UNIVERSITY OF ALBERTA

DEPOSITIONAL ARCHITECTURE OF THE LATE PLEISTOCENE IRONSHORE FORMATION, GRAND CAYMAN, BRITISH WEST INDIES

by

ANURAG SHOURIE

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled DEPOSITIONAL ARCHITECTURE OF THE LATE PLEISTOCENE IRONSHORE FORMATION, GRAND CAYMAN, BRITISH WEST INDIES submitted by ANURAG SHOURIE in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

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January 7, 1993

Dedicated to Dr. Brian Jones,

without whose supervision this work was impossible, and

to my mother and father, without whose efforts and support,

even the thought of this degree

could not cross my mind.

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ABSTRACT

Limestones of the Pleistocene Ironshore Formation of Grand Cayman were deposited approximately 125,000 years ago when the Sangamon highstand was about +6 m above present day sea level. The variable thickness of the formation (0 m to 13.7 m) reflects the fact that it was deposited on the uneven topography that had developed on the underlying Tertiary rocks prior to the Late Pleistocene. The thickest part of the formation occurs on the central part of western Grand Cayman.

The Ironshore Formation is a shallowing upward sequence. Sample availability meant that it was divided into Division X (base of formation to -4 m), Division Y (-4 m to +2 m) and Division Z (+2 m to +6 m). Divisions X and Y are formed of subtidal deposits whereas Division Z is formed of shallow subtidal to upper intertidal deposits.

Subtidal deposits of the Ironshore Formation developed in the Ironshore Lagoon which covered the western half of Grand Cayman. Although the maximum possible water depth was 20 m, most deposition occurred in water less than 10 m deep. The Inner Lagoon, Patch Reef Zone, and Reef Tract were main depositional regimes that existed in the Ironshore Lagoon. The Inner Lagoon, characterized by low-energy, shallow-water conditions, had a muddy seafloor stabilized by *Thalassia*. Bivalves, gastropods, and foraminifera were common in this area. The Patch Reef Zone was characterized by ovate patch reefs, up to 300 m long, formed of a diverse coral and bivalve fauna. The areas between the patch reefs were covered by skeletal sands that were extensively bioturbated. The Reef Tract, which delineated the western margin of the Ironshore Lagoon, was formed of a diverse array of corals.

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CHAPTER 1
INTRODUCTION

Approximately 125,000 years ago, sea level was about 6 m above the present-day sea level (Matthews, 1973; Steinen *et al.*, 1973; Neumann and Moore, 1975; Szabo *et al.*, 1978; Harmon *et al.*, 1981; Woodroffe *et al.*, 1983; Carew *et al.*, 1984; Brasier and Donahue, 1985; and Woodroffe, 1988). As a result, many Caribbean islands such as Grand Cayman, Cayman Brac, and Little Cayman were partially submerged and widespread shallow water carbonate deposition occurred. On Grand Cayman, for example, limestones of the Ironshore Formation were deposited on the irregular topography produced by the erosion of the underlying Bluff Formation between the Middle Miocene to Late Pleistocene times. These deposits formed a gradual shallowing upward sequence that now constitutes the Ironshore Formation. The Ironshore Formation was made up of a number of different facies. Past analyses of this formation have used many different facies schemes in order to determine the depositional conditions under which the limestones developed. It is now appropriate to reconsider this work in view of the large data base that is now available.

Although the general facies framework of the Ironshore Formation of Grand Cayman has been differentiated by Hunter and Jones (1989), a detailed analysis of the facies and a comprehension of the paleogeography of the Ironshore is still required. It is essential to make a detailed investigation of the depositional conditions e.g. water temperature, salinity, clarity of water, substrate types present in the 'Ironshore Lagoon' at the time of the deposition of the Ironshore Formation by studying similar present day samples in order to reconstruct the environments of deposition of the varied facies.

This study will comprise and elucidate upon the following:

1. integration of lithological and biological data obtained from examination of samples collected from the Ironshore Formation,

2. analysis of thin sections in order to delineate the different facies of the Ironshore Formation,
3. classification of facies,
4. distribution of lithofacies,
5. distribution of biofacies, and
6. interpretation of depositional conditions prevalent during the Sangamon highstand (Pleistocene) that occurred on Grand Cayman approximately 125,000 years ago.

LOCATION OF CAYMAN ISLANDS

The Cayman Islands, which consist of Grand Cayman, Cayman Brac, and Little Cayman, are situated south of Cuba and north-northwest of Jamaica (Fig. 1.1). These islands are prominences on the asymmetrical Cayman Ridge, that stretches westwards from the Sierra Maestra range of southwestern Cuba to the Misteriosa bank (Brunt *et al.*, 1973).

Grand Cayman, the largest of the Cayman Islands (Fig 1.1), is 35 km long (east-west) and 6 km wide in the east and 14 km wide in the west. Most of the island is less than 3 m above sea level with a maximum elevation of 18 m. Cayman Brac and Little Cayman are located approximately 95 km northeast of Grand Cayman (Fig. 1.2). Cayman Brac is 19.5 km long and 3.2 km wide with a maximum elevation of about 45 m whereas Little Cayman is 16 km long and 3 km wide with a maximum elevation of 10 m.

