, S3, S4) and one to the east (S5) (Figure 1.5). A brief description and representative sample of the Cayman Formation was collected at each site for thin sectioning purposes. The objective was to provide a general sense of the textures and allochems (facies) in the outcrop exposures at elevations above the top of the two cored wells. This information would in turn, aid in the construction of facies distribution patterns and completion of the overall depositional model for the Cayman Formation.

1.6.3 Thin Section Petrography

Smaller allochems and matrix characteristics were examined using a standard petrographic microscope and conventional thin sectioning techniques. Samples were chosen to represent significant lithological changes, ground to thicknesses < 30 μm and mounted as 2 by 4 cm slides. Grain, cement and textural descriptions were identified and documented with the aid of various petrography guides and photographs (Scholle, 1978; Tucker and Wright, 1990) in addition to other reference thin sections. Most sections were stained with Alizarin Red S to help differentiate between calcite/aragonite and dolomite mineralogies.

Chapter Two: Facies of the Cayman Formation

2.1 Introduction

Despite extensive geological investigation involving full coverage of the Cayman Islands, a complete and consistent internal stratigraphy for the Cayman Formation remains elusive. Observations from limited exposures of the Cayman Formation at several sites including Pedro Castle Quarry (Grand Cayman) and various locales on Cayman Brac reveal high levels of spatial variability in facies distribution and an overall heterogeneous composition (Jones and Hunter, 1989; Jones *et al.*, 1994a). This evidence indicates that the Cayman Formation lacks a simple internal architecture. In fact, the most characteristic feature of these dolostones is the lack of a predictable vertical and lateral variance in facies. Rock fabrics range from mudstones to grainstones and recur several times in a single vertical section (Jones *et al.*, 1994a, Wignall, 1995).

The repetition of texturally and compositionally diverse facies reveals that high frequency variations in paleoenvironmental conditions persisted throughout the Miocene. Despite internal heterogeneity in facies architecture, the Cayman Formation is characterized by recurring lithologies, which were produced by small-scale depositional changes. The consistency of lithological variation results in a homogeneous appearance of the formation when considered in a regional context. In order to assess the continuity and significance of smaller-scale heterogeneities, facies descriptions and distributions must first be compiled into localized depositional models. Later, these models can be combined to reconstruct a depositional history for the entire island. Data collected at Roger's Wreck Point are a vital part to this puzzle because the core retrieved from RWP#2 and QHW#1 represent the deepest, most continuous sections of Cayman Formation available from the eastern part of Grand Cayman.

Previously, much of the effort to define the composition and facies architecture in the Cayman Formation focused on Cayman Brac (Jones *et al.*, 1994a). Measuring only 20 km long by 3 km wide, correlation of facies across this small island was complicated by difficulties in tracing bedding planes and a lack of distinctive internal markers. Together with high lateral variability in facies distribution, these interpretational barriers prevent the application of simple "Waltherian" stratigraphy (Jones *et al.*, 1994a).

Defining the sedimentologic nature of the strata on Cayman Brac required the combination of descriptions and observations from sea cliff exposures, quarries, isolated outcrops, and borehole chip samples into a single composite section that encompassed the entire formation. Estimated to be 102 m thick, the Cayman Formation was informally divided into the lower, middle, and upper parts (Jones and Hunter, 1989). The entire package of fabric-retentive microcrystalline dolostones consists of wackestones and mudstones with scattered beds or lenses of rhodolites, packstones, and grainstones. Faunal and floral components include a variety of colonial, branching, and free-living corals, gastropods, bivalves, echinoids, foraminifera, and red and green algae. Although organisms capable of framework-building are common, there is no evidence of reef development (Jones *et al.*, 1994a).

Examination of the Cayman Formation on Grand Cayman has been limited by the low bedding dip angle, the lack of topographic relief, and the limited number of quarries. One important advance towards the interpretation of this formation was the designation of a type section, 5.5 m thick, in Pedro Castle Quarry (Jones and Hunter, 1989). Attempts to analyze dolostones of the Cayman Formation at other localities have been hampered by extensive karst development on exposed rock surfaces. Not until the early 1990's did the availability of economic portable drilling technology afford a subsurface view *via* a core retrieval program initiated by Dr. Brian Jones of the University of Alberta. Depending on the extent and distribution of porosity development in the Cayman Formation, core recovery rates of up to 99% (RWP#2) have been achieved.

In the summer of 1997, a deep well drilled under the auspices of the Cayman Water Authority, failed to intersect the Cayman-Brac Unconformity in the Lower Valley despite reaching a depth of 154 m subsea. This implies the basal contact of the Cayman Formation lies below that depth (*pers. comm.* Jones, 1998). As a result, the projected thickness of this formation remains uncertain on Grand Cayman but must be at least 165 m thick. Thus, the Cayman Formation may be thicker than previously estimated. This discrepancy could be attributed to misinterpretation of the bedding dip angle (currently assumed as 0.5°W on Cayman Brac) or the development of extensive relief on top of the Cayman Formation by the Cayman Unconformity causing the thickness to vary between islands.

An east-west transect of 10 cored wells penetrating the Cayman Formation at Safe Haven, western Grand Cayman laid the foundation for a detailed facies analysis (Wignall, 1995). Seven facies were distinguished using allochems and their distribution patterns as interpretational criteria. Each facies was interpreted as the product of a storm, sand plain, near reef, or *Porites* reef environment. Wignall (1995) remarked on the extent of preferential preservation visible in the Cayman Formation and how the primary features present had influenced the expression of diagenesis. Efforts at depositional interpretation focused upon the type, distribution, and preservation of skeletal constituents.

2.2 FACIES OF THE CAYMAN FORMATION

Relying heavily upon the recognition of fossil allochems and their relative abundance, five facies have been identified in the Cayman Formation in RWP#2 and QHW#1 (Table 2.1). Descriptions of their respective lithologies, including allochem identification and preservation state, matrix composition and other sedimentary structures are outlined below.

A) *Stylophora* Floatstone Facies:

The *Stylophora* Floatstone facies consists of robust (2 cm diameter) and delicate (0.5 cm) branching finger coral fragments. The original aragonitic skeletons of *Stylophora*

FACIES NAME	MATRIX COMPOSITION	MAJOR ALLOCHEMS	MINOR ALLOCHEMS	RARE
***Stylophora* Floatstone**	Mudstone-Amphisteginid Wackestone	*Stylophora*	Amphisteginids	Echinoid Spines, Red Algae, Gastropods, Bivalves, *Halimeda*
Rhodolite Finger Coral Floatstone	Benthic Foraminifera Wackestone-Packstone	*Stylophora*, *Porites*, Rhodolites, Amphisteginids	Red Algae, *Halimeda*	Benthic Foraminifera, Gastropods, Bivalves
Rhodolite Coral Fragment Rudstone-Grainstone	Benthic Foraminifera Packstone	*Stylophora*, *Montastrea*, Amphisteginids, Rhodolites	Miliolids	Gastropods, Bivalves, Benthic Foraminifera, *Halimeda*, Red Algae, Echinoid Spines, Bryozoans
***Porites-Leptoseris-Montastrea-Stylophora* Floatstone**	Benthic Foraminifera Packstone	*Stylophora*	*Montastrea*, *Porites*, *Leptoseris*, Amphisteginids, Gastropods, Bivalves, *Lithophyllum*	*Favia*, *Siderastrea*, *Halimeda*, Red Algae, Benthic Foraminifera
***Leptoseris-Montastrea* Floatstone**	Benthic Foraminifera Wackestone-Grainstone	*Montastrea*, *Leptoseris*	Rhodolites, Amphisteginids	Bivalves, Gastropods, Echinoids, Scaphopods, *Halimeda*, Red Algae, Benthic Foraminifera

Table 2.1 Facies in the Cayman Formation from wells RWP#2, QHW#1.

are now completely dissolved. These corals, however, can be identified by the corallite imprints preserved on the mould surfaces. Casts of borings (*i.e. Entobia, Trypanites*) partly fill these coral moulds (Pleydell, 1987). Incomplete asymmetrical red algae coatings, 1-2 mm thick, partially encase the coral moulds. A weak horizontal alignment of coral fragments, found locally, may have resulted from sorting or compaction. The matrix is a mudstone to amphisteginid wackestone with fewer fragmented echinoid spines, coralline red algae, gastropods, disarticulated and fragmented bivalves, and *Halimeda*. Most allochems are less than 3 mm long. *Amphistegina* specimens exist as partially-preserved allochems or as mud-filled moulds. This facies was found in the RWP#2 well and at sample sites S1 and S5 (Figure 1.5).

B) Rhodolite Finger Coral Floatstone to Rudstone Facies

This facies consists primarily of rhodolites with nuclei of *Stylophora* and *Porites* fragments along with scattered uncoated skeletal fragments (predominantly *Stylophora*). The *Stylophora* moulds average 1 cm in diameter and up to 10 cm long. Coral moulds are commonly aligned with reduced porosity resulting from preserved internal borings. Rhodolites, 1-3 cm in diameter, have a typical cigar-shape that is inherited from the finger coral nucleus. The larger rhodolites formed around rounded to blocky fragments of *Montastrea*. Beds of floatstone and rudstone, 20-60 cm thick, are typically interspersed with 15-20 cm layers of benthic foraminifera wackestones to packstones. These wackestones and packstones also form the matrix support for the floatstones. Minor allochems include variably-preserved *Amphistegina*, red algae fragments, and disarticulated *Halimeda* fragments. Lesser numbers of *Homotrema*, *Sphaerogypsina*, miliolids, *Sporadotrema*, and echinoid plates, are also found. Rare intact gastropods (6 mm long) and articulated bivalves (2 cm long) are also present. This facies was found in the RWP#2 well and at the S2 sample site (Figure 1.5).

C) Rhodolite Coral Fragment Rudstone to Grainstone Facies

This facies differs from the Rhodolite Finger Coral Floatstone to Rudstone facies in two ways. First, *Porites* fragments are absent, whereas the major coral components include *Stylophora* and *Montastrea*. Second, scattered lenses of grainstones, up to 0.3 m thick consisting of coral rubble or foraminifera and rhodolites alternate with rudstones. A bimodal size distribution exists in the rhodolite population. The smaller group (4 mm diameter) formed about skeletal nuclei of unknown origin (now dissolved), whereas the larger, more abundant group, (0.5 -2 cm) have cores formed of delicate *Stylophora* fragments. Rhodolites along with coral fragments are the dominant allochems.

Coral fragments in this facies include *Stylophora* and *Montastrea*. *Stylophora* fragments are completely dissolved producing vugs 1 cm in diameter and at least 5 cm long (controlled by core diameter). *Montastrea* are less abundant, with a rounded to blocky form 2-5 cm long. Rare moulds of gastropods and disarticulated bivalves (0.3-2 cm long) are also present.

The matrix contains an abundant and diverse assemblage of foraminifera and algae. Significant concentrations of amphisteginids (*i.e. Hyalinea*, *Boreloides*) and lesser numbers of miliolid foraminifera (*Triloculina*, *Sorites*) are present. Fewer rotaliid/globorotaliid (*Sporadotrema*, *Cymbaloporetta*, *Globorotalia*) are found along with variable amounts of coralline red algae, echinoid spines, bryozoan fragments, and *Halimeda* plates. Preservation of skeletal allochems ranges from partial to complete dissolution.

This facies was only found in core from the RWP#2 well.

D) *Porites Leptoseris Montastrea Stylophora* Floatstone Facies

This facies contains the most diverse coral assemblage of all five facies. This biota includes robust *Stylophora* (1-3 cm diameter), rounded *Montastrea* fragments (3 cm diameter), *Porites* (8 mm diameter), and fragmented blocks of *Leptoseris* (2 by 2 cm). *Montastrea*, *Siderastrea*, *Leptoseris*, and *Favia*, either *in situ* or intact and relatively close to life position, are locally common. The vertical growth of individual corals is usually limited to 5-10 cm. Thin, incomplete algal coatings are present on the *Porites* fragments but are conspicuously absent from the larger *Stylophora* allochems. Less abundant megafossils (1-3 mm) include gastropods, disarticulated bivalves, and fragments of *Lithophyllum*. These components, together with numerous benthic foraminifera and micrite, form the wackestone to packstone matrix.

Microscale components of this facies include scattered 1-2 mm fragments of delicate bryozoans, *Halimeda* plates, coralline red algae and rare echinoid spines. Amphisteginids (*i.e. Boreloides*, *Tremastegina*) are the most abundant foraminifera and are present in minor concentrations accompanied by rare miliolids (*Triloculina*, *Nummoculina*), rotaliids (*Cymbaloporetta*, *Siphonina*), globorotaliids (*Globorotalia*), and/or soritiids (*Amphisorus*).

This facies was found in the RWP#2 and QHW#1 wells and at sample sites S3 and S4.

E) *Leptoseris Montastrea* Floatstone

In situ and fragmented *Leptoseris* and *Montastrea* dominate this facies. *Leptoseris* is typically in life position and assumes a platy growth form up to 50 cm high but is also found as rounded fragments to 10 cm. *Montastrea* is equally abundant in smaller sizes (5-10 cm) when *in situ*, and as abraded blocks 4 cm wide. These size ranges are limited by the width of the core and therefore represent minimum values. Lesser numbers of *Porites baracoaensis* and *Stylophora* are evident in the cores of rhodolites and uncoated fragments to 3 mm in diameter.

The matrix is formed primarily of benthic Foraminifera wackestones to grainstones with minor amounts of disarticulated bivalves (1.5 cm), gastropods (3 mm), fragmented echinoid spines, and *Halimeda* plates. Also present are numerous amphisteginids (*i.e. Boreloides*) along with scattered *Sporadotrema* and *Homotrema* fragments (1 mm), fragmented scaphopods (3 mm), and red algae (*Goniolithon, Lithophyllum*) to 3 mm. Rare globorotaliids (*Globorotalia*) and miliolids (*Sorites*) are also found.

This facies is found in RWP#2 and QHW#1.

2.3 CORAL BIOFACIES

Hunter (1994) examined the diverse coral biota in the Cayman and Pedro Castle formations. After examining community-scale recurrences of coral species on Grand Cayman and Cayman Brac, he divided the coral fauna into seven associations which were named after the dominant taxa (Table 2.2). Paleoecological interpretations were made for the various associations using morphological and behavioural criteria of the constituent coral species. As a result, these associations can be used as environmental indicators for the rocks in which they were found.

CORAL ASSOCIATIONS (FROM HUNTER, 1994)	FACIES WITH MATCHING CORAL ASSEMBLAGES (THIS STUDY)
1. ***Stylophora* Association** • Major *Stylophora* • Minor *Porites baracoaensis* • Coral content: 10-20%	***Stylophora* Floatstone Facies**
2. ***Stylophora-Porites* Association** • Major *Stylophora, Porites* • Coral content: 30-40%	Rhodolite Finger Coral Floatstone Facies*
3. ***Porites baracoaensis* Association** • Major *Porites baracoaensis* • Coral content 50-60%	---
4. ***Montastrea limbata* Association** • Major-Minor *M. limbata, M. endothecata, Diploria, Porites, Favia* • Coral content 5-10%	*Porites Leptoseris Montastrea Stylophora* Floatstone Facies*
5. ***Goniopora hilli* Association** • Major *Goniopora hilli, M. limbata, Siderastrea, Porites* • Coral content 15-25%	---
6. ***Leptoseris* Association** • Major *Leptoseris, M. limbata, Porites* • Coral content 10-20%	***Leptoseris Montastrea* Floatstone Facies**
7. **Free-Living Coral Association** • Major *Trachaphyllia, Thysanus excentricus, Teleiophyllia grandis, Placocyathus, Antillocyathus* • Coral content <10%	---

Table 2.2: Comparison chart correlating the coral associations of Hunter (1994) with facies identified in the Cayman Formation (RWP#2, QHW#1). * denotes a slight resemblance, bold denotes a high resemblance.

Regarding coral abundance in the Cayman Formation alone, Hunter (1994) categorized the occurrence of *Stylophora spp.* and *Montastrea limbata* as very common, *Porites baracoaensis* and *Montastrea endothecata* as common, and varieties of *Leptoseris*, *Siderastrea*, and *Favia* as locally common. These distributions match those in the Cayman Formation in the Roger's Wreck Point succession.

2.4 DISCUSSION

Comparing the coral distributions found in RWP#2 and QHW#1 cores on a per-facies-basis to the seven coral associations of Hunter (1994), a match was found with the coral biota found in two of the lithofacies (Table 2.2). Thus, in terms of its coral content the *Stylophora* Floatstone facies is analogous to the *Stylophora* Association, whereas the coral biota in the *Leptoseris Montastrea* Floatstone facies is equivalent to the *Leptoseris* Association. A slight resemblance exists between the corals found in the Rhodolite Finger Coral Floatstone facies and the *Stylophora Porites* Association, as well as between those corals in the *Porites Leptoseris Montastrea Stylophora* Floatstone facies and the *Montastrea limbata* Association. The apparent disparity between the remaining coral associations and lithofacies may result from the limited sample set of this study (2 cores) whereas Hunter's work relied upon examination of surface outcrops, the small core diameter (3.5 cm), or the existence of a unique localized paleoenvironment on northeast Grand Cayman.

The correlation between the coral content of two facies and two of Hunter's (1994) coral associations suggests how differing faunal populations (here coral) may reflect the existence of significant depositional lithofacies. Coral communities are notorious for their environmental sensitivity (wave energy, salinity, temperature, *etc.*) and respond rapidly to perturbations in the depositional setting (Hunter, 1994; James and Bourque, 1992). The exclusivity of two coral assemblages to two lithofacies suggests each was deposited in a unique and significantly different environment. This in turn, supports the interpretation that each lithofacies does indeed represent a modification to the depositional setting.

Despite the interpretational utility of biotic assemblages, the distribution of single taxa may not reveal all depositional parameters affecting the accumulation of a lithofacies. Although corals can be used to accurately interpret temperature, wave energy, and salinity (Kinsman, 1964; Lees, 1975; James and Bourque, 1992) for a given paleoenvironment, correlations with bathymetry are qualitative at best (Wells, 1967; Selley, 1985). As such, single sources of data cannot reveal all aspects of the depositional regime, one must observe all aspects of a carbonate package to understand and appreciate the information it conveys. Only by combining a wide array of sedimentological and paleoecological interpretations within the given depositional context (here a carbonate bank) will a representative paleoenvironmental model be proposed.

2.5 SUMMARY

Five facies have been identified for the Cayman Formation from Roger's Wreck Point. Differentiation between the five sedimentologic packages relies heavily on subtle variations in fossil composition and abundance, especially with respect to the coral fauna. Coral assemblages in two lithofacies matched two coral associations defined by Hunter (1994). Two others displayed similarities in coral population compositions. This match implies that the described lithofacies resulted from substantial depositional change. Habitat criteria derived from the coral biofacies is instrumental, along with other sedimentary evidence, to the interpretation of facies-related paleoenvironments. These criteria will employed to help refine a depositional model for the Cayman Formation at Roger's Wreck Point.

CHAPTER THREE: DEPOSITIONAL FRAMEWORK OF THE CAYMAN FORMATION

3.1 FACIES ARCHITECTURE

The carbonate successions in RWP#2 and QHW#1 show repeated vertical stacking of five lithofacies (Figure 3.1). No systematic vertical or lateral facies variation is apparent, however, their recurrence throughout the Cayman Formation indicates that continued, yet slight fluctuations during deposition controlled paleoenvironmental conditions. Minor changes in the depositional regime modified the composition of faunal and floral communities, which is recorded by the variable distribution of organisms between facies.

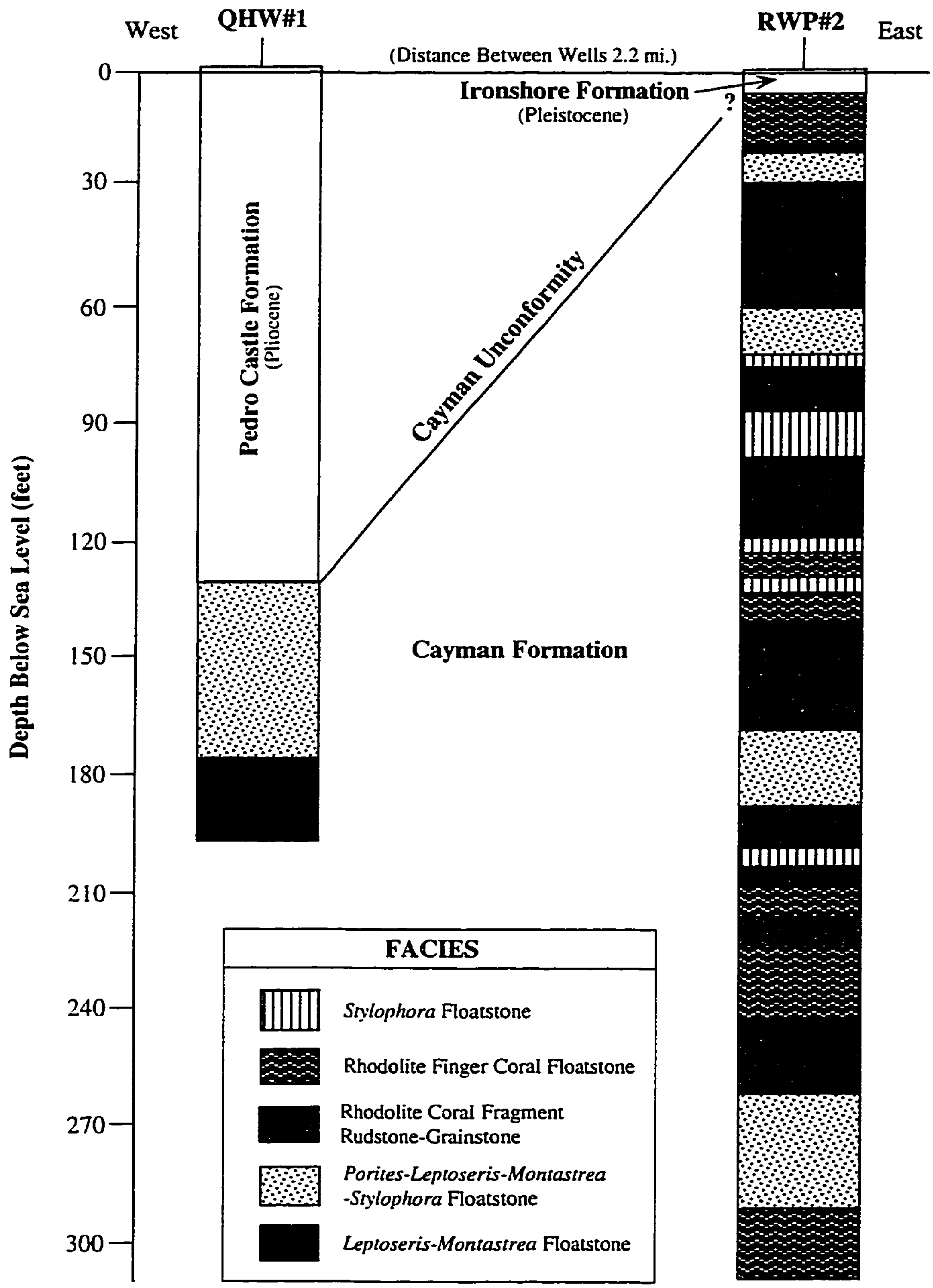
Lateral transitions between facies complicates stratigraphic correlation and is of concern in the Cayman Formation. Hunter (1994) documented this type of spatial zonation between two coral biofacies (*Stylophora* and *Leptoseris* Associations) on Grand Cayman. Interestingly, the biotic composition of these associations bear remarkable resemblance to the *Stylophora* Floatstone and *Leptoseris Montastrea* Floatstone facies of Roger's Wreck Point. Therefore, expectations of lateral variability between facies is extremely high for this study area. However, quantitative analysis of these lateral changes requires that spatial heterogeneities must be traced using more closely spaced core data than is currently available.