TECTONIC SETTING

The Cayman Ridge separates the Cayman Trench in the south from the Yucatan Basin in the north (Fig. 1.3). Although a shallow carbonate bank started building on the top of the Cayman Ridge, it began to subside in the Oligocene to Miocene (Emery and Milliman, 1980; Perfit and Heezen, 1978). Rates of subsidence ranged from 6 cm/1000 yr. (Perfit and Heezen, 1978) to 10 cm/1000 yr. (Emery and Milliman, 1980).

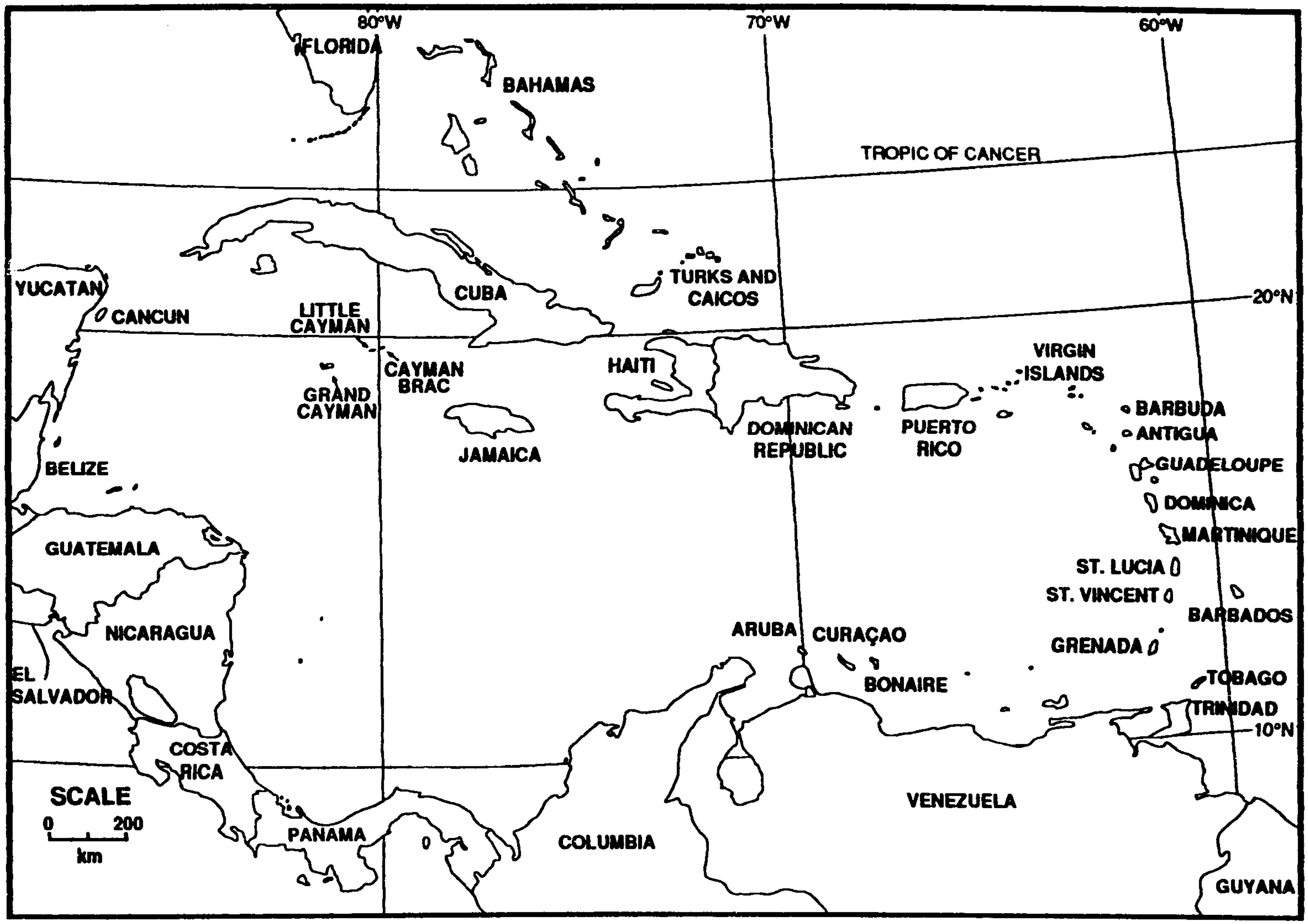


Figure 1.1: Location Map of the Cayman Islands.

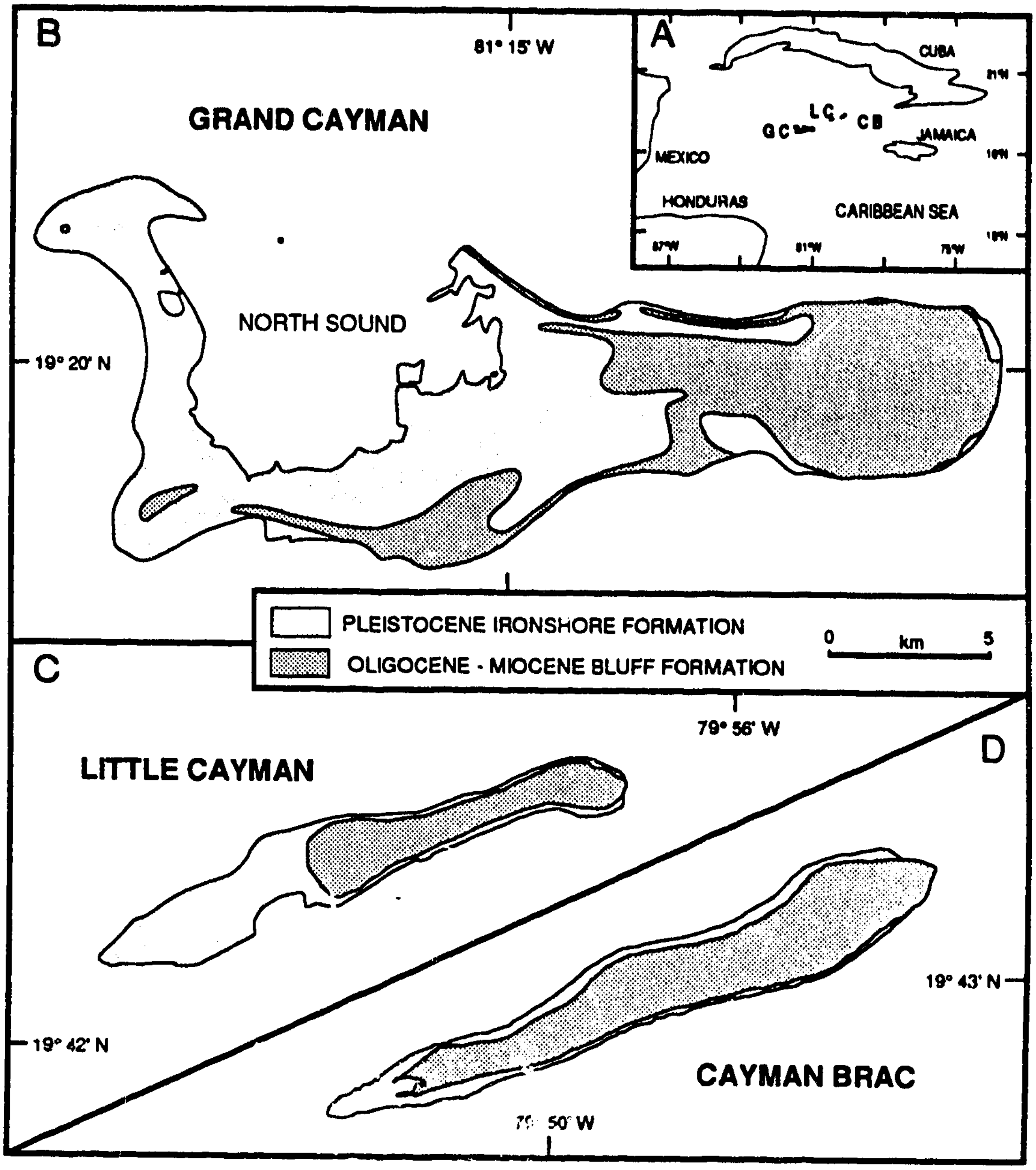


Figure 1.2: (A) Location map showing the Cayman Islands, Grand Cayman (GC), Little Cayman (LC), and Cayman Brac (CB). B, C, and D) Outcrop maps of Grand Cayman, Little Cayman, and Cayman Brac respectively (modified from Matley, 1926; Hunter and Jones, 1989b; Jones and Hunter, 1990).