3.2 PALEOENVIROMENTAL RECONSTRUCTION

3.2.1 General Environmental Setting

Most of RWP#2 consists of the Rhodolite Finger Coral Floatstone, the Rhodolite Coral Fragment Floatstone-Grainstone, and the *Porites Leptoseris Montastrea Stylophora* Floatstone facies. Rhodolites are a major constituent of two of these (Rhodolite Finger

Figure 3.1 Generalized facies strip log of the Cayman Formation.

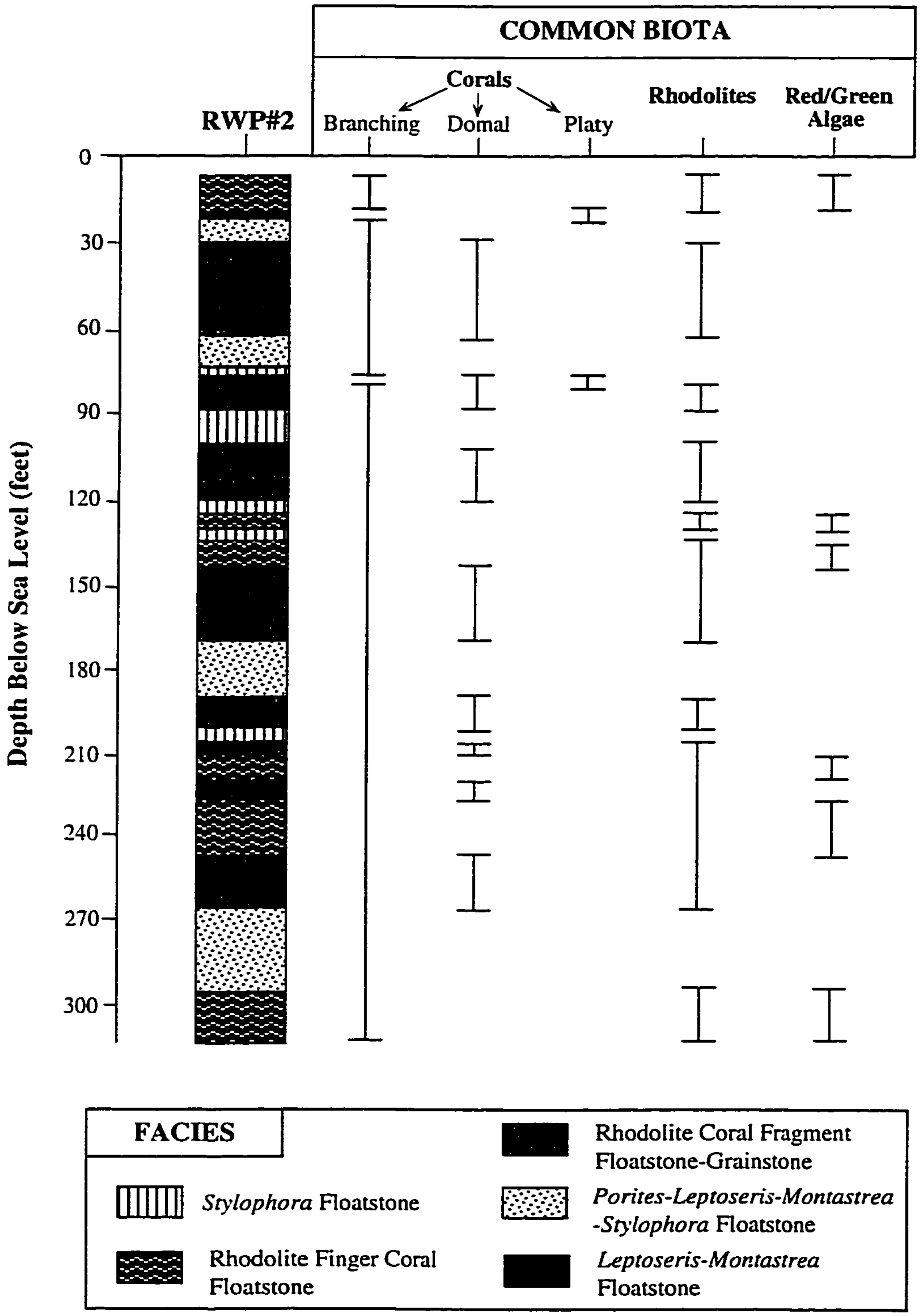


Coral Floatstone, Rhodolite Coral Fragment Floatstone-Grainstone), which explains their widespread distribution throughout the core. Scattered horizons of *Stylophora* Floatstones and *Leptoseris-Montastrea* Floatstones also characterize this sequence.

The prevalence of hermatypic corals and photosynthetic algae throughout the entire RWP#2 sequence indicates that deposition must have taken place in the photic zone (*cf.* Raven *et al.*, 1987). The position of the photic limit depends on light intensity, and indirectly, water clarity (Wray, 1977) and is uniquely defined for each depositional setting. Caution is required when using phototroph distributions to interpret paleobathymetry because photosynthetic species possess a range in lumination tolerances. For example, although actively-growing red algae and corals are found from 60 and 100 m subsea (Wells, 1967; Reid and McIntyre, 1988), most will preferentially colonize shallower depths.

By dividing corals into morphologic groupings (branching, domal, and platy forms) (Figure 3.2), several growth responses can be linked to depositional wave energies. Reef fauna respond variably to sedimentation rate and the degree of water roughness (turbulence) by morphological adaptation (external shape, growth banding) and habitat choice (James and Bourque, 1992). Many species subjected to strong currents evolve flattened growth forms to increase their stability by streamlining. In contrast, the same species may adopt a branching or columnar habit to prevent burial of their polyps by sediment in conditions of high sedimentation and low wave energies. Branching corals dominate the Cayman Formation, either alone or in combination with domal forms (Jones *et al.*, 1994a; Wignall, 1995). However, they do not appear to co-exist with platy species (*Leptoseris*) in the same setting (Figure 3.2). Domal forms (*i.e. Montastrea*) are found in combination with either platy or branching morphs but do not appear to dominate any of the five facies. Relating these observations to the interpretations of James and Bourque (1992), depositional conditions at Roger's Wreck Point during the Miocene appear to have varied between two end states: 1) a high energy, low sedimentation (dominated by platy

Figure 3.2 Distribution of common biota in RWP#2 (Cayman Formation.)



corals) environment, and 2) a low energy, high sedimentation (branching coral domination) environment.

Rhodolite development may indicate relatively high wave energy conditions (Glynn, 1974; Scoffin *et al.*, 1985). Created by the progressive encrustation of red algae about a fossil fragment, rhodolites require sporadic overturning by turbulence to facilitate the completion of their growth laminae. The presence of rhodolites with relatively concentric laminae typically suggests at least moderate water energy to be the turning agent; however, alternate causes (fish, shifting substrates) have been documented under rarer circumstances (Scoffin *et al.*, 1985, Hills, 1998). The abundance of this type of rhodolite throughout RWP#2 likely implies the depositional regime experienced at least moderate wave energy. The absence of rhodolites from the *Porites Leptoseris Montastrea Stylophora* Floatstones, however, implies the existence of a different energy regime.

The biotic diversity of the RWP#2 succession, including hermatypic corals and red and green algae, fulfills the criteria for normal marine conditions established by Heckel (1972). Stenohaline organisms like these respond to salinity variation by developing protective measures to prevent large fluid imbalances across the cell membranes (Wetzel, 1983). Corals are especially intolerant of salinity change and require normal marine conditions for optimal growth (Kinsman, 1964). The abundance of coral in all facies of RWP#2 indicates that water salinity remained relatively stable throughout the Miocene. Stable normal marine conditions were probably maintained by open water circulation between the bank and the open ocean.

Trends in species diversity can be used to make paleoclimactic inferences. Suitable temperatures are required for the successful sexual and asexual reproduction of hermatypic polyps and their constituent symbiotic algae (Raven *et al.*, 1987), which in turn, impact coral distribution. All corals in the Cayman Formation are hermatypic; thus, a semi-tropical to tropical climate must have existed throughout the Miocene to ensure their continued survival. Adey and McIntyre (1973) documented a similar environmental preference of coralline red algae, especially *Porolithon*, a species found in minor numbers in RWP#2. Therefore, a semi-tropical to tropical setting is proposed for the for the accumulation of Cayman Formation sediments, based upon the observed abundance of coral and red algae in RWP#2.

3.2.2 Discussion

Variable faunal and floral content in carbonates reflects a biological response to perturbations in the depositional environment. Sedimentation on isolated carbonate banks is controlled by wave energy, sedimentation rate, salinity, temperature, and bathymetry. These abiotic influences are important because they act as a source of external stress on carbonate-secreting biota. The organism's reaction is constrained by physiology and genetics, forcing a response of either adaptation, relocation, or death. Tracing trends in biotic diversity and abundance in the Cayman Formation allows inference of relative stress levels and helps pinpoint their source. Separating out the impact of each influence from a cumulative response (resultant rock fabric) is a difficult but necessary task towards accurately reconstructing the depositional paleoenvironment.

3.2.3 Facies-Related Paleoenvironments

The interpreted depositional environment and major extrinsic controls for each facies are discussed below (Table 3.1).

a) *Stylophora* Floatstone

The *Stylophora* Floatstone Facies contains numerous delicate and robust *Stylophora* branches (intact or *in situ*), that are indicative of a low to moderate energy setting (Jones and Hunter, 1989; James and Bourque, 1992). Transported mud would have settled from suspension in this environment as currents encroached on the bank and were deflected about the coral polyps by baffling. This lead to an accumulation of mud, surrounding and leeward of the corals. The abundance of finger corals (*i.e. Stylophora*), equipped with elevated polyps capable of sediment shedding (Hubbard and Pocock, 1972; Frost, 1981), and their abundance throughout this facies reflects a relatively high sedimentation rate.

Scattered horizons of faintly-aligned *Stylophora* fragments probably represent thicket-derived rubble oriented by currents. This facies is common throughout the Cayman Formation on Cayman Brac and Grand Cayman (Jones and Hunter, 1989; Jones *et al.*, 1994a; Jones and Hunter, 1994a).

Refining depositional bathymetry for this facies within the photic zone is complicated by the broad environmental tolerances of constituent species. Amphistegenids and Miliolids dominate the sediment make-up in unrestricted waters (normal marine conditions) along modern carbonate banks at depths between 10-30 m (Poag and Tresslar,

Depositional Setting	Facies	Energy	Sedimentation Rate	Salinity (‰)	Temperature	Bathymetry (m)
***Stylophora* Thicket**	*Stylophora* Floatstone	Low-Moderate	Moderate-High	Normal	Tropical	10-30
Distal Bank Edge	Rhodolite Finger Coral Floatstone	Moderate	Moderate-High	Normal	Tropical	5-30 (probably 10+)
Storm-Influenced Bank Edge	Rhodolite Coral Fragment Rudstone-Grainstone	High	High	Normal	Tropical	5-30 (mostly shallow end of range)
Protected Inner Bank	*Porites Leptoseris Montastrea Stylophora* Floatstone	Moderate	Low-Moderate	Normal	Tropical	15-30
Windward Edge of Inner Bank	*Leptoseris Montastrea* Floatstone	Moderate	Low	Normal	Tropical	20-30

Table 3.1 Interpreted depositional setting and the extrinsic influences affecting deposition of the Cayman Formation.

1981; Venec-Peyre, 1991). Therefore, the abundance of these two genera in the Cayman Formation dolostones suggests a similar depositional bathymetry. Schlager (1981) argued that coral communities below 10 m water depth have diminished accretionary abilities and cannot keep pace with sea level change. His research demonstrated that photosynthetic efficiency decreases with reduced light, thereby impacting the coral's calcification rate

(Schlager, 1981). True bioherm development is absent from the *Stylophora* Floatstone Facies; however the interpreted existence of dispersed thicket-like growths suggests a minimum depositional limit of 10 m subsea. The lack of a substantial reef barrier is further supported by outcrop observations at both Roger's Wreck Point and Pedro Castle Quarry. Extensive reefal successions of *Stylophora*, *Porites* and *Millepora* in the Miocene Lirio Limestone of Isla de Mona, Puerto Rico (Ruiz *et al.*, 1991), demonstrates Caribbean reef growth was possible during the Miocene. Therefore, the combined effect of bathymetry and sedimentation at Roger's Wreck Point may have prevented true bioherm development in the Cayman Formation.

In summary, a low to moderate energy ***Stylophora* thicket** setting is proposed for the *Stylophora* Floatstone Facies. This depositional setting is characterized by moderate to high sedimentation of mud, open water circulation, and water depths between 10 and 30 m.

b) Rhodolite Finger Coral Floatstone

Numerous rhodolites in the Rhodolite Finger Coral Floatstone Facies and a mostly grainy matrix (wackestone to packstone) are indicative of at least moderate depositional energies (*cf.* Glynn, 1974; Scoffin *et al.*, 1985). The presence of rounded and abraded coral rubble supports this interpretation. Scattered amounts of both types of allochems along with sharp transitions in mud content suggests water energies fluctuated greatly, perhaps as a result of storms. The retention of at least some mud throughout, however, indicates that turbulence rarely exceeded moderate levels. Rhodolites have been documented in the Cayman Formation at numerous locales about Grand Cayman and Cayman Brac (Jones and Hunter, 1989; Jones *et al.*, 1994a; Hills, 1998). Their turbulent growth requirements have been used previously to infer moderate to high energy flow rates during deposition of sediments that now constitute the Cayman Formation (Jones and Hunter, 1994a). Wignall (1995), for example, interpreted a similar rhodolite-dominated lithofacies, a Rhodolith Lithoclast Grainstone Facies from Safe Haven, as a high energy storm deposit.

Sedimentation rates during deposition ranged from moderate to high, just low enough to allow for the accumulation of a mud substrate between storms. Such high energy conditions would produce a primarily sandy substrate, the preferred growth medium of constituent *Porites* (Frost and Langenheim, 1974; James and Bourque, 1992; Jones and Hunter, 1994a).

Precise determination of the bathymetric limits of this facies relies heavily on faunal criteria. The dominance of constituent amphisteginids and miliolids indicates deposition in water between 10 and 30 m deep (Chaproniere, 1975; Poag and Tresslar, 1981). The composition of rhodolites may also lend insight into depositional paleobathymetries. Rhodolites with cores of *Stylophora* and *Porites* from this facies possess equidimensional laminae, similar to those currently forming around *Acropora* fragments in lagoons about Grand Cayman. Situated behind the reef crest in 0-2 m water, these modern rhodolites develop a concentric growth pattern as a result of moderately high turbulence. Reid and McIntyre (1988) documented similar rhodolites in equivalent energy regimes along eastern Caribbean platform ridges and shelf edge ridges at depths of 20-30 m. Considering the bathymetric implications of abundant concentrically-laminated rhodolites, the relative lack of mud, and the absence of bioherm development, the upper depth limit on this facies is likely 5-10 m. This relatively shallow position experienced moderate energy levels caused by storm waves and current impact which created a variable matrix texture and allochem distribution.

On the basis of the observed lithological evidence, moderate energy, normal marine salinity and intermediate to high sedimentation rates best characterize the ambient water conditions of this facies. Deposition took place between 5 (likely 10) and 30 m, under tropical temperatures. This setting reflects a distal storm or bank edge influence, inferred from the abundance of rhodolites and the grainy rock texture. The depositional environment which best represents this facies is a **distal bank edge**, which could be juxtaposed between a true *Stylophora* thicket and bank edge setting.

c) Rhodolite Coral Fragment Rudstone-Grainstone Facies

Highly energetic and periodically turbulent depositional conditions are inferred from the scattered horizons of foraminifera-rich grainstones, coral rubble, and numerous rhodolites found throughout this facies. Although the coastal proximity of Roger's Wreck Point caused ocean-driven winds and storm currents from the northeast to influence the deposition of the entire Cayman Formation, this facies is the coarsest in texture. By implication, this facies was subject to more direct storm impact as a result of its more proximal position, interpreted as a bank edge setting. Scattered grainstones and rubblized intervals illustrate the result of intermittent storms. The large size and number of broken and abraded coral fragments in this facies also reflect a high base level energy. Storm beds of similar composition have been recognized in the Cayman Formation across Grand Cayman and on Cayman Brac suggesting that turbulent events were common during the Miocene (Jones and Hunter, 1994a; Jones *et al.*, 1994a; Wignall, 1995).

Waves impacting the bank edge would have rapidly diminished in flow velocity resulting in high sedimentation as particles dropped out of the water from bedload and suspension. The low mud content of this facies reveals that a relatively high base energy persisted between storm events. Episodic change in depositional energy between storm and base level wave energy is shown by the textural variability of this facies (*i.e.* grainstones, rubble and rudstone horizons). Substrate conditions were primarily sandy as interpreted from the documented environmental preference of abundant *Porites* (Jones and Hunter, 1994a).

Bathymetric criteria for this facies are scant, primarily due to the lack of *in situ* coral and the potentially wide-ranging presence of rhodolites (Scoffin *et al.*, 1985). However, high flow velocities, as indicated by the grainy rock textures are easier to sustain in shallow areas due to the amplification of storm and wave energies. Although amphisteginids and miliolids preferentially colonize water depths between 10-30 m (Poag and Tresslar, 1981; Venec-Peyre, 1991), small populations have been found in shallower settings. *Amphistegina gibbosa* currently occupies shallow bare sand niches in the outer lagoon around Grand Cayman as does *Cymbaloporetta squammosa*, though the latter prefers protected beaches (Li, 1997). Another species, *Triloculina simplex* colonizes sandy lagoons (Li, 1997). All three species are related to foraminifera found in this facies and imply the existence of shallow sandy near-lagoon or beach accumulations. As a result, an upper depth limit is established at 5 m or less water depth for this facies.

Fluctuation between constant high energy and periodic storm-dominated deposition with high sedimentation rates under normal marine conditions resulted in the Rhodolite Coral Fragment Rudstone-Grainstone Facies. This depositional setting is interpreted as a shallow (5-30 m), tropical, **storm influenced bank edge**.

d) *Porites Leptoseris Montastrea Stylophora* Floatstone

The *Porites Leptoseris Montastrea Stylophora* Floatstone facies represents a diverse community of reef-building organisms, as most corals are intact and appear close to life position. The combined growth preferences of branching (*Porites*, *Stylophora*) and non-branching (*Montastrea*, *Leptoseris*) corals indicate low to intermediate sedimentation rates and moderate wave energies persisted during deposition (James and Bourque, 1992; Jones and Hunter, 1994a).

Despite abundant framework-building fauna, no evidence of bioherm development was evident in the core. The absence of reef build-ups is relatively typical of the Cayman Formation, especially in the eastern vicinities, although small patch reefs and isolated frameworks have been documented on western Grand Cayman (*i.e.* Cottage Point, Blowholes) (Hunter, 1994; Wignall, 1995). Depositional bathymetries for this facies likely exceeded 10 m based upon the diversity and morphological variation of the observed corals. The presence of reef-building species but the lack of observed reef structures may also be linked to a depth-related inhibition of calcification (Schlager, 1981).

Support for a relatively deep setting is provided by constituent foraminifera (*Amphisorus sp.*, *Siphonia pulchra*). Investigations of bay sediments off the coast of Tobago assigned habitat ranges of 15-24 m to modern forms of both species (Radford, 1976). Summarizing all faunal evidence, a depositional range between 15 and 30 m is proposed for this facies. An appreciable mud content, a slightly increased depth in comparison to the other facies, a low sedimentation rate, and moderate wave energy suggest deposition took place in an inner bank setting.