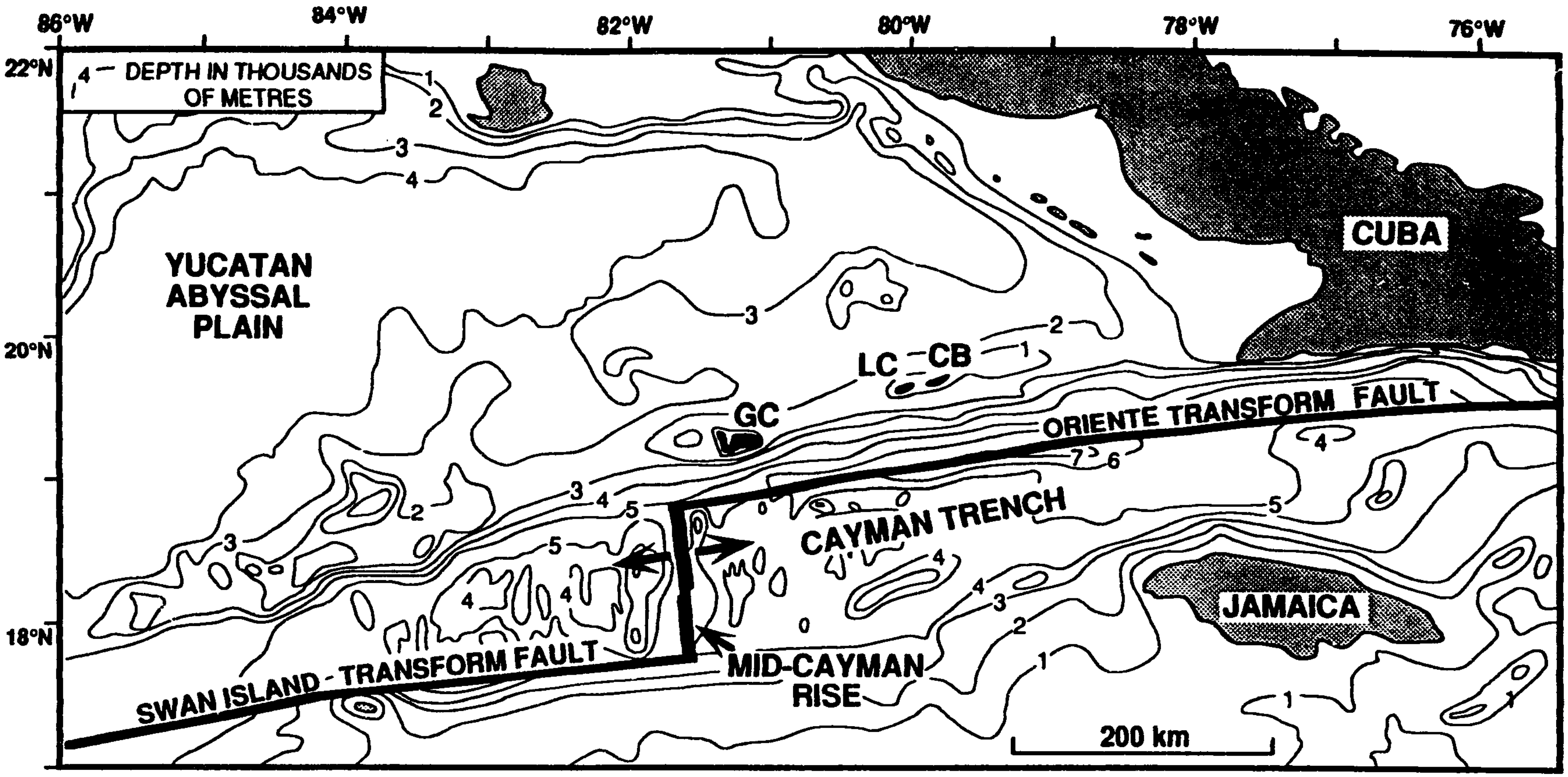


Figure 1.3: Tectonic Setting of the Cayman Islands (modified from Pleydell *et al.*, 1990 and based on information in Perfit and Heezen (1978) and MacDonald and Holcombe (1978).

After Middle Miocene times, the Swan Islands, Cayman Islands, Jamaica, and most of southern Cuba were uplifted due to localized vertical movements, while faulting and subsidence continued in nearby areas (Perfit and Heezen, 1978). Differential vertical tectonic movement continually affected the fault blocks on which the Cayman Islands occur until the last interglacial period (Woodroffe *et al.*, 1983). Since that time, they have undergone little vertical movement (Jones and Hunter, 1990).

The Cayman Islands lie on a base of granodiorite that is overlain by basalts and Tertiary carbonates (Emery and Milliman, 1980; Stoddart, 1980). Granodiorites outcrop at depths of 600 to 3400 m on the Oriente slope to the south of Grand Cayman (Emery and Milliman, 1980; Stoddart, 1980). The thickness of the entire carbonate succession is not yet known.

GENERAL GEOLOGY

Each of the Cayman islands has a core formed of the Oligocene-Miocene Bluff Formation that is unconformably surrounded and overlain by the Pleistocene Ironshore Formation (Fig. 1.2).

Matley (1924, 1925a, 1925b) originally named the Bluff Limestone because it formed bluffs or cliffs. Recent studies by Jones *et al.* (1984), Pleydell (1987) and Pleydell and Jones (1988) demonstrated, however, that most of the formation is formed of dolostone. As a result, Jones and Hunter (1989) suggested the name 'Bluff Formation' should be used in order to avoid the lithological connotation attached to the original name.

The Bluff Formation is divided into the Cayman (Oligocene) and Pedro Castle (Miocene) members by a disconformity. The Cayman Member, which crops out over most of Grand Cayman (Fig. 1.2), consists of extremely hard, dense microcrystalline dolostone that gives a metallic sound when struck with a hammer. These dolostones contain branching and massive corals, gastropods, bivalves, red algae, rhodolites, and foraminifera. The Pedro Castle Member is formed of slightly softer dolostones that contain free-living corals, foraminifera and rhodolites, along with lesser numbers of red algae, colonial corals, bivalves, and echinoids (Jones and Hunter, 1989).

In all of the Bluff Formation, leaching of coral, bivalve, gastropod skeletons, and a few foraminifera resulted in the formation of excellent fossil moldic porosity (up to 25%).

The Ironshore Formation was named by Matley (1924, 1925a, 1925b) after the local Caymanian term for the hard rocky type of shore formed on these calcareous rocks of the coastal platform. Idyll (1966) considered this name 'highly appropriate' because of the dark iron grey colour of the formation. On Grand Cayman, the Ironshore Formation is about 8 m thick on the south shore of North Sound but about 17m thick west and south of Georgetown (Brunt *et al.*, 1973).

Hunter and Jones (1988) suggested that the Ironshore Formation was laid down during the Sangamon sea level highstand (+6m a.s.l.) about 125,000 years ago. Most of it was deposited in the Ironshore Lagoon (Hunter and Jones, 1988) that covered the western half of Grand Cayman (Fig. 1.4). Similar limestones were also deposited in small embayments on the eastern and southern coasts. According to Jones and Pemberton (1989), this formation correlates with the Miami and Key Largo limestones of Florida that are 120,000 to 130,000 years as dated by Osmond *et al.* (1965) and Broecker and Thurber (1965).

The age of the Ironshore Formation has been determined to be 124,000 ± 8000 years by Woodroffe *et al.* (1983) who used U-series dating techniques on four coral samples from the upper part of this formation. The age of the base of this formation is still unknown.

MATERIALS AND METHODS OF STUDY

There are relatively few good exposures of the Ironshore Formation on the western part of Grand Cayman where the land is usually less than 2 m above sea level. Most of the land is covered by mangrove swamps. Therefore, most samples came from coastal exposures along the southwestern and northwestern coasts, Botabano and Paul Bodden's quarries,

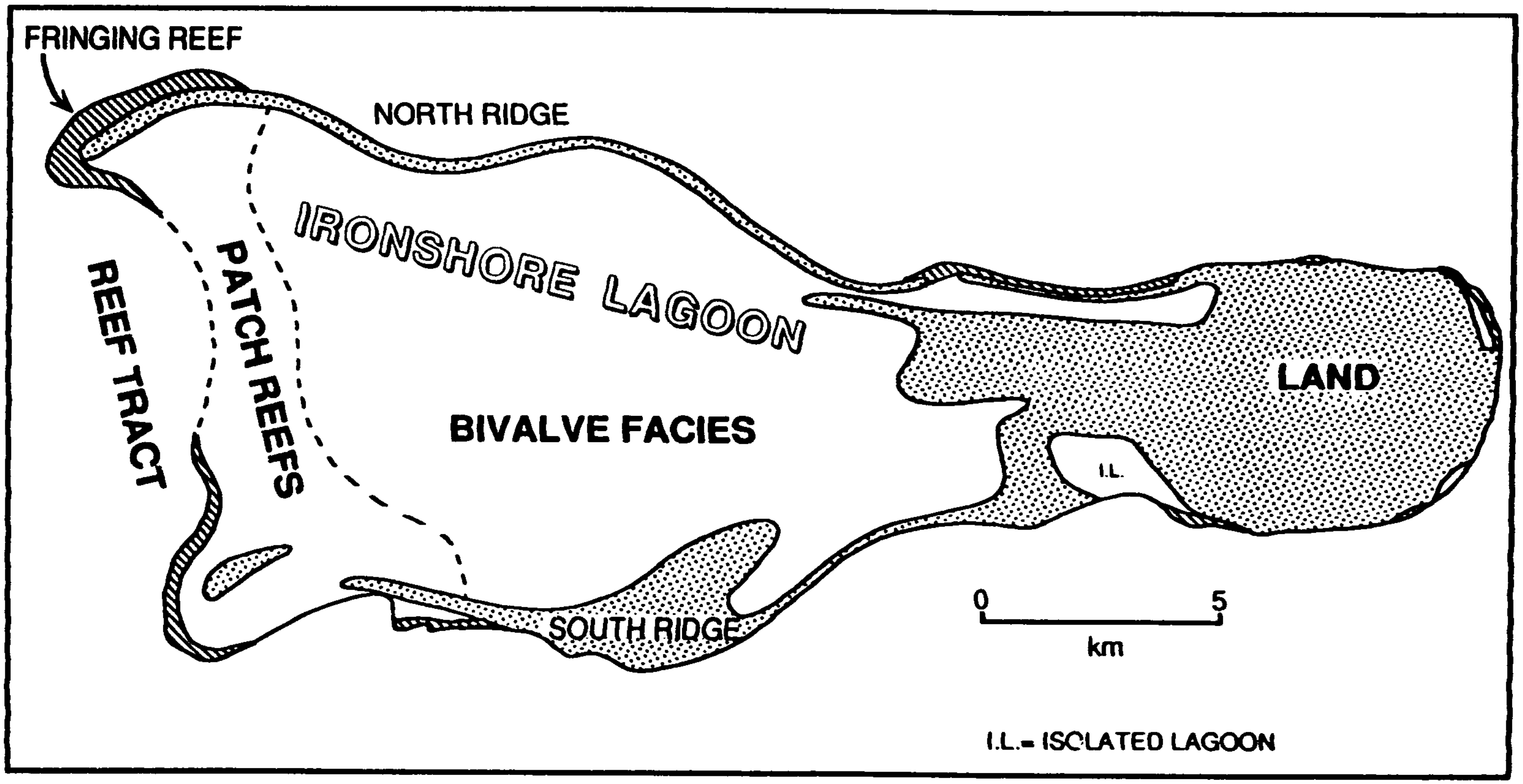


Figure 1.4: Paleogeography of the Ironshore Formation on Grand Cayman, British West Indies (*modified from Hunter and Jones, 1988*).

and outcrops on the west side of North Sound (Figs. 1.4, 1.5). Additional samples came from material excavated during the construction of drainage canals on central and western Gr ... Cayman. This study is based on:

1. ...proximately 1400 samples collected by Hunter, Jones, and other co-workers from 144 localities on various parts of Grand Cayman (Fig.1.5),
2. one hundred and thirty seven thin-sections made from samples from 87 localities that were used to determine the allochem content and matrix type in the various facies that occur in the Ironshore Formation,
3. measured sections from Salt Creek (SC), Little Salt Creek (LSC), Botabano Quarry (BQ), and Paul Bodden Quarry (PBQ, PBA – Fig. 1.5), and
4. cross sections depicting facies changes along east to west, north to south and in the central part of Grand Cayman.