In summary, the *Porites Leptoseris Montastrea Stylophora* Floatstone facies was deposited in a tropical **inner bank** setting with moderate energy, low to intermediate sedimentation, and open water circulation. Sediment deposition most likely occurred between depths of 15 to 30 m.

e) ***Leptoseris Montastrea*** **Floatstone**

Tabular and platy corals (*Montastrea*, *Leptoseris*) dominate this facies suggesting a streamlining response to at least moderate energy conditions (*cf.* James and Bourque, 1992). This flow regime is reinforced by the minor amounts of rhodolites present (Adey and McIntyre, 1973; Hills, 1998). Variability in matrix texture (wackestone-grainstone) suggests fluctuating flow energies controlled the amount of mud deposited. Morphological criteria imply a very low sedimentation rate for this facies as rapid deposition would have smothered the abundant flat-lying corals (James and Bourque, 1992; Jones and Hunter, 1994a). These same flat shapes suggest conditions of low light, as corals develop this type of growth form to maximize photosynthetic efficiency (Tucker and Wright, 1990). Considering the depth implications for low illumination, laminar forms (*Leptoseris*) typically occupy environmental niches exceeding 30 m (Liddell and Olhorst, 1987), whereas domal corals (*Montastrea*) prefer waters from 10 to 30 m depth (Logan *et al.*, 1969). In this core, both species remain in life position, suggesting an intermediate bathymetry between 20-30 m.

Hunter's (1994) *Leptoseris* Association, to which the coral content of this facies is similar, has been described as passing laterally into the *Stylophora* Association, here likened to the previously described *Stylophora* Floatstone facies. This indicates that the *Leptoseris Montastrea* Floatstone facies was deposited in close proximity to a *Stylophora* thicket setting. However, the comparatively lower wave energy and greater bathymetry suggest a windward edge of the inner bank setting, protected from wave onset by the thickets.

In summary, the *Leptoseris Montastrea* Floatstone Facies was likely deposited near the **windward edge of the inner bank**, leeward of *Stylophora* thickets in 20-30 m water. Periodic storms resulted in frequent but short-lived perturbations in wave energy which accounts for the observed variability in matrix texture and rhodolite distribution. Ambient water conditions were tropical and normal marine with a low sedimentation rate and moderate degree of turbulence.

3.3 DEPOSITIONAL MODEL FOR THE CAYMAN FORMATION

3.3.1 Proposed Model

The five facies described for the Cayman Formation at Roger's Wreck Point can be positioned on a bank edge to inner bank transect (Figure 3.3). Each environment was characterized by small yet significant differences in depositional parameters (wave energy, sedimentation rate, *etc.*) (Table 3.1). Frequent environmental perturbations, most likely storm-driven, affected the balance of these parameters, causing the relative position of each facies to shift with time. Continued lateral shifts in facies resulted in the repetitive vertical successions of QHW#1 and RWP#2. Storm frequency and duration were the major influences on these shifts, as revealed by the storm-influenced bank edge sediments (Rhodolite Coral Fragment Rudstone-Grainstones) which typically overlie the inner bank deposits (*Porites Leptoseris Montastrea Stylophora* Floatstone). The apparent thickness of the storm-dominated facies may be used to qualitatively assess the duration of storm

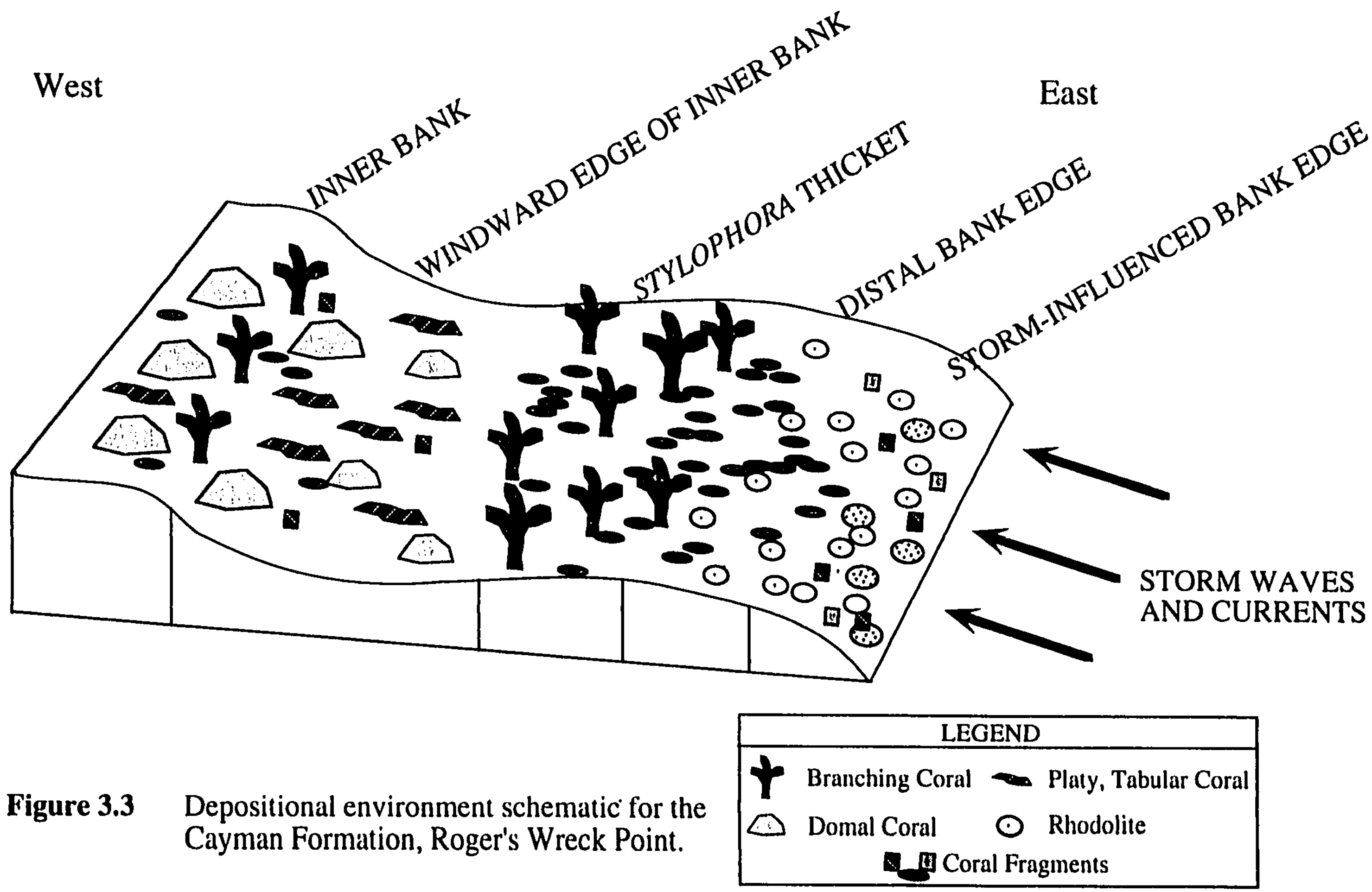


Figure 3.3 Depositional environment schematic for the Cayman Formation, Roger's Wreck Point.

deposition. Here, facies distribution also depends on the recovery time required by biota in affected communities. However, the relative contribution of genetic response to the observed facies patterns is difficult, if not impossible to assess.

The five settings and their depositional facies are arranged primarily according to their respective energy levels (Table 3.1). The storm-influenced bank edge and distal bank edge settings are characterized by higher wave energies due to their lack of protection from direct ocean impact and more coastal proximity. An increase in mud content coupled with a decrease in wave energy and sedimentation rate (determined from faunal criteria) allows the distal facies to be differentiated from the storm-derived one. Moving bankward, the *Stylophora* thickets provide a current baffle or barrier, allowing a quieter, muddier inner bank environment to develop to their leeward (westward) side. This protected environment promoted the development of both an inner bank and a windward edge inner bank setting. The windward edge inner bank environment represents a slightly higher energy setting than that of the inner bank which is attributed to pulses of wave energy penetrating the *Stylophora* thicket. These flow oscillations are caused by the occasional penetration of storm waves through the *Stylophora* thicket. The diversity and environmental criteria of fauna interpreted as inner bank deposits support the existence of low to moderate energies inboard of the thickets.

3.3.2 Discussion

The bank edge to inner bank model for Roger's Wreck Point is oriented west to east with westward-moving currents impinging on the eastern bank edge, similar to modern flow patterns off Grand Cayman today (Darbyshire *et al.*, 1976). Since the late Cretaceous, all three Cayman Islands have been affected by the westward Caribbean current (Stanley, 1988). Modern current velocities off Grand Cayman average 30 cm/s and have been monitored to depths of 300 m (Darbyshire *et al.*, 1976). However, flow velocities may have been slightly reduced during the Miocene due to the re-opening of the mid-America seaway and elevated levels of glacier water storage at that time (Brunner, 1984). Two major hurricane routes approach Grand Cayman from the east (Hubbard, 1988; Woodley, 1992), and meteorological reconstructions suggest these same routes existed in the Miocene. Thus, accumulation of Cayman Formation sediments on the Grand Cayman bank took place within storm wave base. Periodic winnowing of these bank sediments by storms would be expected, especially in relatively unprotected bank edge settings such as Roger's Wreck Point.

The distribution of lithofacies within RWP#2 and QHW#1 reflects a biological response to storm conditions. The vertical truncation of the *Porites Leptoseris Montastrea Stylophora* Floatstone Facies (inner bank) by the Rhodolite Coral Fragment Rudstone-Grainstone Facies (storm-influenced bank edge) at 65, 170, and 260 feet (19.8, 51.8, 79.2 m) below sea level in RWP#2 (Figure 3.1) represents repeat abrupt shifts in the depositional setting as initiated by storm impact. If the storm event was short-lived or of moderate strength, minimal damage would be incurred. As a result, the pre-existing inner bank setting and its characteristic faunal and sediment assemblage (*i.e. Porites Leptoseris Montastrea Stylophora* Floatstone Facies) would be quickly re-established. Severe storm impact, however, would cause extensive environmental modification such that new environmental and depositional conditions would be inhospitable to the original biotic community. As a result, a different faunal assemblage which would be better suited to the new environmental parameters would evolve. These repeat transitions in the carbonate depositional environment at Roger's Wreck Point are revealed by the vertical succession of facies observed in both wells.

Aside from merely increasing flow velocities during the storm event, storm impact can also affect the depositional environment by 1) substrate modification; 2) high sedimentation resulting in the rapid burial of organisms. Storm waves alter the sediment interface by carrying away fines in suspension and redistributing coarser materials (Blanchon and Jones, 1995). This has important implications for faunal distributions. For example, certain branching corals such as *Stylophora*, prefer muddy sediments and avoid colonization of coarse substrates (Jones and Hunter, 1994a). High rates of sedimentation are also generally detrimental to filter feeding organisms and may in some cases, choke some forms of domal and platy corals (*i.e. Montastrea, Leptoseris*) (James and Bourque, 1992). All four of these coral species are found in variable abundance and combinations throughout the Cayman Formation at Roger's Wreck Point. Together as the basis of the five vertically-stacked facies, their recurrence demonstrates the repeated response and recovery of the carbonate biotic community to the periodic storm events over Miocene time.

Although separate bathymetric zones can be assigned for the five depositional paleoenvironments and their representative facies, their relative similarity suggests water depth was a relatively minor control on facies distribution. As faunal criteria constitute the main indicator for bathymetric limits, the depth values assigned are best used as relative indicators as to how the five depositional settings compared.

Detailed facies analysis of the Cayman Formation at Safe Haven, Grand Cayman by Wignall (1995), attributed local sediment accumulation and reef development to sheltering by an easterly energy barrier. Carbonate productivity of Safe Haven was reasoned to be insufficient to maintain the observed thickness of sediment accumulation in the absence of wave protection. Wignall (1995) proposed that a reef or raised bedrock rim to the east of the island must have existed to prevent sediments from being swept off the bank. No evidence for such an energy barrier has been observed at Roger's Wreck Point, excepting the identification of a coral thicket setting. Although branching coral thickets do possess excellent baffling efficiencies and may have served some form of protection for the inner bank, their appearance at Roger's Wreck Point suggests they were most likely patchy and delicate in form. However, the necessity of such a barrier to facilitate the accumulation of the observed sediment section at Safe Haven remains questionable. The lack of flow data to support the claim that sediments would be swept away lends the argument little credence.

3.3.3 Summary

Until this point, attention has been focused on interpreting the depositional features and textures characteristic of the Cayman Formation at Roger's Wreck Point. Strata have been assessed qualitatively and quantitatively, significant lithofacies separated out, and paleoenvironmental conditions interpreted for each recurring sediment package. However, deposition represents only one facet of the geological evolution of a complex unit such as the Cayman Formation. The diverse array of diagenetic fabrics apparent in RWP#2 and QHW#2 reveals evidence of a multistage and episodic diagenetic history. Detailed examination of these features (*i.e.* cements, cavity fills, dissolution patterns) including discussion of their type, distribution, and causal mechanisms will benefit our geological understanding of the Cayman Formation. Furthermore, constructing a paragenetic sequence which assigns each diagenetic event a relative timing will allow a regional assessment of the controls on carbonate diagenesis.

CHAPTER FOUR: DIAGENESIS OF THE CAYMAN FORMATION

4.1 INTRODUCTION

Extensive research has been conducted on many aspects of the diagenetic processes that have affected the Cayman Formation (Jones *et al.*, 1984; Pleydell, 1987; Squair, 1988; Ng, 1990; Pleydell *et al.*, 1990; Jones, 1992; Ng *et al.*, 1992; Wignall, 1995). With the exception of Wignall (1995), most of these studies have focused on samples collected from surface outcrops. As a result, there is relatively little information on the distribution of various diagenetic fabrics with depth. This study describes in detail the diagenetic fabrics of the Cayman Formation found in the 311 feet (102.6 m) of core from RWP#2 on the northeast coast of Grand Cayman (Figure 1.5). As such, it provides an unparalleled view of the vertical distribution of diagenetic fabrics throughout this formation. This allowed comparison to the limited core of QHW#1 (194'5" or 59.3 m) in order to support the data presented. As a result, these findings represent a significant advance in our understanding of these enigmatic dolostones.

4.2 DIAGENETIC FEATURES

The Cayman Formation at Roger's Wreck Point is characterized by two types of matrix dolomite (Table 4.1), five types of cavity fills (Table 4.2), and five types of cement (Table 4.3). Porosity varies with depth (Figure 4.1, Figure 4.2) and includes solution-enlarged to partly-filled mouldic, vug, interparticle, intraparticle, and skeletal pore space. Five depth-related diagenetic zones have been defined using a combination of matrix dolomite type, cement type, cavity fill and porosity criteria (Figure 4.1).

Matrix dolomites I and II (Table 4.1, Plate I) are fabric-retentive and fabric-destructive respectively, and can be differentiated on the basis of crystal size, habit, clarity, and inclusion type. Both are found in diagenetic zones 1, 3, and 5 in RWP#2 (Figure 4.1).

TYPE	CRYSTAL SIZE	CRYSTAL HABIT	CRYSTAL SHAPE AND FABRIC	COMMENTS
I	very fine-fine crystalline (0.005-0.01 mm)	anhedral-subhedral	equigranular, interlocking mosaic	• cloudy, inclusion-rich with patches of calcite inclusions • replaces original matrix in mudstones-wackestones
II	fine-medium crystalline (0.02-0.03 mm)	subhedral-euhedral	equigranular, interlocking mosaic	• mostly clear crystals with clear inclusions • more common in original wackestone-packstone matrix

Table 4.1 Matrix dolomites and their distinguishing features in RWP#2 (Cayman Formation).

TYPE	TEXTURE	COMPOSITION	COMMENTS
C_{f1}	peloidal wackestone	dolomite matrix, peloids mostly dolomite with remnant calcite	• peloids: ~ 0.02 mm diameter • matrix: very fine-aphanocrystalline (0.004 mm), cloudy, anhedral crystals
C_{f2}	mudstone (caymanite)	dolomite with variable Al, Fe, Mg content	• massive to laminated, laminae sets defined by variable metal content
C_{f3}	mudstone breccia	dolomite matrix and clasts	• clasts: angular, ~ 0.03 mm, replaced by clear dolomite • matrix: cloudy, aphanocrystalline, interlocking, anhedral crystals
C_{f4}	terra rosa	dolomite (mostly) and Fe oxides (present as staining)	• aphanocrystalline, interlocking crystals (0.01-0.05mm)
C_{f5}	foraminifera wackestone	dolomite	• matrix similar to matrix dolomite I but denser, mouldic porosity unaltered

Table 4.2 Lithological and mineralogical characteristics of the five cavity fills found in the Cayman Formation in RWP#2.

Cements	Composition	Crystal Size	Crystal Habit	Crystal Shape/Fabric	Comments
A	dolomite	very fine-fine crystalline (0.02-0.05 mm)	subhedral-euhedral	• equigranular, isopachous • minor enfacial junctions and drusy crystal growth	• cavity filling cements show development of drusy growth forms with enfacial junctions • limpid with clear inclusions • replaces allochems (fabric-selective and retentive) and fills moulds
B	dolomite with rare calcite growth bands	fine-medium crystalline (~ 0.05 mm)	subhedral-euhedral	• isopachous to drusy rhombs • growth banding common	• cloudy, drusy with growth banding on youngest surfaces • usually based on substrate of cement A
C	dolomite	fine-medium crystalline (~ 0.05 mm)	euhedral (most)	• isopachous with enfacial junctions to interlocking mosaic and drusy	• clear crystals with minor clear inclusions • based on substrates of cements A or B
D	dolomite	coarse crystalline (~ 0.2 mm)	euhedral	• bladed circumgranular to meniscal crust	• clear with rare clear inclusions of relict calcite
E	calcite	medium-coarse crystalline (0.05-0.2 mm)	subhedral-euhedral	• pore-lining isopachous crystals to pore-filling mosaic	• partially cloudy and clear • very minor, patchy distribution • substrates of cements A & B

Table 4.3 Characteristics of cement types found in RWP#2 including mineralogy, crystal size, habit , shape and fabrics.

Figure 4.1 Depth-related diagenetic zones for the Cayman Formation in RWP#2 devised using porosity trends, facies analysis and diagenetic features.