Skeletal grain types were determined from thin section microscopy by comparison with thin sections of known skeletal material and descriptions provided by Scholle (1978) and Bathurst (1975). A visual estimate of the percentages of different skeletal types present was made in order to determine their relative distributions throughout the Ironshore Formation on Grand Cayman. Analysis of the percentages of skeletal types, grain size, sorting, the nature of the matrix and the different types of cements permitted identification of the different facies in the Ironshore Formation.

This study also incorporates and builds upon data obtained from the previous studies of facies (Brunt *et al.*, 1973; Woodroffe *et al.*, 1980; Jones and Goodbody, 1984; Hunter and Jones, 1988; Jones and Pemberton, 1989; Hunter and Jones, 1989a, 1989b; Jones and Hunter, 1990), corals (Hunter and Jones, 1988; Jones and Pemberton, 1988; Jones and Hunter, 1991), bivalves (Cerridwen, 1989; Cerridwen and Jones, 1991), trace fossils (Pemberton and Jones, 1988; Jones and Pemberton, 1989), and stratigraphy (Matley, 1926; Jones and Hunter, 1990). This is done so that a more comprehensive paleogeographic picture of the Ironshore Formation can be obtained.

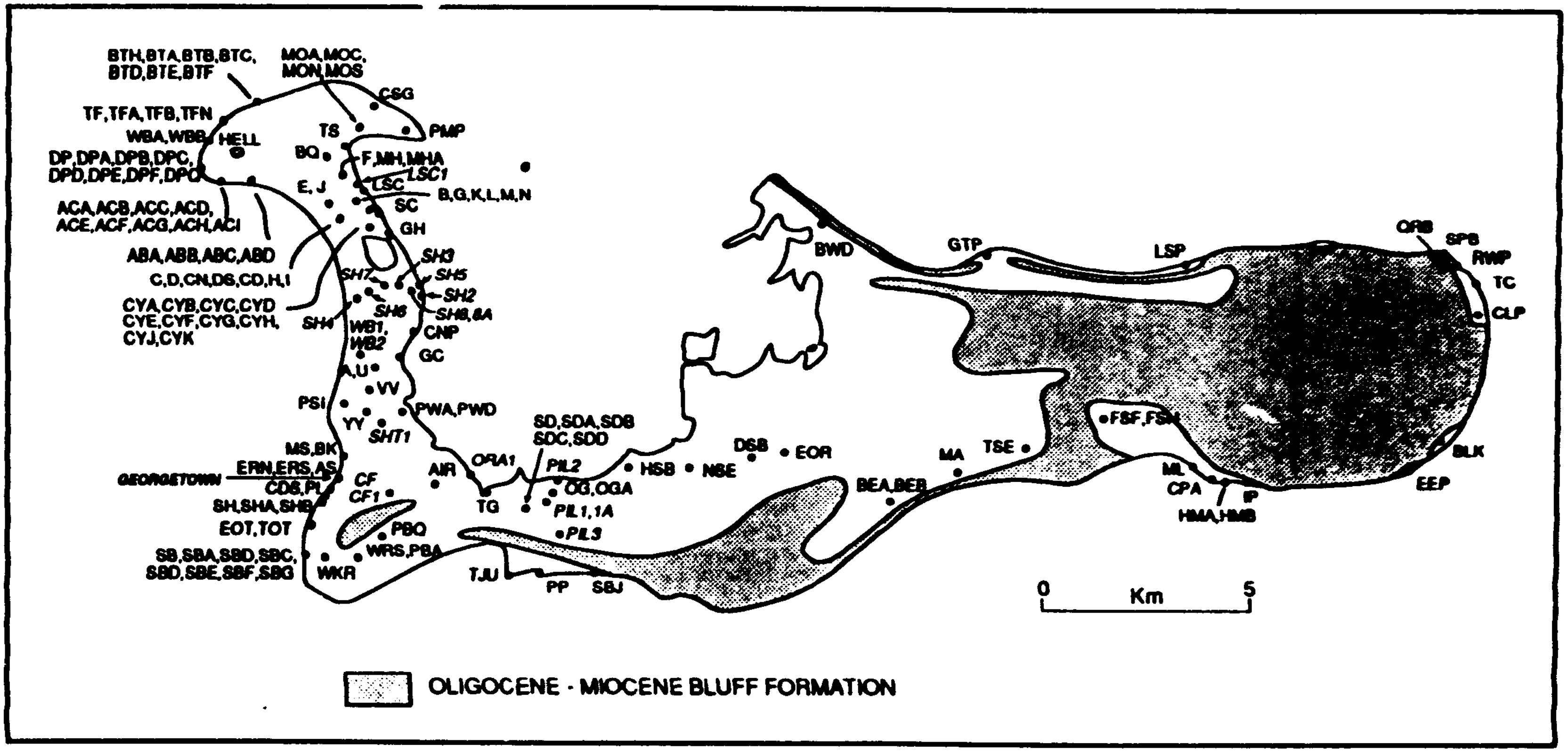


Figure 1.5: Locations of Pleistocene Outcrops and well locations on Grand Cayman (modified from Hunter and Jones, 1989b).