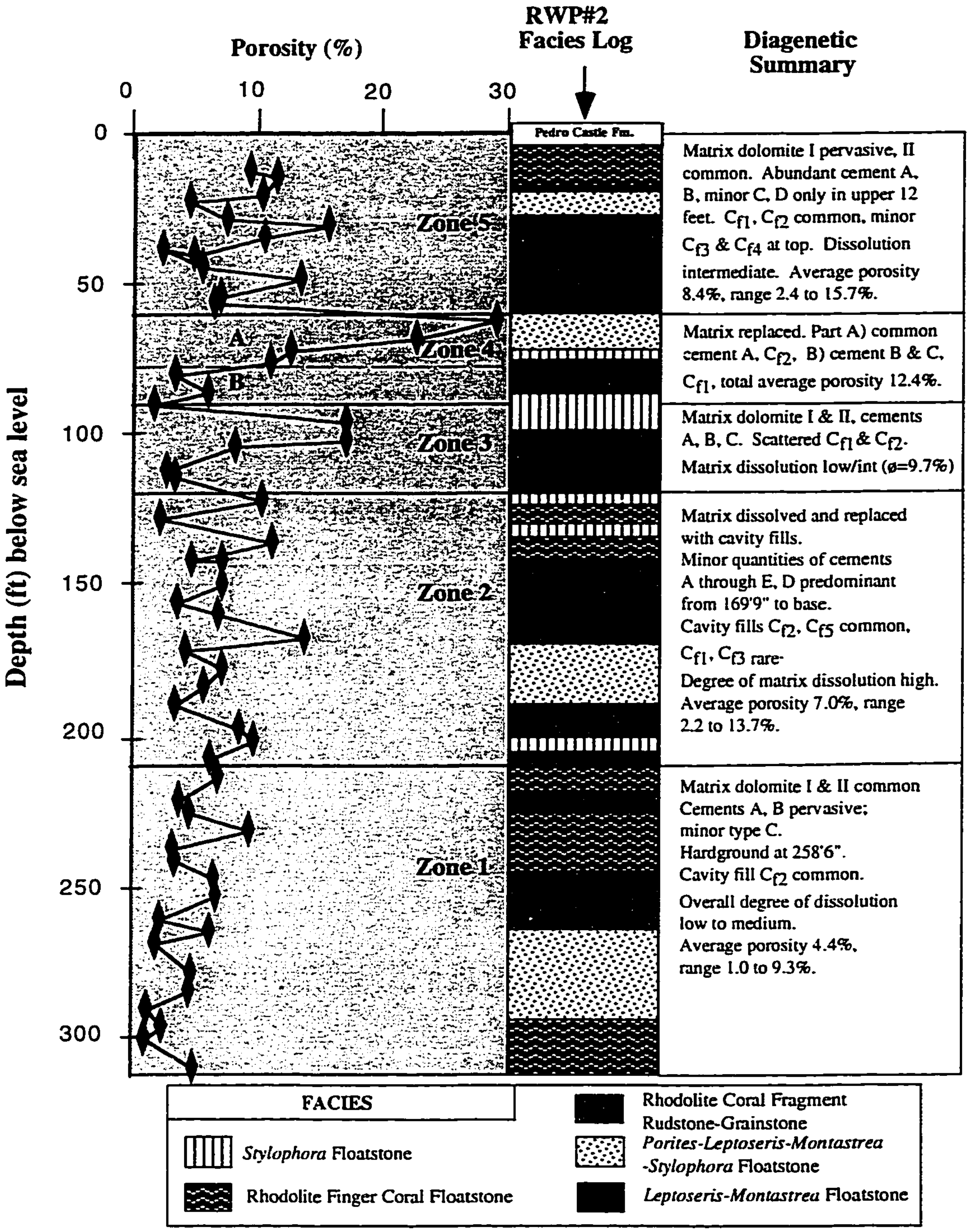
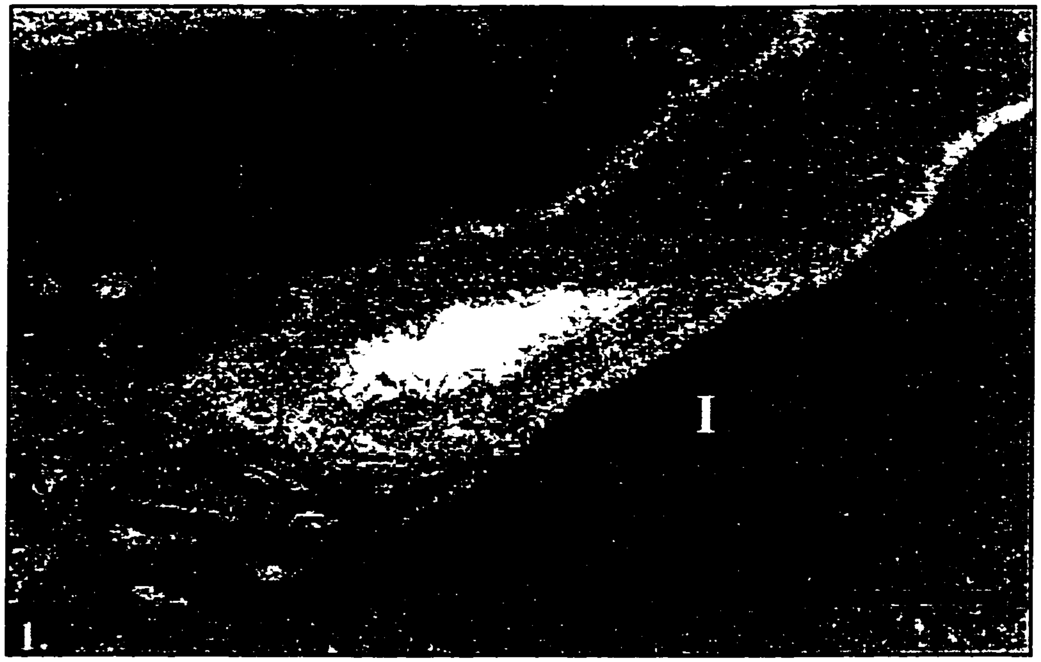
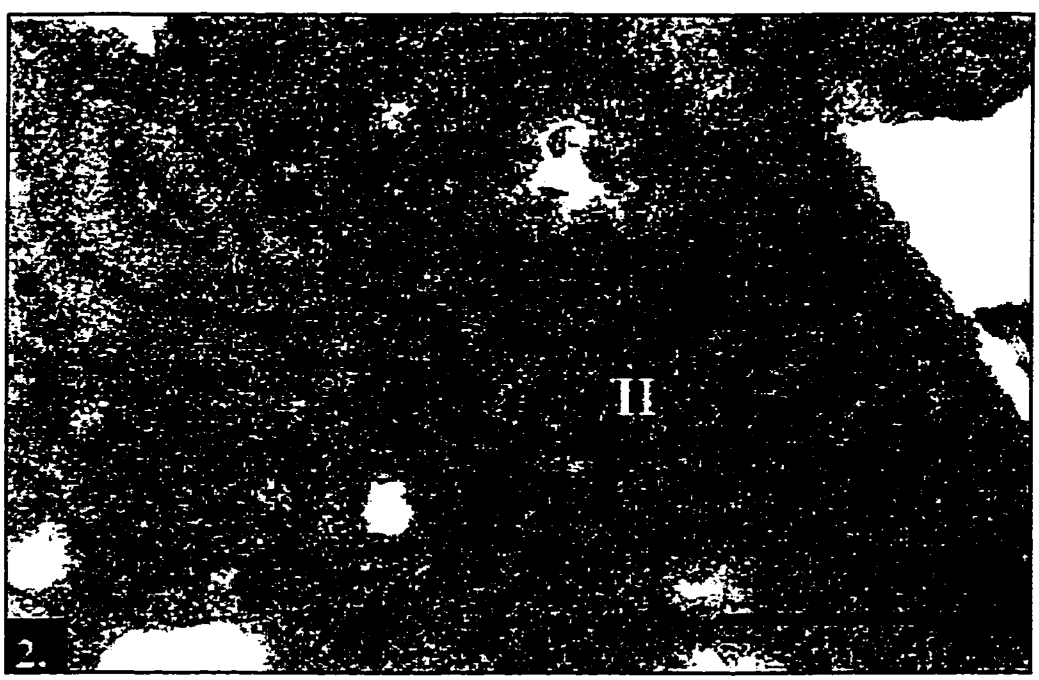


Plate I



1. Matrix dolomite I surrounding a coral vug, partially-filled with cement and mud. Note the fabric-retentive replacement by dolomite evidenced by the retention of fine-scale fossil fragments.



2. Matrix dolomite II. Dolomitization of the matrix material has overprinted original matrix fabrics as well as some fossils.

Plate II

1. Vug shown lined with isopachous rim of cement A (A) surrounded by isopachous to drusy rhombs of cement B (B).

2. Stained rhombic calcite crystals (cement E) partially fill intercrystalline pore space already lined with cements A and B (dolomite).

Plate III

1. Foraminifera surrounded by circumgranular to meniscal crust of bladed dolomite (cement D).

2. Closer view of euhedral bladed dolomite crystals (D).

Plate IV

1. Arrow points to hardground surface (78.3 m) indicated by truncation of amphisteginid foraminifera. Replaced algal material (by cement C) overlies surface and was likely established as an encrusting growth form following early marine cementation.

2. Close-up on hardground. The non-brittle appearance of the truncation suggests dissolution, rather than erosion as the origin of the surface.

Zones 2 and 4 show partial to full replacement of the resulting matrix dolomite from dissolution of the primary matrix (where originally present). These areas are now filled by dolomitized internal sediments (cavity fills). Wignall (1995) and Ng (1990) identified the same two types of matrix dolomites in the Cayman Formation at other locales and suggested that each represented a separate phase of matrix dolomitization.

Five cavity fills (peloidal wackestone, mudstone, mudstone breccia, terra rosa, and foraminifera wackestone) are found in the RWP#2 succession (Table 4.2, Table 4.4). Each is dolomitized and can be distinguished on the basis of texture, composition, and fabric. Caymanite (Jones, 1992) is pervasive throughout the entire succession (Table 4.4) whereas the peloidal wackestone is found only in diagenetic zones 3, 4, and 5 (Figure 4.1). The foraminifera wackestone is abundant in zone 2 (Table 4.4, Figure 4.1), whereas terra rosa is found only in the shallowest part of zone 5. Mudstone breccia is present in zones 5, 4 (Part A only), and in zone 2.

Cayman Formation dolostones in RWP#2 contain five different cements (A to E) (Table 4.3, Plates II, III, IV). Each of the four dolomite and one calcite cements is unique with respect to crystal size, habit, shape, fabric, appearance, and substrate, and represents a distinct phase in the paragenetic sequence. Cements A and B are common throughout the entire succession (Table 4.4), cement C has a scattered distribution, whereas cements D and E are relatively rare.

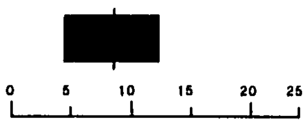
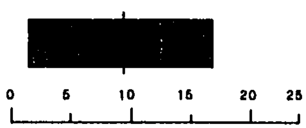
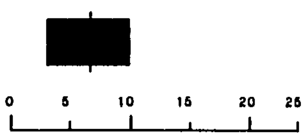
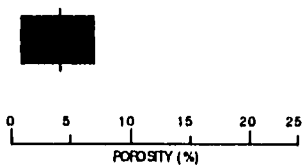
A dissolution rating (high, moderate, or low) (Table 4.4) expressing the extent of dissolution was applied to each sample interval using matrix and allochem preservation, the extent of cavity fill, and the presence and degree of cementation as criteria.

No evidence supporting the presence of significant sedimentation breaks (*i.e.* intraformational unconformity) has been observed in Cayman Formation strata at the study locale. However, careful examination of the textural, sedimentological and diagenetic fabrics in RWP#2 has revealed a hardground surface (Plate IV) at 258'6" (78.9 m). The time required to produce this feature is open to debate, as is the need for a halt in sedimentation. Most likely, the hardground is the result of synsedimentary lithification of the water-sediment interface. Otherwise, depositional rates are assumed to have remained relatively constant during the accumulation of Cayman Formation sediments.

4.3 DIAGENETIC ZONES

The Cayman Formation in RWP#2 is divided into five diagenetic zones (Figure 4.1). Zone 1 consists of interbedded Rhodolite Finger Coral Floatstones and Rhodolite Coral Fragment Rudstones to Grainstones with only a few corals. Porosity in this zone is low and constant (4.4±1.2%) (Figure 4.2). Initial porosity probably ranged from 8 to 12% after allochem leaching; however, the present range reflects the fact that many pores were partly filled with caymanite. Cements A and B (Table 4.3) are abundant whereas cement C is present only in minor quantities. A hardground at 258'6" (78.9 m) is encrusted with a thin layer of red algae and grains beneath the surface have been truncated by dissolution (Plate IV).

Zone 2 is dominated by Rhodolite Coral Fragment Rudstones to Grainstones (Figure 4.1) with lesser amounts of *Stylophora* Floatstones, Rhodolite Finger Coral Floatstones and *Porites Leptoseris Montastrea Stylophora* Floatstones. Porosity in this zone is higher than in zone 1 (7.0±3.2%) but has a low range (Figure 4.2). The nature of effective porosity varies widely due to a combination of mouldic, vug, intraparticle, interparticle, and skeletal pores, cementation and cavity filling. Scattered horizons, ~10 cm thick, with evidence of intense dissolution account for several anomalous high porosity intervals (*i.e.* 12%, 15%, Figure 4.1). Small quantities of cements A, B, C, D, and E are found throughout the zone and cement D (bladed dolomitic circumgranular to meniscal crust) is particularly abundant from 169'9" (51.7 m) to the base of the zone. The absence of matrix dolomite I and II (Table 4.4), which replaced the primary matrix, and the abundance of cavity fills (C_{f1}, C_{f2}, C_{f4}, and C_{f5}), support the interpretation that extensive dissolution affected this zone. Alternatively, certain horizons within this zone may have

DIAGENETIC ZONE	POROSITY DISTRIBUTION	POROSITY TYPES	FACTORS AFFECTING RESULTANT POROSITY
5 0 to 61 ft		• Vug, mouldic, interparticle, intraparticle, skeletal; enhanced, partly-filled to filled	• Abundant coral results in high porosity (mouldic). • Matrix dolomites dissolved and replaced with a variety of cavity fill types, some with appreciable interparticle porosity.
4 A: 61 to 79 ft B: 79 to 91 ft		• A) Interparticle (secondary), mouldic, vug and enhanced mouldic and vug dominant • B) Same as above but less mouldic porosity, high occlusion by cavity fills	• Primary matrix commonly dissolved in part (a) and replaced with high porosity grainstone fill. Facies control on mouldic porosity (high coral content). • Facies control (less coral) results in lower mouldic porosity. Extensive cavity filling (primarily caymanite) reduces porosity.
3 91 to 120 ft		• Mouldic, vug, enhanced and part-infilled skeletal framework, intraparticle and interparticle • Distribution variable throughout zone	• Upper half shows abundant coral mouldic porosity (facies-controlled). • Lower half has less mouldic porosity as a result of a lower coral volume as well as more extensive cavity filling.
2 120 to 206 ft		• Mouldic, vug, intraparticle, interparticle, skeletal • Extreme variation in porosity alteration, most partly occluded to filled	• Scattered rubbly intervals ~ 10 cm thick resulting from dissolution which may represent grainier horizons in orginal matrix (i.e. enhanced porosity around 170').
1 206 to 310.6 ft		• Mouldic, vug, intraparticle, interparticle, skeletal • Degree of preservation extremely variable ranging from unaffected, solution-enlarged, partly to totally infilled	• Muddier matrix of this zone is apparently less susceptible to the diagenetic enhancement of interparticle porosity resulting in a lower overall porosity mean and range. • Reduction to complete fill of pore space by caymanite common but patchy in distribution. • Coral content less than upper zones, therefore coral mouldic porosity is less.

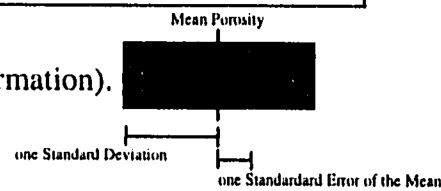


Figure 4.2 Porosity features of the five diagenetic zones for RWP#2 (Cayman Formation).

Table 4.4 Depth-related variance in lithologic features observed in RWP#2.
Dissolution Extent: □ Low ■ Medium ■ High

Thin Section	Matrix Dolomite		Cements					Cavity Fills					Dissolution
Depth (ft)	I	II	A	B	C	D	E	Cf1	Cf2	Cf3	Cf4	Cf5	Extent
9'6"	■	■			■				■		■		■
16'11"	■	■	■	■	■	■			■	■			■
38'10"	■		■	■				■	■				■
45'3"	■		■						■				
52'8"	■	■	■	■				■	■				■
53'3"		■	■	■				■	■				■
61'9"	■		■	■				■					■
69'4"	■		■					■	■				■
77'8"			■		■				■	■			■
78'9"			■						■				■
83'3"		■		■	■			■					■
88'2"				■	■			■					■
96'1"	■	■	■	■	■			■	■				■
107'9"	■	■	■										
113'3"	■	■	■	■	■			■	■				■
116'8"	■	■		■					■				
121'				■	■							■	■
133'8"			■									■	■
141'4"			■	■			■		■			■	■
144'2"			■	■					■			■	■
157'8"			■	■								■	■
169'9"	■			■	■	■	■			■			■
171'7"			■	■	■				■	■			■
179'6"												■	■
188'6"	■	■		■	■	■			■			■	■
199'6"						■		■	■				■
208'	■	■	■	■	■				■			■	■
209'1"	■	■	■	■									
231'5"	■	■	■	■									
234'2"			■	■					■				■
245'7"	■	■		■	■				■				
254'	■	■		■	■			■	■				
255'2"	■		■	■					■				
256'9"	■	■		■	■				■				■
258'6"	■	■	■	■					■				
273'4"	■	■	■	■					■				
279'10"	■	■	■	■					■				■
291'9"	■	■	■	■					■				■
294'	■		■	■					■				■
299'8"	■	■	■	■					■				■
309'9"	■	■	■	■				■	■				■

lacked primary matrix material, although the allochem-fill relationships observed suggest this was more likely the exception than the rule.

Zone 3 is composed of Rhodolite Coral Fragment Rudstones to Grainstones and *Stylophora* Floatstones (Figure 4.1). The average porosity is relatively high (9.7±7.2%) (Figure 4.2) with a large range in values. Elevated porosities in the upper part of this zone reflect the presence of numerous coral moulds in the *Stylophora* Floatstone facies. An increase in cavity fills (C_{f1}, C_{f2}) in the lower half of the zone indicates that this portion of the core was highly porous prior to internal sedimentation. Cements A, B, and C are scattered throughout the zone (Table 4.4).

Zone 4 is characterized by the highest average porosity of all zones, an absence of matrix dolomite I and II (Table 4.4) and high volume of cavity fill sediments. All of these features suggest exposure to at least moderate dissolution took place. Further examination allowed division of this zone, into parts A and B (Figure 4.1, Figure 4.2). Part A consists of *Porites Leptoseris Montastrea Stylophora* Floatstones and *Stylophora* Floatstones. Part B is composed of *Leptoseris Montastrea* Floatstones and Rhodolite Coral Fragment Rudstones to Grainstones (Figure 4.1). Porosity in Part A is higher than in Part B due to the abundance of coral moulds and combined partial matrix dissolution and subsequent infill by highly porous foraminifera grainstones and caymanite (Figure 4.1; Table 4.4, Figure 4.2). Coral mouldic porosity is facies-controlled and less abundant in Part B. Internal sediments (peloidal wackestones-C_{f1}) have decreased the pore space substantially (Table 4.4, Figure 4.2). The large variation in porosity between part A and part B is shown by the large standard deviation (±10.2%) (Figure 4.2). Cement A is pervasive throughout part A (Table 4.4) whereas cements B and C are more common in part B.

Diagenetic zone 5 consists primarily of Rhodolite Coral Fragment Rudstones to Grainstones with minor thicknesses of *Porites Leptoseris Montastrea Stylophora* Floatstones and Rhodolite Finger Coral Floatstones (Figure 4.1). Porosity throughout this zone is relatively constant (8.4±3.9%) (Figure 4.2) and slightly lower than zones 3 and 4.

Most of this pore space is coral mouldic and secondary interparticle in origin. The distribution of matrix dolomites I and II is patchy throughout the zone, suggesting the primary matrix was dissolved and infilled with cavity fill sediments (Figure 4.1). Peloidal wackestones (C_{f1}) and caymanite (C_{f2}) are common throughout whereas minor amounts of mudstone breccia (C_{f3}) and terra rosa (C_{f4}) are found in the upper half of the zone (Table 4.4). Cements A and B are pervasive throughout zone 5 (Table 4.4) whereas cements C and D are only found in the upper 12' (3.6 m).

Average porosity decreases with depth from zone 5 to a maximum in zone 4 (Figure 4.1, Figure 4.2), then decreases systematically to zone 1. Although the standard error for zones 1, 2, and 5 overlap, the combined differences in porosity and standard deviation reveals a distinct porosity signature for each of the five zones.

4.4 INTERPRETATIONS

4.4.1 Matrix Dolomites

Matrix dolomites I and II (Plate I) are closely associated (mm-scale intergrowths) in RWP#2, an observation that agrees with Wignall (1995) and Ng (1990). Development of Type I is fabric-retentive, whereas Type II assumes a fabric-destructive growth form. Previously, differences in crystal size, replacement form, and the enclosure of Type I remnants in Type II crystals have been cited as evidence for at least two dolomitization events (Ng, 1990; Wignall, 1995). Although the samples examined from RWP#2 fulfill the first two criteria, most of the Type II matrix crystals do not contain Type I relicts. The minor portion of Type II dolomites which do contain inclusions show randomly distributed impurities with non-diagnostic shapes, leaving the question of origin unanswered. However, considering the photographic evidence of included Type I crystals in Type II dolomites (Wignall, 1995), the potential for multiple dolomitization events in the Cayman Formation remains real. The distribution of the two dolomite types appears to be linked to depositional texture (Table 4.1). Matrix dolomite Type I appears to have preferentially replaced the mud component of the mudstones to wackestones whereas the primary matrix in the coarser horizons appears to have been replaced by Type II dolomites.

Sibley (1982) argued that the three controls on the distribution and size of replacement dolomites are 1) the abundance of nucleation sites, 2) the degree of fluid supersaturation with respect to dolomite, and 3) the saturation state of the mineral being replaced. Assuming both dolomites are of replacement origins, and conditions 2 and 3 are met by a suitable water chemistry, the abundance of nucleation sites will control dolomitization. For example, fine-grained limestones are more susceptible to rapid dolomitization as a function of the high surface area to volume ratio of the sediments which enhances the reactivity and number of dolomite nucleation sites (Berner, 1980; Sibley, 1982). Fine-scale crystal replacement allows primary fabrics to be retained with minimal loss of primary structures (Sibley, 1982; Tucker and Wright, 1990). Conversely, the replacement of coarser-grained materials is thermodynamically unfavourable because the relative number of nucleation sites per volume of material is reduced (Berner, 1980). A decrease in solution saturation with respect to dolomite may also cause an increase in dolomite crystal size (Sibley and Gregg, 1987). Slight variations in the orientation of replaced crystals, caused by the large crystal size will result in fabric-destructive dolomitization.

Inclusions in both types of matrix dolomites are interpreted as relict impurities concentrated during the calcite-dolomite transition, as described by Sibley (1982) in Pliocene Seroe Domi dolomites. The cloudy nature and great abundance of inclusions in matrix dolomite I suggests a higher degree of impurity existed (*i.e.* organics, clays) in the primary matrix of Cayman Formation mudstones and wackestones, as compared to the packstones. The rare clear inclusions in matrix dolomite II are interpreted as empty or fluid-filled microcavities as per Tucker and Wright (1990).

4.4.2 Cavity Fills

Three of the cavity fills identified in RWP#2 (Table 4.2); the peloidal wackestones (C_{f1}), caymanite (C_{f2}), and skeletal (foraminifera) wackestones (C_{f5}) are similar to those found in the Cayman Formation at Safe Haven (Wignall, 1995). Terra rosa (C_{f4}) is derived from surficial weathering processes linked to subaerial exposure and karst development (Esteban and Klappa, 1983). This explains why it is found only in the shallowest portion of RWP#2 (Table 4.4). This sediment was most likely eroded and emplaced during formation of the Cayman Unconformity during the late Messinian Lowstand event (Jones and Hunter, 1994b) or perhaps even earlier. Origins of the mudstone breccias (Cf_3) are less obvious. Either marine erosion or karst-related weathering could have generated such a fine grained breccia. Its distribution is also limited to shallow depths within RWP#2 (Table 4.4).

Cavity-filling peloidal wackestones and skeletal (Foraminifera) wackestones, which probably are marine in origin (Pleydell, 1987; Wignall, 1995), are most prevalent in zones 1 and 2 in RWP#2 (Table 4.4). Delivery of this sediment to deeper portions of the core must have been mediated by groundwater transport through a complex interconnected pore network. Tectono-eustasy and karst-related dissolution established this flow network on Grand Cayman by creating open fissures and joints (Ng *et al.*, 1992). Together these features have substantially enhanced the porosity and permeability of the formation, thereby facilitating the widespread dispersal of cavity fill sediments throughout the subsurface.