CHAPTER 2
REVIEW OF PREVIOUS STUDIES

The facies and other aspects of sedimentology of the Ironshore Formation on Grand Cayman have been studied and discussed by Brunt *et al.* (1973), Rigby and Roberts (1976), Woodroffe *et al.* (1980), Jones and Goodbody (1984), Hunter and Jones (1988; 1989b), Jones and Pemberton (1989), and Jones and Hunter (1990). Each study was designed with specific objectives in mind. As a result, the facies classification developed for this purpose varied from study to study (Table 2.1). Such variation is evident in the scale, name, and definition of the facies that were employed. Consequently, it is necessary to review these schemes in order to obtain an understanding of the current level of knowledge.

FACIES OF THE IRONSHORE FORMATION

Matley (1924, 1925a, 1925b, 1926) provided a brief description of the Ironshore Formation and recorded 11 species of molluscs including *Strombus gigas*, *Bullaria striata* and *Chione cancellata*. No further work was done on this formation until Richards (1955) added 8 species of molluscs to the list produced by Matley (1926). Rehder (1962), later expanded this list by incorporating another 31 species. Even that list was an underestimation of the total molluscan fauna because Cerridwen (1989) and Cerridwen and Jones (1991) described 83 species of marine bivalves and 90 species of marine gastropods from the Ironshore Formation on Grand Cayman.

Brunt *et al.* (1973) divided the Ironshore Formation of Grand Cayman (Fig. 2.1) into the (1) *Lagoonal Facies*, (2) *Back Reef Facies*, (3) *Reef Facies*, (4) *Shoal Facies*, and (5) *Beach Ridge Facies*. These facies were named according to their inferred depositional environments.

BRUNT ET. AL 1973	WOODROFFE ET. AL 1980	JONES AND GOODBODY 1984	HUNTER AND JONES 1988	JONES AND PEMBERTON 1989	HUNTER AND JONES 1989a	HUNTER AND JONES 1989b	JONES AND HUNTER 1990	THIS STUDY
LAGOONAL FACIES	N/A	N/A	BIVALVE FACIES	N/A	FACIES A	BIVALVE A	BIVALVE FACIES	PENEROPLID-MILIOLID BIVALVE WACKESTONE / PACKSTONE FACIES
				N/A	FACIES B	BIVALVE B		NUMMULITID-BIVALVE WACKESTONE / PACKSTONE FACIES
								POORLY SORTED HALIMEDA-BIVALVE WACKESTONE / PACKSTONE FACIES
								PELOIDAL-BIVALVE WACKESTONE / PACKSTONE FACIES
	CORAL BEARING FACIES	N/A	LAGOONAL ENVIRONMENT; PATCH REEFS	N/A	FACIES C	CORAL A	CORAL FACIES A	CORAL A FLOATSTONE / FRAMESTONE FACIES
								HALIMEDA-CORAL FLOATSTONE / FRAMESTONE FACIES
	LAGOONAL FACIES			N/A	FACIES D	SKELETAL GRAINSTONE	LAMINATED TO HIGHLY BURROWED GRAINSTONE	POORLY SORTED SKELETAL GRAINSTONE / PACKSTONE FACIES
REEF FACIES / BACK-REEF FACIES	N/A	N/A	REEF TRACT	N/A	FACIES E	CORAL B	CORAL FACIES B	CORAL B FLOATSTONE / FRAMESTONE FACIES
N/A	N/A	N/A		N/A	FACIES F	WELL SORTED SKELETAL GRAINSTONE		WELL SORTED SKELETAL GRAINSTONE FACIES
SHOAL FACIES	OOLITIC FACIES	FACIES B	OOID FACIES	FACIES A / FACIES B	FACIES G	MODERATELY BURROWED GRAINSTONE	LAMINATED TO HIGHLY BURROWED GRAINSTONE	MODERATELY BURROWED OOID GRAINSTONE FACIES
		FACIES A		FACIES C		HIGHLY BURROWED GRAINSTONE		HIGHLY BURROWED OOID GRAINSTONE FACIES
		FACIES C		FACIES D		UNIDIRECTIONAL CROSS-BEDDED GRAINSTONE	UNIDIRECTIONAL HIGH-ANGLE CROSS-BEDDED GRAINSTONE	UNIDIRECTIONAL CROSS-BEDDED OOID GRAINSTONE FACIES
		N/A		FACIES E		MULTIDIRECTIONAL CROSS-BEDDED GRAINSTONE	MULTIDIRECTIONAL HIGH-ANGLE CROSS-BEDDED GRAINSTONE	MULTIDIRECTIONAL CROSS-BEDDED OOID GRAINSTONE FACIES
				FACIES F		LITHOCLAST RUDSTONE	RUDSTONE	LITHOCLAST RUDSTONE FACIES
				FACIES G		BIOCLAST FLOATSTONE		BIOCLAST FLOATSTONE FACIES
				N/A		LAMINATED GRAINSTONE	LAMINATED TO LOW-ANGLE CROSS-BEDDED GRAINSTONE	LAMINATED OOID GRAINSTONE FACIES

Table 2.1: Correlation of different facies of the Ironshore Formation of Grand Cayman identified in previous studies.