Caymanite is the most abundant and distinctive cavity fill in RWP#2. These laminated dolomitized mudstones range in colour from cream to rust to black, reflecting traces of Mn, Fe, Al, Ni, P, K, Si, and Ca (Jones, 1992). They contain sedimentary structures including normal and reverse graded planar and cross-laminations (Lockhart, 1986). Postulated sources for the mud includes brackish ponds, swamps, shallow offshore lagoons, and reworked terra rosa (Jones, 1992). Sediment generation has been linked to weathering *via* subaerial exposure and karst diagenesis in a meteoric vadose environment (Jones, 1992). Caymanite deposition in RWP#2 was multi-stage and episodic, producing a complex pattern of primary and secondary pore occluding sediment fills throughout the sequence. Caymanite both predates and postdates the other four cavity fill types.

Cavity fill distribution can be correlated to core depth. Zones 4 and 5 are characterized by internal sediments of terrestrial or marine origin, whereas the cavity fills observed throughout the deeper zones (3, 2, 1) are solely marine in source. Shallower strata have been more affected by surficial weathering processes due to a greater extent of exposure, both past (*i.e.* Cayman Unconformity) and present (currently Cayman Formation strata outcrop near Roger's Wreck Point). Zones 4 and 5 show that caymanite deposition postdated the emplacement of the mudstone breccias and terra rosa. Both the caymanite and mudstone breccia are dolomitized demonstrating both were deposited previous to dolomitization. However, the presence of appreciable quantities of calcite in the terra rosa reveals it was emplaced after dolomitization.

In diagenetic zones 1, 2, and 3 (Figure 4.1, Table 4.4), the depositional sequence of cavity fills is indistinct and difficult to interpret. Mudstone breccias and foraminifera wackestones appear to be the oldest stage of sediment fill, lining the basal portions of cavities, followed by caymanite, and most recently, peloidal wackestones. All consist of 100% dolomite, which dates their emplacement as pre-dolomitization. Dolomitized cavity fills or a lack thereof, provides unequivocal evidence as to the timing of their emplacement relative to pervasive dolomitization. This information is invaluable to accurately reconstructing the complex diagenetic history of intensely altered strata such as the Cayman Formation dolostones.

4.4.3 Cements

Crystal mineralogy, habit, shape, and distribution provide clues about the environment of crystal growth. In a pervasively dolomitized sequence such as the Cayman Formation (Pleydell *et al.*, 1990), cement mineralogy indicates the timing of precipitation relative to the dolomitization event. Cement E must have post-dated dolomitization because it is the only calcite cement (Table 4.3). Conversely, the genesis of cements A through D is assumed to have predated this event because they have all been replaced by dolomite.

Applying cement stratigraphy to complex diagenetic sequences can help identify environmental changes responsible for diagenesis more easily than hand scale observations alone. Certain cement shapes and styles are unique to particular diagenetic realms and their distinction in RWP#2 has helped clarify their relative position and causal mechanisms in the overall context of Cayman Formation history. All four dolomite cements (A, B, C, D) appear to have been originally precipitated as calcite (based on their relative position and crystal habit). Therefore the question of whether their replacement was pseudomorphic is vital to accurately interpreting the diagenetic environment. Pervasive dolomitization in RWP#2 appears to have been primarily a fabric-retentive replacement (exception matrix dolomite Type II), so the mimic replacement of cement is a valid assumption. Therefore, textural analysis can be applied to the dolomite cements as if they were primary precipitates and diagenetic environments can be interpreted accordingly.

The equigranular, isopachous nature (Table 4.3) of cement A (Plate II) suggests it formed as a high-Mg calcite precipitate under the influence of mixed (*cf.* Folk and Siedlecka, 1974; Fluegel, 1982) or marine water (*cf.* Tucker and Wright, 1990). Minor development of enfacial junctions between crystals suggests growth was hiatal (Scoffin, 1990), perhaps in response to fluctuating mineral saturations (Fluegel, 1982). This cement predates all others and is found as pore-lining and pore-filling precipitates. The widespread distribution of this cement throughout the RWP#2 core indicates the entire section was subject to diagenesis in a mixing or marine phreatic zone.

Cement B (Plate II) is typically found on a substrate of cement A, demonstrating its growth post-dated the first generation cement. The similar distribution of A and B (Table 4.4) indicates that the conditions and water chemistry which mediated precipitation were similar and uniform throughout. This cement is found as equigranular to drusy rhombs and isopachous rims which reflect marine phreatic origins (*cf.* Fluegel, 1982). Growth banding is typical and has developed in response to varying Mg:Ca ratios (*cf.* Fluegel, 1982) in solution during precipitation. This cement commonly assumes a pore-lining to pore-filling habit similar to cement A.

Cement C (Table 4.3, Plate IV) postdates cements A and B and typically grew on a substrate of cement B. Identical to cement A in terms of shape (equigranular), and fabric (isopachous rims, drusy growth, enfacial junctions), it is interpreted as a marine phreatic precipitate (*c.f.* Fluegel, 1982; Tucker and Wright, 1990). The slightly larger crystal size (fine-medium crystalline) of cement C suggests a longer period of growth with slower precipitation (*cf.* Berner, 1980) or fewer nucleation points (Sibley, 1982) during the initiation of growth. The clear inclusions in this cement are interpreted as fluid-filled or empty microcavities created during dolomite replacement (Fluegel, 1982). The patchy distribution of cement C is a direct function of its late timing relative to cements A and B. Precipitation of these two earlier phases of cement filled most of the pore space, leaving only random openings within the larger cavities for the precipitation of C.

Cement D (Plate III) is a bladed, circumgranular to meniscal crustal growth form which probably precipitated in a transitional meteoric vadose to phreatic environment (*cf.* Tucker and Wright, 1990). It is presently found only in diagenetic zones 2 and 5 (Figure 4.1, Table 4.4), suggesting a link between the intense dissolution of these zones and the emplacement of this cement. As such, the inference can be made that these two zones were subject to mixed waters at one point in their diagenetic history (*cf.* Fluegel, 1982). Alternatively, cement D may have precipitated in all zones but was preferentially preserved in zones 2 and 5 only. The bladed crystal shape and relict calcite inclusions suggest an original mineralogy of high-Mg calcite (Fluegel, 1982). Precipitation of cement D postdates cements A through C in both diagenetic zones. It typically encrusts pre-existing cements around allochems and is found in association with extensive cavity fills.

Cement E (Plate II) is composed of calcite and ranges from pore-lining isopachous crystals to cavity-filling mosaics (Table 4.3). Volumetrically, its impact on porosity is minor and its presence is restricted to diagenetic zone 2 only (Table 4.4, Figure 4.1). Similar to cements A through C, a marine phreatic origin is postulated; however, its calcitic composition demonstrates its emplacement postdated dolomitization (Jones *et al.*, 1984; Pleydell *et al.*, 1990).

Several correlations can be made between the five Cayman Formation cements described in RWP#2 and those identified by previous researchers on Grand Cayman (Figure 4.5). The features and relative position of cements A, C, and E correspond to the first, third, and fourth generation cements described by Wignall (1995) at Safe Haven. Considering cements identified in surface outcrops by Jones *et al.* (1984) and in the East End vicinity by Ng (1990), cement A corresponds to their first generation cements, and B with their second generation cements. A similar calcite cement to cement E was also described by the same researchers (Jones *et al.*, 1984; Ng, 1990). No match was found for cement D which may be explained by the new data acquired by drilling RWP#2.

This Study:	**Wignall (1995)**	**Jones *et al.*, (1984) Ng (1990)**
A	1	First Generation
B	-	Second Generation
C	3	-
D	-	-
E	4	Similarly Described

Table 4.5 Cement types described for the Cayman Formation (this study) and their correlatives documented in previous research.

4.4.4 Porosity

Porosity development in the Cayman Formation varies between effective (connected) and ineffective (not connected) pore space, dependent on the presence and type of primary porosity as well as the extent of subsequent dissolution, cementation, and internal sedimentation. The high variability in porosity in RWP#2 (Figure 4.1), even when considered on a per-diagenetic zone basis reflects facies-controlled differences in matrix porosity, the availability and deliverability of cavity fills, and dissolution and cementation associated with eustatic change. Coral mouldic porosity is not included in these values due to the technical difficulties in their assessment *via* standard core analysis methods.

As presented by Ng *et al.* (1992) and Wignall (1995) the two main sources of porosity in the Cayman Formation are 1) the leaching of metastable fossil material (primarily aragonite) resulting in mouldic porosity, and 2) fracture and karst features caused by dissolution controlled by eustatic change. Secondary mouldic porosity ranges in size from mm-scale Foraminifera moulds to dm-scale cavities produced by leaching large domal corals. The isolated nature of these vugs renders most of this pore space ineffective in terms of permeability unless connected by karst-related fissures and joints (Ng, 1990; Ng *et al.*, 1992). Sea level fluctuations have initiated and solution-enlarged such features over time, resulting in an extremely heterogeneous and unpredictable pore network (Ng *et al.*, 1992).

Less significant in its contribution to overall porosity is the primary interparticle porosity created during deposition of the RWP#2 succession. Consistent reduction of this pore space by recrystallization, cementation, internal sedimentation, and dolomitization has effectively diminished the interparticle (now intercrystalline) porosity, to zero in some cases. The tightly intergrown crystals of matrix dolomite and minor enfacial junctions are reflected by the low values measured for matrix porosity. Primary intraparticle and skeletal porosity, assuming the allochem has not been leached completely, is also typically reduced to occluded by cavity fills and/or successive cementation.

A large proportion of the secondary porosity in RWP#2 has been reduced by the episodic delivery of internal sediment and/or the precipitation of cement. Although eustatic change may have enhanced dissolution of Cayman Formation dolostones and initially increased the overall primary pore space, the extent of void-fills suggests present day porosity has been reduced from a previous high. The emplacement of cavity fills, whether of marine or surficial sediments, is linked to subaerial exposure and vadose flow mechanisms. Therefore, sea level change has played an important role not only in the genesis of secondary porosity and generating sediment to fill cavities but has also aided in its destruction by facilitating vadose sediment transport.

4.5 PARAGENETIC SEQUENCE

The complex diagenetic history of the Cayman Formation evident in RWP#2 can be divided into 11 stages (Table 4.6). Each stage represents a period of time where a eustatic change modified the diagenetic environment to which Cayman Formation strata were exposed. Comparing the key diagenetic features for each zone (Figure 4.1) on a per-stage level, allows identification of the alteration mechanisms operating at each depth over time. Separating out these influences and correlating them to specific diagenetic environments (Figure 4.3) permits construction of a eustatic history for the Cayman Formation.

Paragenetic stage 1 (Table 4.6) began with the establishment of a carbonate bank faunal community atop the Brac Formation, most probably during the Middle Miocene (Jones *et al.*, 1994b). Paleobathymetry ranged between 5 and 30 m and the depositional setting between a storm-influenced bank edge, distal bank edge, leeward bank edge, *Stylophora* thicket and an inner bank as represented by facies changes in RWP#2. Throughout the Miocene, a gradual relative rise in sea level took place. This facilitated the accumulation of at least 311' (94.8 m) of carbonate sediments (see RWP#2) as a constant accommodation space was maintained. Key paleoenvironmental controls included sedimentation rate, bathymetry, and water energy. Isolated synsedimentary lithification of

stage	description	zone 5	zone 4	zone 3	zone 2	zone 1
11	• Relative sea level drop • Zone 5 vadose, rest marine phreatic	C_{f4}			Cement E	
10	• Relative sea level rise • Pervasive dolomitization (most fabric retentive) by mixed or marine waters	Dolomitization	Dolomitization	Dolomitization	Dolomitization	Dolomitization
9	• Relative sea level drop • All in vadose environment, extensive internal sedimentation	C_{f3} followed by Cement D	C_{f1}	C_{f1}, C_{f2}, C_{f3}	C_{f3}	C_{f2}, C_{f3}
8	• Relative sea level rise • All zones mixed marine/meteoric or marine phreatic	Cement C	Cement C	Cement C	Cement C	-
7	• Relative sea level drop • Zones 5, 4, 3: Vadose conditions, upper Zone 2 (120'-190') undersaturated meteoric phreatic, lower Zone 2 (190'-206') saturated meteoric phreatic conditions, Zone 1 mixed meteoric/marine conditions	C_{f2}	-	-	Upper part: Dissolution Lower part: Precipitation of Cement D	-
6	• Relative sea level rise • All zones mixed meteoric/marine to marine phreatic	Cement B	Cement B	Cement B	Cement B	Cement B
5	• Relative sea level drop • Zones 5, 4, vadose, Zones 3, 2, 1 mixed marine/meteoric	C_{f1}, C_{f2}, C_{f3},	C_{f1}, C_{f2}, C_{f3},	-	-	-
4	• Relative sea level rise • Mixing zone to marine phreatic water	Cement A	Cement A	Cement A	Cement A	Cement A
3	• Vadose dissolution of metastable fossils	Leaching of fossils	Leaching of fossils	Leaching of fossils	Leaching of fossils	Leaching of fossils
2	• Relative sea level drop begins, marine phreatic to vadose transition	Lithification	Lithification	Lithification	Lithification	Lithification
1	• Deposition in carbonate bank setting	Deposition	Deposition	Deposition	Deposition	Deposition

Table 4.6 Paragenetic stages established from RWP#2 and their key features as observed in the five diagenetic zones.

the soft marine bottom is shown by the hardground surface found in zone 1 at 258'6" (79.8 m). During this depositional hiatus, and following cementation of the sediment interface, encrusting red algae colonized the surface. Hardground formation is typically promoted

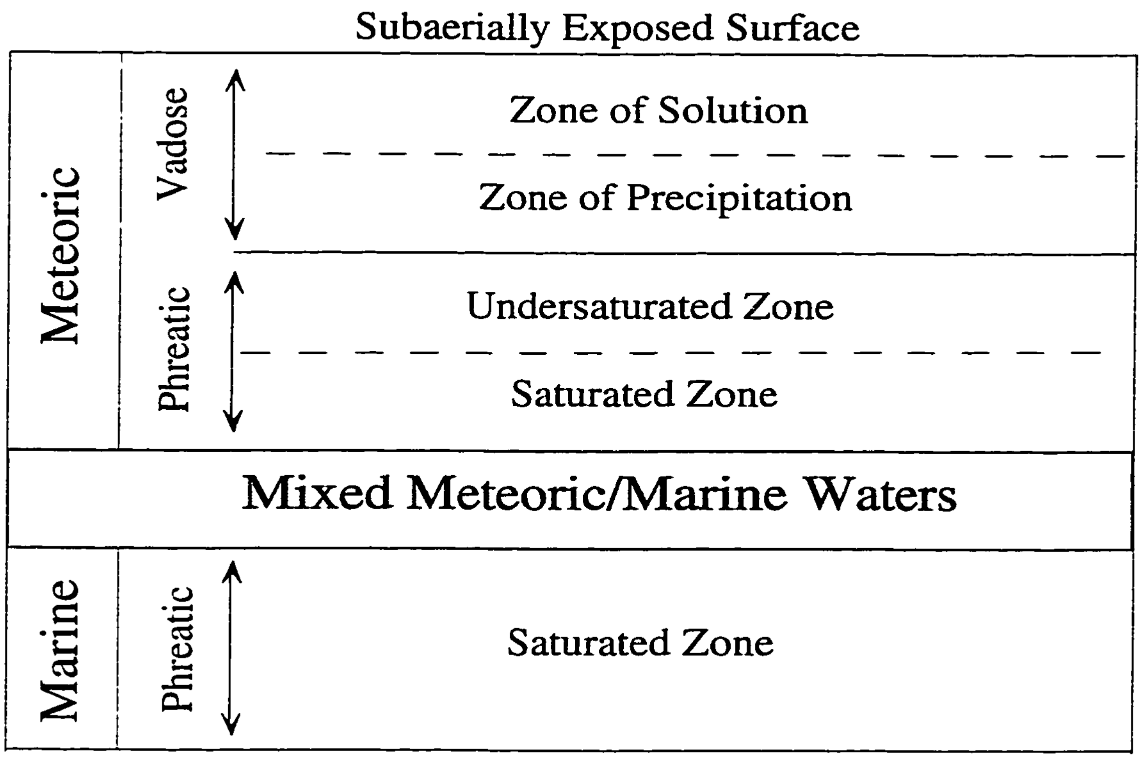


Figure 4.3 Groundwater zones affecting the diagenesis of RWP#2 (after Fluegel, 1982) and the relative state of calcite saturation/undersaturation.

either by very slow sedimentation or rapid cementation of extremely fine-grained material (Milliman, 1976; Dravis, 1979). This theory is supported by the interpreted low sedimentation conditions for the *Porites Leptoseris Montastrea Stylophora* Floatstone facies (Table 3.1) found at this depth. This stage ended with initiation of a gradual eustatic decrease, which eventually halted Cayman Formation deposition by subaerially exposing the carbonate factory. Timing for the end of this stage is indeterminable on the basis of the observed textural evidence but was most likely during the Late Miocene.

Paragenetic stage 2 is characterized by a continuing relative drop in sea level which likely terminated in the Late Miocene (Messinian Lowstand Event). This transition completed sediment lithification which may have commenced during stage 1 and exposed all RWP#2 strata to vadose conditions. Duration of the lowstand is an estimated 1.5 Ma (Jones and Hunter, 1994), long enough for the development of considerable karst-related relief (41 m in QHW#1) along the upper surface of the Cayman Formation. This dissolution surface (Cayman Unconformity) marks the removal of an unknown thickness of Cayman Formation strata.

Paragenetic stage 3 began with all five diagenetic zones within the meteoric vadose environment as a result of the eustatic drop linked to stage 2. Aragonitic fossils such as *Stylophora*, molluscs and domal corals were leached completely due to their unstable mineralogy (*cf.* Sibley, 1982; Tucker and Wright, 1990) in this diagenetic regime. Allochems composed of high-magnesium calcite were partially dissolved or stabilized by pseudomorphic replacement by low-magnesium calcite (*i.e. Amphistegina*). Dissolution associated with both of these processes created substantial mouldic porosity in RWP#2 and the end of this stage may represent maximum porosity development in the Cayman Formation.

Paragenetic stage 4 was initiated by a relative eustatic rise which positioned the RWP#2 sequence either within the mixing zone, or just below it in the marine phreatic diagenetic environment (Figure 4.3). Interpretation of the diagenetic regime is established using the precipitation of cement A as a criterion (Table 4.3). The uniform appearance of cement A in each zone may result from sequential precipitation as the mixing zone rose slowly in conjunction with sea level. Sea level could have fluctuated somewhat, however, the net result is of an overall increase during the stage. Therefore, although cementation appears to be uniform over the entire sequence, the thickness of the section (311' or 94.8 m) suggests precipitation of cement A was probably not contemporaneous between the zones.

Paragenetic stage 5 demonstrates evidence of a relative drop in sea level which lowered the mixing zone from zone 5 to encompass zones 3, 2, and 1. As a result, zones 5 and 4 were subject to vadose diagenesis including subaerial exposure, karst development and the emplacement of several cavity fills (C_{f1}, C_{f2}, C_{f3}). Internal sedimentation in general, and caymanite (C_{f2}) deposition in particular, has been documented as a phenomenon exclusive to the vadose environment (Lockhart, 1986; Jones, 1992). Their presence in zones 5 and 4 supports the interpreted position of sea level for this stage.

Paragenetic stage 6 experienced a relative eustatic increase which elevated the water table, exposing the five zones of RWP#2 to either mixing zone or marine phreatic waters. As a result, cement B, which precipitated from mixed or marine waters is found throughout the entire succession.

Paragenetic stage 7 experienced a relative drop in sea level responsible for positioning most of the RWP#2 sequence within the meteoric vadose and meteoric phreatic diagenetic zones (Figure 4.3). Extensive dissolution of most primary matrix material in the upper part of diagenetic zone 2 (120'-190' or 36.6-57.9 m) coupled with the precipitation of bladed calcite cement in the lower part of zone 2 (190'-206' or 57.9-62.8 m) places the undersaturated/saturated meteoric phreatic boundary at ~190' (57.9 m) (Figure 4.3). Extensive caymanite fill in zone 5 suggests the upper zones were subject to vadose conditions. The absence of dissolution features or cement D in zone 1 suggests it experienced mixing zone to marine phreatic conditions and places sea level at least as deep as zone 1 during this stage.

Paragenetic stage 8 was characterized by a relative sea level rise that elevated the mixing zone from zone 1 to zone 5. This change in diagenetic environment promoted precipitation of cement C in all zones as the mixed or marine waters rose. The morphology and crystal habit of cement C is suggestive of precipitation from either type of water.

Paragenetic stage 9 was caused by a relative sea level drop, which exposed the sequence to vadose diagenesis. The widespread distribution and multi-phase occurrence of cavity fills (C_{f1}, C_{f2}, C_{f3}) could only have been produced by karst development and weathering associated with vadose conditions (Jones, 1992). Late in the stage a meniscal form of cement D precipitated in the shallow part of zone 5.

Paragenetic stage 10 was characterized by a relative eustatic rise which may have initiated or accompanied pervasive dolomitization of the Cayman Formation (Pleydell *et al.*, 1990). Dolomite replacement was predominantly fabric retentive and the limpid nature of cements A, B, C, and D suggest this alteration was mediated by either mixed or marine waters. Isotopic values (∂C^{13}, ∂O^{18}) measured from these dolostones suggest dolomitization occurred under typical Caribbean temperatures by waters of normal marine salinity (Pleydell *et al.*, 1990). The timing of dolomitization has been determined by ∂Sr^{87} dating as between 2 and 5 Ma. However, acknowledging the capability of diagenesis to reset Sr isotopes (Banner, 1995), this date may reflect only the most recent dolomitization event. Following the research of Pleydell *et al.* (1990), further study of Cayman Formation dolostones has presented textural evidence (*i.e.* Type I dolomite inclusions in Type II dolomites) for at least two phases of dolomitization (Ng, 1990; Wignall, 1995). Lacking unequivocal proof from RWP#2 for multiple dolomitization events leads to the conclusion that strata at Roger's Wreck Point were affected by a minimum of one dolomitization phase. Irrespective of whether single or multiple events did take place, the textural features observed in the RWP#2 core constrain the relative timing of dolomite replacement to paragenetic stage 10.

Paragenetic stage 11 is the final diagenetic phase distinguished from the RWP#2 succession. It began with a relative eustatic drop which moved diagenetic zone 5 within the vadose environment while the four lower zones remained in mixed to marine phreatic waters. The presence of calcite-bearing terra rosa fill, likely derived from surface weathering (Esteban and Klappa, 1983) within zone 5 supports the vadose interpretation. Calcite cement E was also precipitated in zone 2 during this stage and its crystal habit (Table 4.3) supports the existence of mixed or marine waters at depth.

Paragenetic stage 11 is still in effect. Presently the upper contact of the Cayman Formation in RWP#2 is situated at ~2 m a.s.l. and is overlain unconformably by ~2 m of Member D of the Pleistocene Ironshore Formation (Vézina, 1997).

4.6 SUMMARY

The impact of relative sea level change on the depositional and diagenetic history of Cayman Formation dolostones cannot be underestimated. Each of the conditions controlling carbonate factory growth, sediment accumulation, lithification, and subsequent diagenetic alteration has been influenced by the position of sea level. Stages within the paragenetic sequence for RWP#2 are defined on the basis of relative eustasy and its impact on the position of diagenetic environments affecting the core sequence. Dissolution patterns, cement sequences, and cavity fill distributions observed in the Cayman Formation can be interpreted within the context of local and global sea level history. Using the eleven paragenetic stages for RWP#2 and their directional shift in relative sea level position, correlations can be attempted to accepted eustatic curves for the Tertiary and Pleistocene. In the event of a match, the timing of depositional and diagenetic events which impacted the Cayman Formation can be refined more precisely. This in turn, may result in modification to pre-existing geological theory on the evolution of the Cayman Islands and perhaps the greater Caribbean.

CHAPTER FIVE: EUSTATIC CHANGE AND THE CAYMAN FORMATION

5.1 INTRODUCTION

The causes, mechanisms, and implications of global sea level change are the subject of active research (*i.e.* Lambeck, 1990; Nummedal *et al.*, 1987), not only for geological advancement (refining stratigraphy, geological prediction, *etc.*) but for larger concerns such as global warming and climate change prediction. From a purely geological perspective, recognizing and assessing evidence for sea level change (*i.e.* unconformities, bounding disconformities) is the first step toward global correlation of chronostratigraphic units. Pursuit of this goal has fueled the rapid development of seismic and stratigraphic concepts (Sarg, 1988; Wilgus *et al.*, 1988). Numerous local and global eustatic curves have been created (*e.g.* South Pacific: Lu *et al.*, 1996; Russian platform: Sahagian and Jones, 1993; general: Haq *et al.*, 1987; Vail *et al.*, 1977), to further our understanding of the impact and controls on sea level change (Revelle, 1990; Morner, 1976). Eustatic variations directly influence the four major diagenetic environments (vadose, meteoric, mixed, marine) which impact isolated carbonate successions. Therefore, interpreting the sequence of diagenetic events from complex lithologies like the Cayman Formation requires a comprehensive understanding of relevant sea level history.

5.2 EUSTATIC CORRELATION

5.2.1 Background

Eustasy was first defined by Suess (1906) as a global-scale change in sea level. Worldwide, sea level position is a delicate balance between the total volume of ocean water (glacio-eustasy) and the volumetric capacity of ocean basins (tectono-eustasy) (Revelle, 1990). Localized deviations from this position are caused by the interplay of tectonics (subsidence, uplift) and sedimentation particular to a single basin. Sedimentation rate has a direct influence on carbonate depositional environments because continued accumulation of sediments will reduce the accommodation space (water depth) and eventually stop production of the carbonate factory (James and Bourque, 1992). Both global and local controls effect changes in water depth. Relative sea level refers to the position of sea level expressed in comparison to a datum plane (*i.e.* present day sea level). Interpretations of relative sea level change and/or crude estimations of absolute water depth can be derived from facies analysis of carbonate sequences such as that in RWP#2. The impact of local over global sea level variations must however, be deciphered from the rock fabric prior to suggesting that these changes are eustatic in nature.

5.2.2 Tectonic Concerns

Determining the history of sea level changes in a regional basin (*i.e.* Caribbean Sea) requires consideration of local tectonic history and its impact on the sedimentary record. The interpretation of eustatically-controlled facies changes and diagenetic fabrics is simplified for carbonate build-ups that developed under tectonically stable conditions. Grand Cayman is situated on a horst block in an active tectonic zone characterized by stress-related subsidence and uplift (Mann *et al.*, 1990; Leroy *et al.*, 1996). The near horizontal appearance of Tertiary carbonates exposed on the island (Jones and Hunter, 1989) indicates however, that there has been little, if any structural impact on deposition. Although, the island could have moved up or down vertically during this time, the relative homogeneity of the strata, in combination with the uniform bathymetric interpretation for all facies suggests this possibility is slight. However, if the island was tectonically active and did move relative to a constant sea level, the rate of sedimentation would have had to match the rate of uplift or subsidence of the block to produce such a uniform sedimentary sequence. At present , the available data does not permit discrimination between these two possibilities. On Cayman Brac the same Tertiary strata experienced differential uplift and tilting, as revealed by the apparent dip of 0.5°W (Jones *et al.*, 1994a). The contrast in structural histories between the two islands reflects their position on separate, tectonically-isolated horst blocks.

5.2.3 Eustatic Curves Compared

Distinguishing between true eustatic variations and local epeirogenic effects for the Caribbean has been difficult due to the tectonic activity that took place throughout the Tertiary. Therefore, global eustatic curves must be considered in order to assess how eustasy may have affected depositional sequences like the Cayman Formation. The most widely accepted eustatic curves which span the Tertiary (Haq *et al.*, 1987; Hallam, 1984) include two opposing perspectives in a heated controversy surrounding the recognition of globally synchronous events.

Haq *et al.* (1987) used seismic stratigraphy to construct the EXXON eustatic curves. Seismic imaging and biostratigraphic dating were employed to classify continental margin sequences as either onlap or offlap packages (Plint *et al.*, 1992). By tying the interpretations of onlap and offlap to relative increases and decreases in relative sea level, local sea level curves were produced. Supplementary evidence from borehole data and facies and biostratigraphic controls refined the timing and accuracy of the curve configuration. Correlation of the cycles of rise and fall between several, geographically separate regions demonstrated the global synchroneity of events and was summarized as a eustatic curve.

The primary criticism of this technique is the assumption that the impedance contrasts imaged using seismic waves follow chronostratigraphic surfaces (Hallam, 1984; Miall, 1986; Miall, 1990). If correlations based on the time-continuity of these reflective interfaces are incorrect, then both the timing and position of sea level highstands and lowstands will be inaccurate. Haq *et al.* (1987) redressed this issue since the first curves were released in 1977 by providing additional evidence including sequence stratigraphy, magnetostratigraphy, and detailed paleontological data to support their eustatic interpretations (*i.e.* Hardenbol *et al.*, 1985; Mitchum *et al.*, 1977).

The alternative eustatic curve proposed by Hallam (1984) was constructed using areal plots, hypsometric (continental elevation) data and various stratigraphic criteria (biogeography, organic evolution, facies and isotope changes). Relative positions of sea level were established by estimating shoreline positions for successive time intervals on a global scale and then matching them against transgressive/regressive and shallowing/deepening episodes for a given region. This curve is promoted as a more generalized, qualitative reconstruction, requiring more detailed biostratigraphic resolution, regional tectonic analysis, and stage-by-stage facies analysis. Relative sea level changes are charted for first (200-400 Ma) and second (10-100 Ma) order cycles only, rendering use of this curve imprecise for smaller time periods.

Comparing the eustatic histories suggested by Haq *et al.* (1987) and Hallam (1984) is complicated by differences in the scale of curve resolution (Figure 5.1). Hallam's (1984) curve since 25 Ma indicates two highstand events: a relatively high one in the Middle Miocene and another spanning the entire Plio-Pleistocene. Haq's (1987) curve shows approximately 15 highstands during the same period. The general trend of Hallam's (1984) eustatic curve is evident in Haq's (1987) more detailed version however, the discrepancy in resolution between them prevents comparison on an event-by event basis.

Interpreting the extrinsic controls on the complex paragenetic sequence derived from the Cayman Formation in RWP#2 requires the most detailed eustatic curve available. Weighing the advantages of the Haq *et al.*(1987) and Hallam (1984) curves, the former (Figure 5.2) was chosen because 1) it includes third order cycles (1-10 My) and a greater level of detail, 2) it is widely accepted by the scientific community (Christie-Blick *et al.*, 1990; Plint *et al.*, 1992), and 3) it is supported by a greater diversity of evidence. Even with this choice, the applicability of generalized global curve to such a limited area as Grand Cayman is questionable. The lack of alternative means to assess the Tertiary eustatic history and its expression in the Caribbean, however, means that the curve of Haq *et al.* (1987) is the best option available.

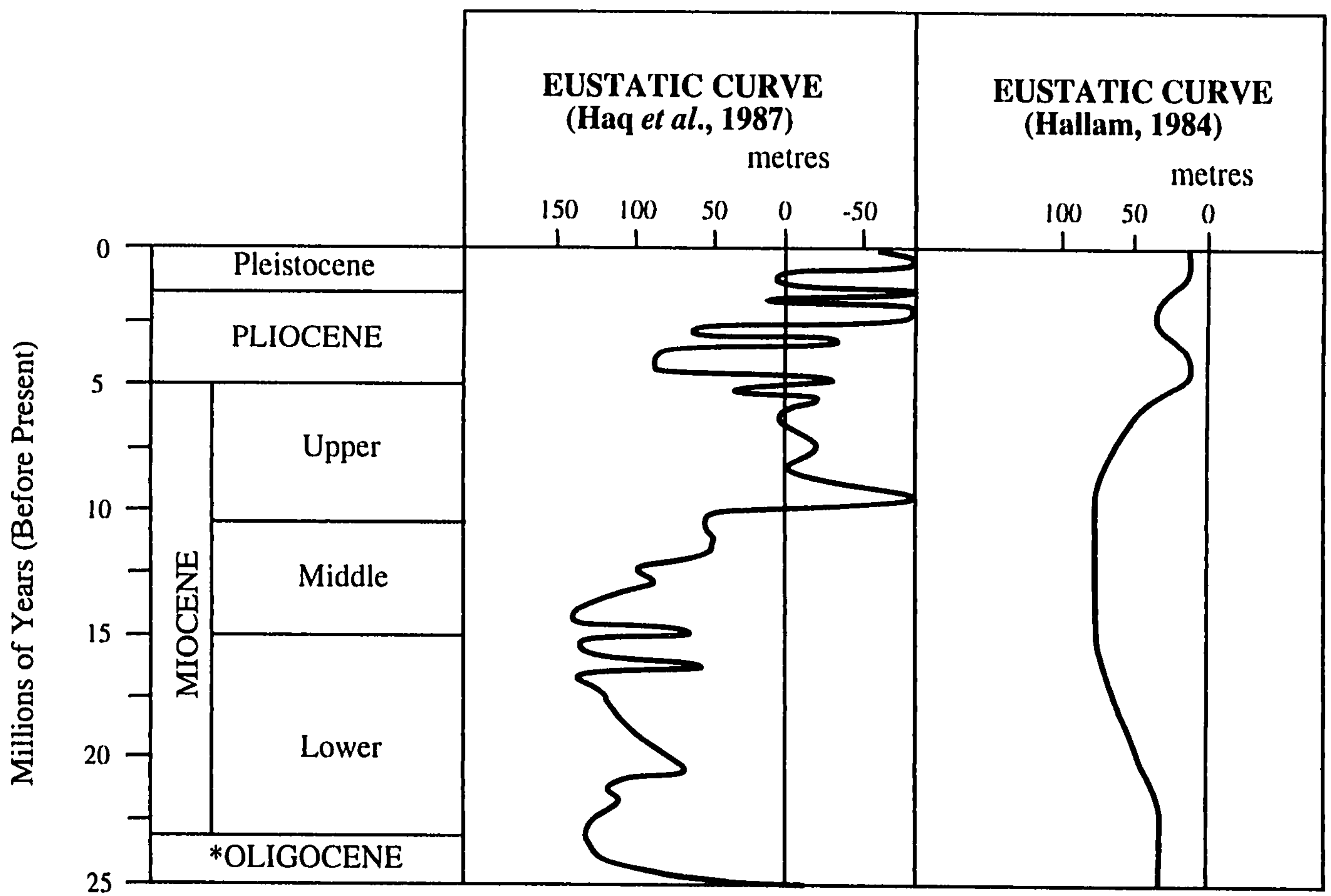


Figure 5.1 Comparison of the eustatic curves of Haq *et al.* (1987) and Hallam (1984). Sea level variations are plotted relative to present sea level (0 m). * Note only the latest portion of the Oligocene is shown.

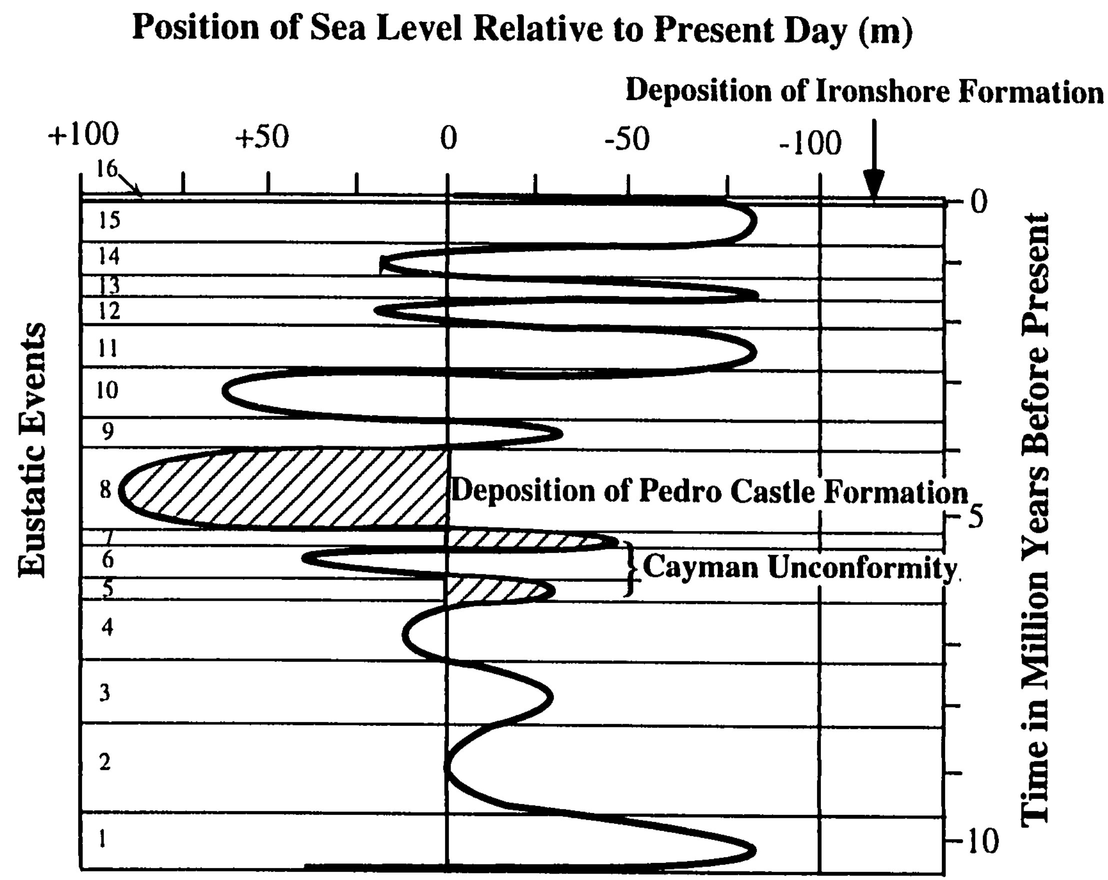


Figure 5.2 The Late Miocene-Pleistocene portion of the eustatic curve of Haq *et al.* (1987) with the absolute timing and eustatic causes of events significant to Cayman stratigraphy as shown.

5.2.4 Haq's Curve and Cayman Stratigraphy

Comparison between the relative timing of diagenetic events (Table 4.5) on Grand Cayman and the absolute timing of eustatic change requires a frame of reference. Dating of Cayman Formation dolostones has been difficult because of the lack of age diagnostic fossils and the diagenetic resetting of Sr isotope ratios (Pleydell *et al.*, 1990). As a result, four events significant to Cayman Island stratigraphy are used to place the Cayman Formation in a chronological context. These well-constrained events, for which evidence can be found on Grand Cayman, include the Cayman Unconformity, and deposition of the Brac, Pedro Castle and Ironshore formations. Although the Brac Formation has yet to be found on Grand Cayman, its stratigraphic position directly below the Cayman Formation on Cayman Brac has been used to infer the same relationship exists on all of the Cayman Islands. Deposition of the Brac Formation terminated in the late early Oligocene (Rupelian), as determined using $^{87}Sr/^{86}Sr$ ratios and foraminiferal biostratigraphy. Thus, based on the assumed relationship of these strata with the Cayman Formation, the earliest possible timing for the initiation of Cayman Formation deposition is also the late early Oligocene. However, comparison to the timing of highstands from the eustatic curve of Haq *et al.*, (1987) suggests a later date is more probable to provide the necessary accommodation space.

A large eustatic drop during the Messinian was responsible for the exposure, erosion and karstification of the Cayman Formation on Grand Cayman (Jones and Hunter, 1994b). The resultant erosional sequence boundary was called the Cayman Unconformity (Jones and Hunter, 1989). Initiation of the drop began between 6.6 to 4.5 Ma (Kastens, 1992), resulting in erosion and the lowstand was maintained for approximately 1.5 My (Aharon *et al.*, 1993). Absolute drops in sea level ascribed to the Messinian lowstand range from 40 m (Berggren and Haq, 1976) to 180 m (Pigrim *et al.*, 1992). The exact drop in sea level is, however, open to debate (Jones and Hunter, 1994b). Evidence from

Grand Cayman indicates that sea level was at least 50 m below present-day sea level (Jones and Hunter, 1994b).

Considering the Miocene-Pliocene portion of the Haq *et al.* (1987) curve (Figure 5.2), the Messinian lowstand is represented by eustatic events 5 and 7 with a minor highstand in between (eustatic event 6). The relative drop of ~45 m in eustatic event 7 (~5.6 to 5.2 Ma) falls within the range of Messinian lowstand positions determined by independent researchers (*i.e.* Loutit and Keigwin, 1982, Hodell *et al.*, 1986). Eustatic event 5 (~6.3 to 6 Ma) is characterized by a smaller relative drop of only ~30 m below present sea level.

Haq *et al.* (1987) proposed that the Messinian spans ~1.1 Ma (6.3 to 5.2 Ma) (Figure 5.2) although only the periods from 6.3-6 Ma (eustatic event 5) and 5.6-5.2 Ma (eustatic event 7) are indicated as actual eustatic lowstands. This total value of 1.1 Ma is slightly less than the 1.5 Ma assigned to the Cayman Unconformity by Jones and Hunter (1994b). However, as the level of resolution to Haq's curve appears as ±0.5 Ma, there is no major discrepancy. For the sake of simplicity, this study will assume that eustatic event 6 represents only a minor interruption in the erosion and karst development which continued from eustatic events 5 to 7. As the magnitude of the most recent drop was greater, any lithological evidence of the minor highstand (eustatic event 6) was probably destroyed as sea level fell.

The third means of calibrating the relative timing of sea level changes on Grand Cayman to the quantitative determinations of the eustatic curve involves Sr isotope data from the Pedro Castle Formation. Comparison of measured Sr^{87}/Sr^{86} ratios from Pedro Castle limestones from Grand Cayman and Cayman Brac to Sr evolution curves (*e.g.* DePaolo and Ingram, 1985; Hess *et al.*, 1986) indicates that this formation is probably Pliocene (Jones *et al.*, 1994b). As the Pedro Castle Formation was deposited directly on top of the Cayman Unconformity (Jones and Hunter, 1989), emplacement of these sediments can be related to the first major Pliocene highstand following the Messinian lowstand event. Therefore, deposition of the Pedro Castle Formation is represented by eustatic event 8 on Haq's curve (Figure 5.2).

The fourth means of calibrating eustatic events to an absolute time scale involves the interpreted stillstand positions (+6 to -5.7 m asl) of four unconformity-bound members of the Ironshore Formation at Roger's Wreck Point (Vézina, 1997). Ur/Th dating of aragonitic coral components from each member has demonstrated their deposition took place from > 400 ka (< 500 ka) to 131 ka. These high amplitude, short frequency sea level changes are above the third order resolution of Haq's curve and hence are not represented individually. However the generalized trend for this period is approximated by eustatic event 16 (Figure 5.2).

By tying the relative timing of these four stratigraphically significant events (on Grand Cayman) to the absolute scale of Haq's eustatic curve, eustatic implications can be attempted for the entire paragenetic sequence. The order of paragenetic stages (Table 4.5) was evaluated from the apparent relative timing of diagenetic effects (cement stratigraphy, cavity fills, etc.) as determined from the strata in RWP#2. Once the chronological tie points are established, and the textural relationships interpreted, the termination of Cayman Formation deposition and start of diagenesis must be ascertained.

5.2.5 Termination of Cayman Formation Deposition

Calibration of significant events in Cayman stratigraphy to the eustatic curve of Haq *et al.* (1987) suggests two possible lowstand events which may have terminated deposition of the Cayman Formation. The first, represented by eustatic event 1 (Figure 5.2), may have involved a relative eustatic drop of ~ 80 m (Haq *et al.*, 1987). This timing corresponds to the late Middle Miocene to early Late Miocene age proposed by Jones and Hunter (1994b). Alternatively, deposition may have continued intermittently following this event, finally terminating with prolonged exposure during Messinian lowstand (eustatic events 5-7: Figure 5.2).

The choice between these two timings is complicated by the lack of age diagnostic fauna and representative Sr isotope dates for the Cayman Formation strata. In addition, if deposition continued until the Messinian, the proposed eustatic drop (-80 m or -262') in the late Middle Miocene (Haq *et al.*, 1987) would have created a recognizable break in deposition. However, the substantial erosion associated with the Cayman Unconformity (~128' or 39 m in QHW#1) may have removed any evidence of such a feature, if it existed.

The paragenetic sequence determined from RWP#2 can be used to decide between the two timings for termination of Cayman Formation deposition. The number of diagenetic events, their cause and relative timing as discerned from textural relationships observed in the core can help constrain the number and magnitude of eustatic stillstands and hence, place an absolute timing on the end of deposition. Comparing the paragenetic stages of RWP#2 to sea level fluctuations shown by the eustatic curve of Haq *et al.* (1987) assumes that the diagenetic fabrics preserved in Cayman Formation strata are the result of globally synchronous events (Table 5.1). Although the paragenetic sequence correlates with the position of stillstands associated with either timing, the timing of dolomitization is not so flexible. Interpretation of the Sr isotope ratios from Cayman Formation dolostones places the most recent dolomitization event (s) between 2 and 5 Ma (*cf.* Pleydell et al., 1990). With option one, the most recent dolomitization of the Cayman Formation is linked to eustatic event 12 (Table 5.1). Therefore, the timing of this dolomitization event is constrained to between ~1.6-2 Ma (Figure 5.2), a value acceptable within the error associated with isotopic dating and the construction of eustatic curves. Option two, however, interprets the most recent dolomitization (paragenetic stage 10) as having taken place during eustatic event 14 (Table 5.1), between ~0.8 to 1.3 Ma (Figure 5.2). As these values fall outside the timing range determined from Sr isotope analysis (2 to 5 Ma), it is used to rule against the probability of option two.

EUSTATIC EVENT (FIGURE 5.1)	OPTION ONE: **Cayman Fm. Deposition Terminates in Middle Miocene**	OPTION TWO: **Cayman Fm. Deposition Terminates with Messinian Lowstand**
16	• Paragenetic Stage 12 • Deposition of Ironshore Fm.	• Paragenetic Stage 12 • Deposition of Ironshore Fm.
15	• Paragenetic Stage 11 continued.	• Paragenetic Stage 11, • Erosion of Pedro Castle Fm.
14	• No evidence preserved.	• Paragenetic Stage 10, • Dolomitization of Cayman Fm. (~1.3-0.8 Ma)
13	• Paragenetic Stage 11, • Erosion of Pedro Castle Fm. begins.	• Paragenetic Stage 9
12	• Paragenetic Stage 10, • Dolomitization of Cayman Fm. (~2-1.6 Ma).	• Paragenetic Stage 8
11	• Paragenetic Stage 9	• Paragenetic Stage 7
10	• Paragenetic Stage 8 continued.	• Paragenetic Stage 6
9	• No evidence preserved.	• Paragenetic Stage 5
8	• Paragenetic Stage 8, • Deposition of Pedro Castle Fm.	• Paragenetic Stage 4, • Deposition of Pedro Castle Fm.
5-7	• Paragenetic Stage 7, • Cayman Unconformity	• Paragenetic Stages 2, 3, • Cayman Unconformity
1-4	• Paragenetic Stages 2-6	• Continued deposition of Cayman Fm.

Table 5.1 Comparison of Eustatic Event-Paragenetic Stage Matches for Option One (Deposition of Cayman Formation terminated at end of Middle Miocene) and Option Two (Deposition terminated in Late Miocene with onset of Messinian Lowstand).

5.3 DIAGENESIS AND EUSTASY

5.3.1 Absolute Timing of Diagenesis

Haq *et al.* (1987) proposed that since Middle Miocene times, sixteen eustatic events of third order or greater scale have taken place (Figure 5.2). Assuming these events are indeed globally synchronous, it is thereby reasoned that each perturbation in the position of sea level would result in the re-positioning of each diagenetic environment at Roger's Wreck Point. Therefore, a variety of diagenetic fabrics would be created in the Cayman Formation. To interpret the absolute timing of the twelve paragenetic stages established by textural criteria (Table 4.5), the absolute magnitude of these sea level stillstands must be compared directly to the five diagenetic zones delineated in the RWP#2 core (Figure 4.1, Figure 5.3). By matching the interpreted position of sea level for a given paragenetic stage to the actual stillstand elevation from the curve of Haq *et al.* (1987), an absolute timing can be suggested for each paragenetic stage. The results of this correlation (Table 5.1) demonstrate an uncanny match between the interpreted sea level positions and those from the eustatic curve of Haq *et al.* (1987) (Figure 5.2, Figure 5.3).

For interpretation purposes, the top of the Cayman Formation in RWP#2 is placed at +8m (Figure 5.3) because this elevation matches the maximum elevation of exposed Cayman Formation dolostones in the cliff west of Roger's Wreck Point. This represents the minimum elevation of the upper contact of the Cayman Formation in RWP#2 preceeding the Cayman Unconformity. Subsequent erosion would have lowered this contact to it's present position (-2.1 m), perhaps as early as eustatic event 5 (Figure 5.3, Table 5.2). The following discussion of individual eustatic events, including the position and timing of stillstands are based upon these assumptions.

Eustatic event 1 was characterized by a substantial drop in relative sea level (~80m), which probably terminated Cayman Formation deposition and initiated lithification and leaching of metastable fossils (Table 5.2). The timing of this event correlates to the textural relationships shown in paragenetic stages 2 and 3 (Table 4.5).

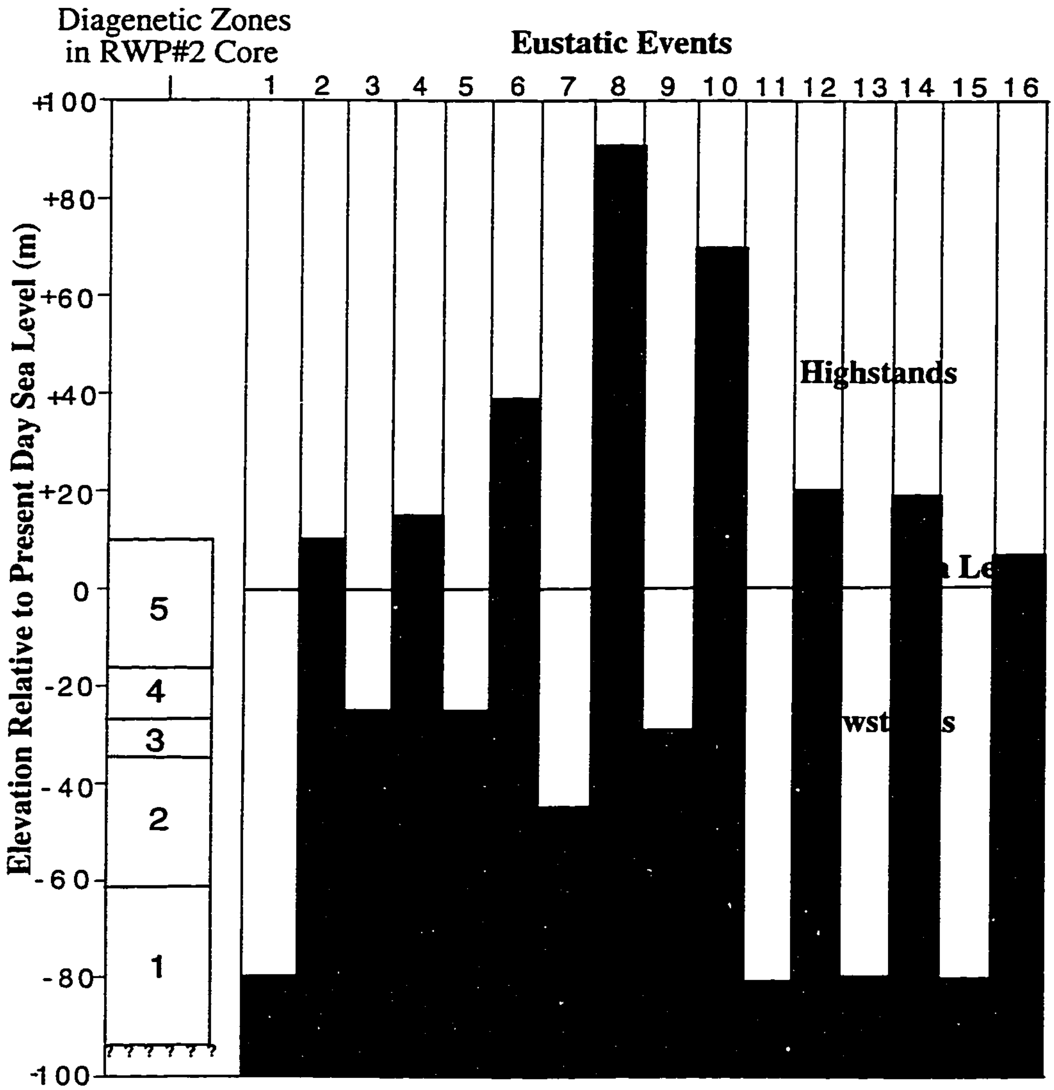


Figure 5.3 Position of RWP#2 (Cayman Formation only) and its 5 diagenetic zones relative to changes in eustatic sea level beginning at the end of the Middle Miocene. Relative eustatic positions determined from Haq *et al.* (1987). Refer to Table 5.1 for timing and duration of events.

EUSTATIC EVENT (FIGURE 5.3)	RELATIVE SEA LEVEL COMPARED TO PRESENT DAY	CORRELATIVE PARAGENETIC STAGE (TABLE 4.5)
16	Highstand	11
15	Lowstand	11
14	Highstand	11
13	Lowstand	11
12	Highstand	10
11	Lowstand	9
10	Highstand	8
9	Lowstand	-
8	Highstand	8
7	Lowstand	7
6	Highstand	-
5	Lowstand	7
4	Highstand	6
3	Lowstand	5
2	Highstand	4
1	Lowstand	2, 3

Table 5.2 Comparison of eustatic events identified from Haq *et al.* (1987) and the RWP#2 paragenetic stages.

Eustatic event 2 is a relative sea level highstand responsible for the precipitation of mixed/marine cement A (Table 4.3) throughout the entire RWP#2 core. Exposure of all five diagenetic zones to mixed/marine waters is identified as paragenetic stage 4 (Table 4.5).

Eustatic event 3 resulted in a sea level lowstand which re-established sea level at the base of diagenetic zone 4 (Figure 5.3). This drop in sea level caused vadose alteration effects above zone 4 and presumably initiated mixed/marine conditions below. Based upon the timing and position of sea level for this event, it is interpreted as the cause of paragenetic stage 5 (Table 5.2, Table 4.5).

Eustatic event 4 represents another highstand (Table 5.2), slightly above present sea level (Haq *et al.*, 1987, Figure 5.3). As sea level rose through the RWP#2 sequence, cement B (Table 4.3) was probably precipitated from mixed/marine waters. This eustatic rise correlates to the diagenetic fabrics of paragenetic stage 6 (Table 4.5).

Eustatic events 5, 6, and 7 are associated with the Messinian lowstand event and erosion of the Cayman Unconformity (Table 5.2). At that time, erosion probably removed a portion of Cayman Formation strata in RWP#2 to result in the current upper contact at -2.1 m. Together these three eustatic changes were responsible for the emplacement of cavity fill deposits in diagenetic zone 5 and the existence of meteoric phreatic conditions in zone 2 (dissolution and cement D) (Table 4.5). These diagenetic features were associated with paragenetic stage 7 and hence their timing spans the duration of eustatic events 5-7.

Eustatic event 8 correlates to paragenetic stage 8, a highstand event that led to deposition of the Pliocene Pedro Castle Formation (Figure 5.2, Figure 5.3). As sea level rose, a mixed/marine precipitates and cement C (Table 4.3) were emplaced throughout diagenetic zones 2 to 5 (Table 5.2). No lithological evidence was preserved for the relatively short lowstand attributed to eustatic event 9. Deposition of the Pedro Castle Formation may have continued with the next highstand, eustatic event 10 (Figure 5.3, Table 5.2).

Eustatic event 11 represents another sea level lowstand (Figure 5.3) whereby sea level dropped to a position within diagenetic zone 1. As a result, the entire RWP#2 core was exposed to vadose alteration and substantial internal sedimentation, the emplacement of which is identified as paragenetic stage 9.

Eustatic event 12 is linked to paragenetic stage 10 based upon the relative timing and highstand position required for pervasive dolomitization. Paragenetic stage 10 represents the most recent phase of dolomitization to affect the Cayman Formation *via* marine or mixed waters. As evidence for a single *versus* multiple dolomitization event(s) is equivocal, only the most recent known event is considered for the sake of simplification. The elevated position of sea level during eustatic event 12 (Figure 5.2, Figure 5.3) would have submerged the entire Cayman Formation to facilitate pervasive dolomitization. Partial dolomitization of the overlying Pedro Castle Formation strata, suggests perhaps a time-dependent metastabilization of the sediment mineralogy made the older Cayman strata more susceptible to diagenesis (*cf.* Sibley, 1982).

Eustatic events 13 and 15 were relative lowstand periods which subaerially exposed the Pedro Castle and Cayman formations on Grand Cayman, resulting in erosion. At Roger's Wreck Point in particular, this drop has been associated with the complete removal of Pedro Castle Formation strata from RWP#2 (Figure 1.6). Limited thickness' of indistinct strata which may belong to the Pedro Castle Formation have been found in other Roger's Wreck Point wells (Vézina, 1997). Continued erosion may also have removed an unknown thickness of Cayman Formation, thus removing the previous surface produced by the Cayman Unconformity. The ability to distinguish between the Cayman Unconformity and a more recently developed one is impossible with the resolution of the available core. These two lowstands are separated by a short highstand which probably halted the erosion process and removed any loose debris with the onset of transgression. All three eustatic events are therefore grouped together and correlated collectively to the diagenetic features of paragenetic stage 11 (Figure 4.5). This includes the emplacement of vadose cavity fills in diagenetic zone 5, which reinforces the interpretation of an exposure event. By the end of eustatic event 15, erosion of the Pedro Castle Unconformity on the top of Pedro Castle Formation strata, where still present, would have been complete. No evidence of this surface was apparent in RWP#2, perhaps as a result of nearshore erosion associated with later Pleistocene transgressions. Surficial karst development appears to have obscured this surface in QHW#1 as well.

Eustatic event 16 represents a generalized third-order highstand which spanned the Pleistocene and led to deposition of the Ironshore Formation on Grand Cayman. Using a variety of analytical techniques, a more detailed Pleistocene eustatic history has been resolved (*i.e.* Hearty and Vacher, 1994; Imbrie *et al.*, 1984) indicating high frequency sea level oscillations persisted during this time. Deposition of four unconformity-bound members in the Ironshore Formation at Roger's Wreck Point have been attributed to successive highstands of -5.8, +0.4, +1, +6 m (Vézina, 1997). However, these relatively short-lived events are beyond the level of resolution of Haq *et al.*'s eustatic curve and the available Cayman Formation core. Due to the limitations ascribed to textural interpretation of sea level variations, the Pleistocene and present time are assigned as a continuation of paragenetic stage 11.

5.3.2 Discussion

Correlations made between the timing of the sixteen eustatic stillstands (Haq *et al.*, 1987) and the eleven paragenetic stages determined from RWP#2 represent the best possible interpretation of the available data. Many assumptions have been made as to the validity and applicability of Haq *et al*.'s (1987) eustatic curve to Caribbean sea level history, the tectonic stability of Grand Cayman since the Miocene, as well as the timing of Cayman Formation deposition. A certain degree of error in each of these assumptions is recognized; however, provided the uncertainty surrounding these issues, the interpretations presented here are felt to best represent the geological evolution of the Cayman Formation.

Reconstructing eustatic events from lithological evidence is extremely difficult in dolomitized strata such as the Cayman Formation because the interpretation of the relative timing and cause of diagenetic fabrics is rarely unequivocal. Recognizing these limitations, the coincidence of the generalized stillstand positions and the textural features observed in RWP#2 and QHW#1 is a compelling argument that the eustatic curve of Haq *et al*. (1987) provides an excellent framework for understanding the Cayman Formation. Eustatic change appears to have been the primary control on both the genesis and diagenesis of these dolostones. Having established the utility of Haq *et al.*'s (1987) curve by this study, sea level variations must be considered in future research in explaining the distribution of alteration features throughout the formation.

CHAPTER SIX: CONCLUSIONS

Detailed sedimentological analysis of the Cayman Formation at Roger's Wreck Point has significantly improved our understanding of the depositional and diagenetic histories of these complex strata. The following conclusions are important.

(1) The Cayman Formation is formed of the *Stylophora* Floatstone, the Rhodolite Finger Coral Floatstone, the Rhodolite Coral Fragment Rudstone-Grainstone, the *Porites Leptoseris Monstastrea* Floatstone, and the *Leptoseris Montastrea* Floatstone facies.

(2) The Cayman Formation lacks a consistent and predictable internal facies architecture.

(3) Each of the lithofacies was deposited on a transitional bank edge to protected inner bank setting. Although depositional conditions fluctuated continuously, they were generally shallow (5-30 m water depth), well-illuminated, with variable wave energy and rates of sedimentation.

(4) Diagenetic fabrics found in the Cayman Formation include two types of matrix dolomite, five types of cement, five varieties of cavity fill sediments, and several forms of primary and secondary pores. Collectively, these parameters define five diagenetic zones in RWP#2.

(5) Porosity development in the Cayman Formation involved multiple events of porosity enhancement and destruction. The existing porosity developed through the interplay between primary pore space and subsequent dissolution, cementation, and internal sedimentation.

(6) Eleven paragenetic stages, established by textural evidence, represent the relative timing of diagenetic changes within RWP#2. Each paragenetic stage was associated with a different sea level.

(7) At least one phase of dolomitization, mediated by either mixed or marine waters, affected the Cayman Formation. The most recent timing of such pervasive alteration is constrained to 2 Ma.

(8) Provided the detailed facies analysis and diagenetic interpretations applied to RWP#2 as well as its extensive vertical coverage of the Cayman Formation, it is proposed that this succession be a designated reference standard for future geological comparison.

REFERENCES

Adey, W.H., and MacIntyre, I.G., 1973. Crustose coralline algae: a re-evaluation in the geological sciences. Geological Society of America Bulletin, v. 84, p. 883-904.

Aharon, P., Goldstein, L.S., Wheeler, C.W., and Jacobson, G., 1993. Sea-level events in the South Pacific linked with the Messinian salinity crisis. Geology, v. 21, p. 771-775.

Banner, J.L., 1995. Application of the trace element and isotope geochemistry of strontium to studies of carbonate diagenesis. Sedimentology, v. 42, p. 805-824.

Beggren, W.A., and Haq, B.U., 1976. The Andulusian stage (Late Miocene): biostratigraphy, biochronology and paleoecology. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 20, p. 67-129.

Berner, R.A., 1980. Early Diagenesis, A Theoretical Approach. Princeton University Press, New Jersey, 237 p.

Blanchon, P., and Jones, B., 1995. Marine-planation terraces on the shelf around Grand Cayman: a result of stepped Holocene sea-level rise. Journal of Coastal Research, v. 11, p. 1-33.

Blanchon, P., Jones, B., and Kalbfleisch, W., 1997. Anatomy of a fringing reef around Grand Cayman: storm rubble, not coral framework. Journal of Sedimentary Research, v. 67, no. 1, p. 1-16.

Brunner, C.A., 1984. Evidence for increased volume transport of the Florida Current in the Pliocene and Pleistocene. Marine Geology, v. 54, p. 223-235.

Brunt, M.A., Giglioli, M.E.C., Mather, J.D., Piper, D.J.W., and Richards, H.G., 1973. The Pleistocene rocks of the Cayman Islands. Geology Magazine, v. 110, no. 3, p. 209-221.

Chaproniere, G.C.H., 1975. Palaeoecology of the Oligocene-Miocene larger foraminifera, Australia. Alcheringa, v. 1, p. 37-58.

Christie-Blick, N., Mountain, G.S., and Miller, K.G., 1990. Seismic stratigraphic record of sea level change, *in* Revelle, R. *ed.*, Sea Level Change. National Research Council, Studies in Geophysics, Washington, D.C., National Academy Press, p. 116-140.

Conyers, S., 1990. The larvicidal control of *Aedes taeniorhynchus* (Wiedemann) in the mangrove swamps of Grand Cayman, British West Indies. Unpublished M.Phil. thesis, University of Newcastle upon Tyne, 257 p.

Darbyshire, J., Bellamy, I., and Jones, B., 1976. Results of the investigations into the physical oceanography, *in* Wickstead, J.H. *ed.*, Cayman Island Natural Resources Study, Part III. Ministry of Overseas Development, 122 p.

De Paolo, D.J., and Ingram, B.L., 1985. High-resolution stratigraphy with strontium isotopes. Science, v. 227, p. 938-941.

Dillon, W.P., Vedder, J.G., and Graf, R.J., 1972. Structural profile of the northwestern Caribbean. Earth and Planetary Science Letters, v. 17, p. 175-180.

Dravis, R.J., 1979. Rapid and widespread generation of recent oolitic hardgrounds on a high energy Bahamian platform, Eleuthera Bank, Bahamas. Journal of Sedimentary Petrology, v. 49, no. 1, p. 195-207.

Embry, A., and Klovan, J., 1971. A Late Devonian reef tract on Northeastern Banks Island, N.W.T. Bulletin of Canadian Petroleum Geology, v. 19, p. 730-781.

Emery, K., and Milliman, J., 1980. Shallow-water limestone from the slope off Grand Cayman Island. Journal of Geology, v. 88, p. 483-488.

Esteban, M., and Klappa, C.F., 1983. The subaerial exposure environment, *in* Scholle, P.A., Bebout, D.G., and Moore, C.H., *eds.*, Carbonate Depositional Environments. American Association of Petroleum Geologists Memoir 33, p. 1-54.

Falquist, D., and Davies, D., 1971. Fault block origin of the Western Cayman Ridge. Deep Sea Research, v. 18, p. 243-254.

Fluegel., E., 1982. Microfacies Analysis of Limestones, Springer-Verlag, New York, 663 p.

Frost, S.H., and Langenheim, R.L., Jr., 1974. Cenozoic Reef Biofacies: Tertiary Larger Foraminifera and Scleractinian Corals from Chiapas, Mexico, Northern Illinois University Press, 388 p.

Frost, S.H., 1977. Miocene to Holocene evolution of Caribbean Province reef-building corals. Proceedings of the Third International Coral Reef Symposium, University of Miami, v. 2, p. 353-359.

Frost, S., 1981. Oligocene reef coral biofacies of the Vincentin, Northeast Italy. Society of Economic Paleontologists and Mineralogists Special Publication, v. 30, p. 483-539.

Glynn, P.W., 1974. Rolling stones among the scleractinia: mobile coralliths in the Gulf of Panama. Proceedings of the Second International Coral Reef Symposium, Brisbane, v. 2, p. 183-198.

Hallam, A., 1984. Pre-Quaternary sea-level changes. Annual Review of Earth and Planetary Sciences, v. 12, p. 205-243.

Hardenbol, J., Haq, B.U., and Vail, P.R., 1985. Mesozoic and Cenozoic chronostratigraphy and cycles of sea level change, *in* Wilgus, C.K., Hastings, B.S., Ross, C.A., Posamentier, H.W., Van Wagoner, J., and Kendall, C.G.St.C., *eds.*,Sea Level Changes: An Integrated Approach, Special Publication of the Society of Economic Paleontologists and Mineralogists, v . 42, p. 72-108.

Haq, B., Hardenbol, J., and Vail, P., 1987. Chronology of fluctuating sea levels since the Triassic. Science, v. 235, p. 1156-1167.

Hearty, P.J., and Vacher, H.L., 1994, Quaternary stratigraphy of Bermuda: a high resolution Pre-Sangamonian rock record. Quaternary Science Reviews, v. 13, p. 685-697.

Heckel, P.H., 1972. Recognition of ancient shallow marine environments, *in* Rigby, J.K. and Hambline, W.K., *eds.*,Recognition of Ancient Sedimentary Environments, Society of Economic Paleontologists and Mineralogists, v. 16, p. 226-276.

Hess, J., Bender, M.L., and Schilling, J.G., 1986. Evolution of the ratio of strontium-87 to strontium-86 in seawater from Cretaceous to present. Science, v. 231, p. 979-984.

Hills, D.J., 1998. Rhodolite development in the modern and Pleistocene of Grand Cayman. Unpublished M.Sc. thesis, University of Alberta, Edmonton, 88 p.

Hodell, D.A., Elmstrom, K.M., and Kennett, J.P., 1986. Latest Miocene benthic ∂O^{18} changes, global ice volume, sea level, and the "Messinian Salinity Crisis". Nature, v. 320, p. 411-414.

Hsu, S., Giglioli, M., Reiter, J. and Davies, J. 1972. Heat and water balance studies on Grand Cayman. Caribbean Journal of Science, v. 12, p. 9-27.

Hubbard, J.A.E.B. and Pocock, Y.P., 1972. Sediment rejection by recent scleractinian corals: a key to paleo-environmental reconstruction. Geol. Rundschau, v. 61, p. 598-626.

Hubbard, D.K., 1988. Controls of modern and fossil reef development: common ground for biological and geological research: 6th International Coral Reef Symposium, v. 1, p. 243-252.

Hunter, I., and Jones, B., 1988. Corals and paleogeography of the Pleistocene Ironshore Formation of Grand Cayman. Proceedings of the Sixth International Coral Reef Symposium, Townsville, Australia, v. 3, p. 431-435.

Hunter, I., 1994. Modern and ancient coral associations of the Cayman Islands. Unpublished Ph.D. thesis, University of Alberta, Edmonton, 345 p.

Imbrie, J., Hays, J.D., Martinson, D.G., McIntyre, A., Morley, J.J., Pisias, N.G., Prell, W.L., and Shackelton, N.J., 1984. The orbital theory of Pleistocene climate: support from a revised chronology of the marine $\partial^{18}O$ record, *in* Berger, A., Imbrie, J., Hays, J., Kukla, G., and Saltzman, B., *eds*., Milankovitch and Climate, Part I: NATO ASI Series C. D. Reidel Publishing Co., Dordrecht (Netherlands), v. 126, p. 269-305.

Iturralde-Vinent, M.A., 1969. Principal characteristics of Cuban Neogene stratigraphy. American Association of Petroleum Geologists Bulletin, v. 53, p. 1938-1955.

James, N.P. and Bourque, P.A., 1992. Reefs and Mounds *in* Walker, R.G. and James, N.P., *eds*., Facies Models: Response to Sea-Level Change. Geological Association of Canada, 409 p.

Jones, B., Lockhart, E.B., and Squair, C., 1984. Phreatic and vadose cements in the Tertiary Bluff Formation of Grand Cayman Island, British West Indies. Bulletin of Canadian Petroleum Geology, v. 32, p. 382-397.

Jones, B. and Hunter, I.G., 1989. The Oligocene-Miocene Bluff Formation on Grand Cayman. Caribbean Journal of Science, v. 25, no. 1-2, p.71-85.

Jones, B. and Smith, D., 1988. Open and filled karst features on the Cayman Islands: implications for the recognition of paleokarst. Canadian Journal of Earth Sciences, v. 25, p. 1277-1291.

Jones, B., and Hunter, I.G., 1990. Pleistocene paleogeography and sea levels on the Cayman Islands, British West Indies. Coral Reefs, v. 9, p. 81-91.

Jones, B., 1992. Caymanite, a cavity-filling deposit in the Oligocene-Miocene Bluff Formation of the Cayman Islands. Canadian Journal of Earth Sciences, v. 29, p. 720-736.

Jones, B., 1994. Geology of the Cayman Islands, *in* Brunt, M., and Davies, J., *eds*., The Cayman Islands: Natural History and Biogeography. Kluwer Academic Publishers, Amsterdam, p. 13-49.

Jones, B., and Hunter, I., 1994a. Evolution of an isolated carbonate bank during Oligocene, Miocene and Pliocene times, Cayman Brac, British West Indies. Facies, v. 30, p. 25-50.

Jones, B., and Hunter, I., 1994b. Messinian (Late Miocene) karst on Grand Cayman, British West Indies: an example of an erosional sequence boundary. Journal of Sedimentary Research, v. B64, p. 531-541.

Jones, B., Hunter, I. and Kyser, T., 1994a. Stratigraphy of the Bluff Formation (Miocene-Pliocene) and the newly defined Brac Formation (Oligocene), Cayman Brac, British West Indies. Caribbean Journal of Science, v. 30, no. 1-2, p. 30-51.

Jones, B., Hunter, I. and Kyser, T., 1994b. Revised stratigraphic nomenclature for Tertiary strata of the Cayman Islands, British West Indies. Caribbean Journal of Science, v. 30, no. 1-2, p. 53-68.

Kastens, K.A., 1992. Did glacio-eustatic sea level drop trigger the Messinian salinity crisis? New evidence from Ocean Drilling Program site 654 in the Tyrrhenian Sea. Palaeooceanography, v. 7, p. 333-356.

Kinsman, D.J.J., 1964. Reef coral tolerance of high temperatures and salinities. Nature, v. 202, p. 1280-1282.

Lambeck, K., 1990. Late Pleistocene, Holocene and present sea-levels: constraints on future change. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 89, p. 205-217.

Lees, A., 1975. Possible influence of salinity and temperature on modern shelf carbonate sediments. Marine Geology, v. 19, p. 159-198.

Leroy, S., Mercier de Lepinay, B., Mauffret, A., and Pubellier, M., 1996. Structural and tectonic evolution of the Eastern Cayman Trough (Caribbean Sea) from seismic reflection data. American Association of Petroleum Geologists Bulletin, v. 80, no. 2, p. 222-247.

Loutit, T.S., and Keigwin, L.D., 1982. Stable isotope evidence for Late Miocene sea-level fall in the Mediterranean region. Nature, v. 300, p. 163-166.

Li, C., 1997, Foraminifera: their distribution and utility in the interpretation of carbonate sedimentary processes around Grand Cayman, British West Indies. Unpublished Ph.D. thesis, University of Alberta, Edmonton, 187 p.

Liddell, W.D. and Olhorst, S.L., 1987. Patterns of reef community structure, North Jamaica. Bulletin of Marine Science, v. 40, p. 311-329.

Lockhart, E.B., 1986. Nature and genesis of caymanite in the Oligocene-Miocene Bluff Formation of Grand Cayman Island, British West Indies. Unpublished M.Sc. thesis, University of Alberta, Edmonton, 111 p.

Logan, B.W., Harding, J.L., Ahr, W.M., Williams, J.D., Snead, R.G., 1969. Carbonate Sediments and Reefs, Yucatan Shelf, Mexico. American Association of Petroleum Geologists Memoir 11, 198 p.

Lu, G., Aharon, P., Wheeler, C.W., and McCabe, C., 1996. Magnetostratigraphy of the uplifted former atoll of Niue, South Pacific: implications for accretion history and carbonate diagenesis. Sedimentary Geology, v. 105, p. 259-274.

MacDonald , K.C. and Holocombe, T.L., 1978. Inversion of magnetic anomalies and sea floor spreading in the Cayman Trough. Earth and Planetary Science Letters, v. 40, p. 407-414.

Mann, P., Schubert, C., and Burke, K., 1990. Review of Caribbean neotectonics, *in* Dengo, G., and Case, J.E., *eds.*, The Caribbean Region. Geology of North America, Geological Society of America, v. H, p. 307-338.

Mather, J., 1972. The geology of Grand Cayman and its control over the development of lenses of potable groundwater. Transactions of the Fourth Caribbean Geology Conference, Isla de Margarita, Venezuela, p. 154-157.

Matley, C., 1924a, Reconnaissance geological survey of Cayman Islands, British West Indies. The Pan American Geologist, v. XLII, p. 313-315.

Matley, C., 1924b, Report of a reconnaissance geological survey of the Cayman Islands, British West Indies. Supplement to the Jamaica Gazette, 13 June, v. 47, p. 69-73.

Matley, C., 1926, The geology of the Cayman Islands (British West Indies) and their relation to the Bartlett Trough. Quarterly Journal of the Geological Society of London, v. 82, p. 352-387.

Miall, A.D., 1986. Eustatic sea level changes interpreted from seismic stratigraphy: a critique of the methodology with particular reference to the North Sea Jurassic record. American Association of Petroleum Geologists Bulletin, v. 70, p. 131-137.

Miall, A.D., 1990. Principles of Sedimentary Basin Analysis. Springer-Verlag, New York, 668 p.

Milliman, J.D., 1976. Marine Carbonates. Elsevier, Amsterdam, 375 p.

Mitchum, R.M. Jr., Vail, P.R., and Thompson, III S., 1977. Seismic stratigraphy and global changes of sea-level part 2: the depositional sequence as a basic unit for stratigraphic analysis, *in* Payton, C.E. *ed.*, Seismic Stratigraphy -Applications to Hydrocarbon Exploration. American Association of Petroleum Geologists Memoir 26, p. 53-62.

Morner, N.A., 1976. Eustasy and geoid changes. Journal of Geology, v. 84, no. 2, p. 123-151.

Ng, K.C., 1990. Diagenesis of the Oligocene-Miocene Bluff Formation of the Cayman Islands-a petrographic and hydrochemical approach. Unpublished Ph.D. thesis, University of Alberta, Edmonton, 344 p.

Ng, K.C., and Jones, B, 1990. Chemical and stable isotopic characteristics of groundwater on Grand Cayman, *in* Krishna, J.H., Quinones-Aponte, V., Gomez-Gomez, F. and Morris, G., *eds.*, Proceedings of the International Symposium on Tropical Hydrology and the Fourth Caribbean Islands Water Resources Congress. San Juan, Puerto Rico, July 22-27, p. 411-420.

Ng, K.C., Jones, B., and Beswick, R.G.B., 1992. Hydrogeology of Grand Cayman, British West Indies: a karstic dolostone aquifer. Journal of Hydrology, v. 134, p. 273-295.

Ng, K.C., and Beswick, R.G.B., 1994. Ground water of the Cayman Islands, *in* Brunt, M., and Davies, J., *eds.*, The Cayman Islands: Natural History and Biogeography. Kluwer Academic Publishers, Amsterdam, p. 61-74.

Nummedal, D., Pilkey, O.H. and Howard, J.D., 1987. Sea Level Fluctuation and Coastal Evolution. Society of Economic Paleontologists and Mineralogists, Special Publication 41, 267 pp.

Perfit, M. and Heezen, B., 1978. The geology and evolution of the Cayman Trench, Geological Society of America Bulletin, v. 89, p. 1155-1174.

Pigrim, C.J., Davies, P.J., Feary, D.A., and Symonds, P.A., 1992. Absolute magnitude of the second-order middle to late Miocene sea-level fall, Marion Platform, northeast Australia. Geology, v. 20, p. 858-862.

Pleydell, S., 1987. Aspects of diagenesis and ichnology in the Oligocene-Miocene Bluff Formation of Grand Cayman Islands, British West Indies. Unpublished M.Sc. thesis, University of Alberta, Edmonton, 209 p.

Pleydell, S. and Jones, B., 1988. Boring of various faunal elements in the Oligocene-Miocene Bluff Formation of Grand Cayman, British West Indies. Journal of Paleontology, v. 62, p. 348-367.

Pleydell, S., Jones, B., Longstaffe, F. and Baadsgaard, H., 1990. Dolomitization of the Oligocene-Miocene Bluff Formation on Grand Cayman, British West Indies. Canadian Journal of Earth Science, v. 27, p. 1098-1110.

Plint, A.G., Eyles, N., Eyles, C.H., and Walker, R.G., 1992. Control of sea level change, *in* Walker, R.G. and James, N.P., *eds*., Facies Models: Response to Sea Level Change. Geological Association of Canada, p. 15-26.

Poag, C.W., and Tresslar, R.C., 1981. Living foraminifers of West Flower Garden Bank, northernmost coral reef in the Gulf of Mexico. Micropaleontology, v. 27, p. 31-70.

Radford, S.S., 1976. Depth distribution of recent foraminifera in selected bays, Tobago Island, West Indies. Revista Espanola de Micropaleontologia, v. 8, no. 2, p. 219-238.

Rau, C.P. and Nelson, C.S., 1992. Oxygen and carbon isotope fields for temperate shelf carbonates from Tasmania and New Zealand. Marine Geology, v. 103, p. 273-286.

Raven, P.H., Evert, R.F. and Eichhorn, S.E., 1987. Biology of Plants. Worth Publishers Inc., New York, 4th ed., 774 p.

Reid, R.P. and MacIntyre, I.G., 1988. Foraminiferal-algal nodules from the Eastern Caribbean: growth history and implications on the value of nodules as paleoenvironmental indicators. Palaios, v. 3, p. 424-435.

Revelle, R., *ed*., 1990. Sea Level Change: National Research Council, Studies in Geophysics. Washington, D.C., National Academy Press, 234 p.

Rigby, J. and Roberts, H., 1976. Geology, Reefs and Marine Communities of Grand Cayman Island, British West Indies. Brigham Young University Geological Studies Special Publication, v. 4, p. 1-95.

Roberts, H., 1976. Carbonate Sedimentation in a Reef-Enclosed Lagoon, North Sound, Grand Cayman Island. Brigham Young University Geological Studies Special Publication, v. 4, p. 97-122.

Ruiz, H., Gonzalez, L.A., and Budd, A.F., 1991. Sedimentology and diagenesis of the Miocene Lirio Limestone, Isla de Mona, Puerto Rico, British West Indies. American Association of Petroleum Geologists Bulletin, v. 75, p. 664-675.

Sahagian, D., and Jones, M., 1993. Quantified Middle Jurassic to Paleocene eustatic variations based on Russian platform stratigraphy: stage level resolution. Geological Society of America Bulletin, v. 105, p. 1109-1118.

Sarg, J.F., 1988. Carbonate sequence stratigraphy *in* Sea-Level Changes: An Integrated Approach. Special Publication of the Society of Economic Paleontologists and Mineralogists, v. 42, p. 155-181.

Schlager, W., 1981. The paradox of drowned reefs and carbonate platforms. Geological Society of America Bulletin, v. 92, no. 4, p. 197-211.

Scholle, P., 1978. A Colour Illustrated Guide to Carbonate Rock Constituents, Textures, Cements and Porosities. American Association of Petroleum Geologists Memoir 27, 241 p.

Scoffin, T.P., Stoddart, D.R., Tudhope, A.W., and Woodroffe, C., 1985. Rhodoliths and coralliths of Muri Lagoon, Rarotonga, Cook Islands. Coral Reefs, v. 4, p. 71-80.

Scoffin, T.P., 1990. An Introduction to Carbonate Sediments and Rocks. Blackie, Glasgow, 274 p.

Selley, R.C., 1985. Ancient Sedimentary Environments. Ithaca Press, New York, 483 p.

Shourie, A., 1993. Depositional Architecture of the Late Pleistocene Ironshore Formation, Grand Cayman, British West Indies. Unpublished M.Sc. thesis, University of Alberta, Edmonton, 100 p.

Sibley, D.F., 1982. The origin of common dolomite fabrics: clues from the Pliocene. Journal of Sedimentary Petrology, v. 52, no. 4, p. 1087-1110.

Sibley, D.F. and Gregg, J.M., 1987. Classification of dolomite rock textures. Journal of Sedimentary Petrology, v. 57, no. 6, p. 967-975.

Squair, C.A., 1988, Surface Karst on Grand Cayman Island, British West Indies. Unpublished M.Sc. thesis, University of Alberta, Edmonton, 107 p.

Stanley, D.J., 1988. Deep-sea current flow in the Late Cretaceous Caribbean: measurements on St. Croix, U.S. Virgin Islands. Marine Geology, v. 70, p. 127-133.

Stoddart, D., 1980. Geology and geomorphology of Little Cayman. Atoll Research Bulletin, v. 241, p. 11-16.

Suess, E., 1906. The Face of the Earth. Oxford, Clarendon, 759 p.

Tucker, M., and Wright, V., 1990. Carbonate Sedimentology. Blackwell Scientific Publications, Oxford, 482 p.

Vail, P., Mitchum, R., and Thompson, S., 1977. Seismic stratigraphy and global changes of sea level, part IV: global cycles of relative changes in sea level, *in* Payton, C., *ed.*, Stratigraphic Interpretation of Seismic Data. America Association of Petroleum Geologists, p. 83-97.

Vaughan, T., 1926. Species of *Lepidocyclina* and *Carpenterea* from the Cayman Islands and their geological significance. Quarterly Journal of the Geological Society of London, v. 82, p. 388-400.

Venec-Peyre, M.T., 1991. Distribution of living benthic foraminifera on the back-reef and outer slopes of a high island (Moorea, French Polynesia). Coral Reefs, v. 9, p. 193-203.

Vézina, J., 1997. Stratigraphy and sedimentology of the Pleistocene Ironshore Formation at Roger's Wreck Point, Grand Cayman: a 400 ka record of sea-level highstands. Unpublished M.Sc. thesis, University of Alberta, Edmonton, 131 p.

Wells, J.W., 1967. Corals as bathometers. Marine Geology, v. 5, p. 349-365.

Wetzel, R.G., 1983. Limnology. Saunders College Publishing, Chicago, 760 p.

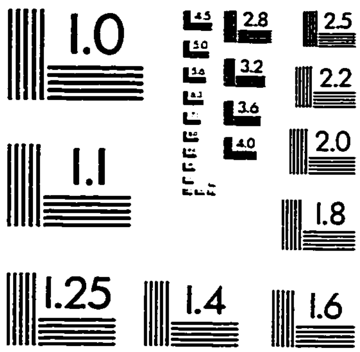
Wignall, B.W., 1995. Sedimentology and diagenesis of the Cayman (Miocene) and Pedro Castle (Pliocene) Formations at Safe Haven, Grand Cayman, British West Indies. Unpublished M.Sc. thesis, University of Alberta, Edmonton, 110 p.

Wilgus, C.K., Hastings, B.S., Posamentier, H.W., Ross, C.A. and Kendall, C.G.St.C., *eds*., 1988. Sea Level Changes: An Integrated Approach: Society of Economic Paleontologists and Mineralogists, Special Publication, v. 42, 407 p.

Woodley, J.D., 1992. The incidence of hurricanes on the north coast of Jamaica since 1870: are the classic reef descriptions atypical? Hydrobiologia, v. 247, p. 133-138.

Wray, J.L., 1977. Calcareous Algae. Elsevier Scientific Publications, New York, 185 p.

IMAGE EVALUATION TEST TARGET (QA-3)



150mm

6″

APPLIED IMAGE . Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989