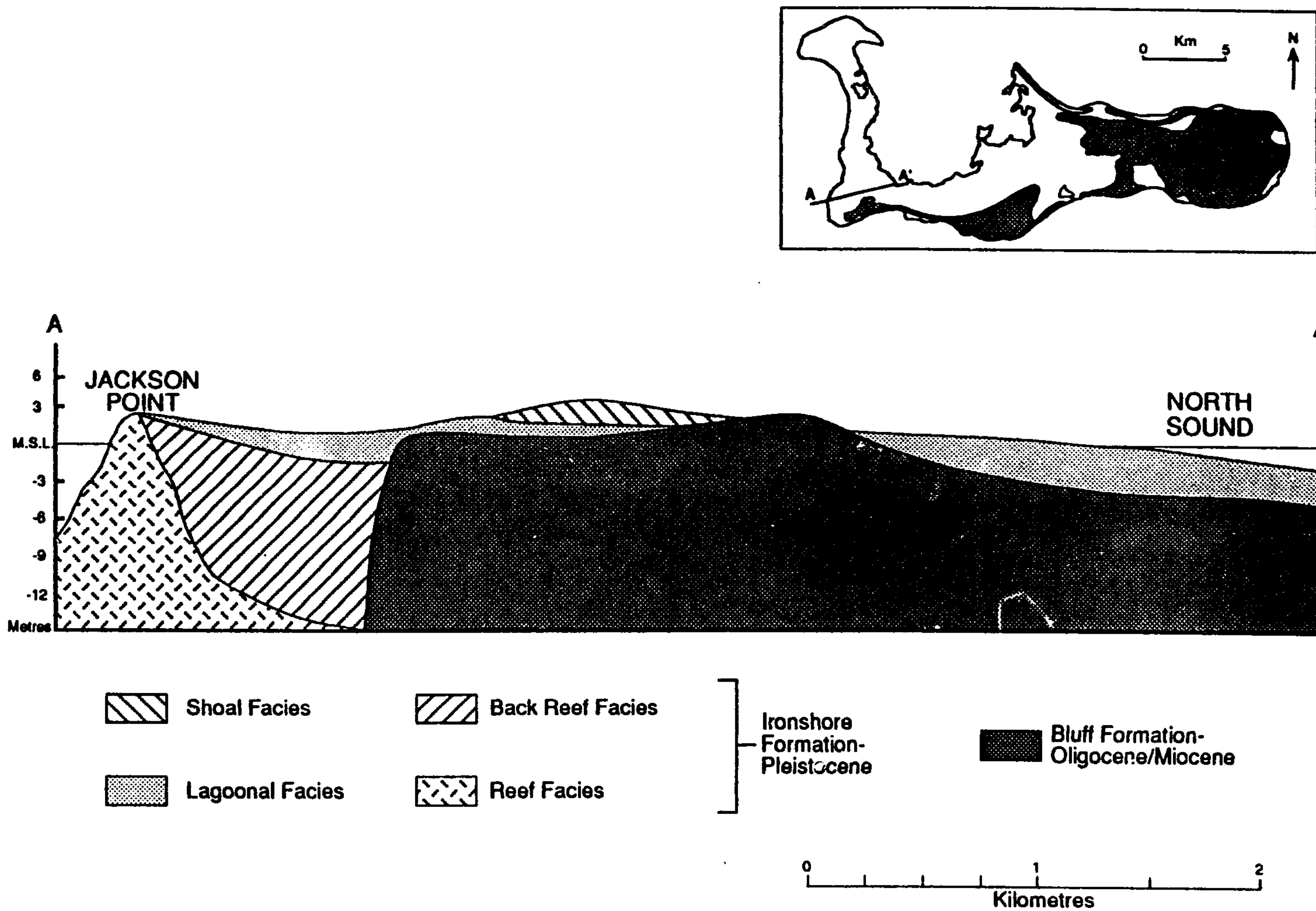


Figure 2.1: Geological cross-section along A – A' depicting the various facies of the Ironshore Formation on Grand Cayman (modified from Brunt *et al.*, 1973).

The *Lagoonal Facies*, known locally as 'marl', is formed of very poorly indurated and poorly sorted chalky limestones that contain a diverse assemblage of well preserved molluscs and locally, a few small silt, sand, and cobble-sized coral fragments.

The *Reef Facies*, formed predominantly of *Acropora* and *Porites* held in a matrix of coral detritus is geographically flanked by a *Back Reef Facies* consisting of *Siderastrea siderea, Montastrea annularis*, and *Diploria clivosa* in a bioclastic sandy matrix.

The *Shoal Facies*, which overlies the *Lagoonal Facies*, is formed of cross-bedded oolitic limestones that contain cylindrical casts of roots and burrows. It is overlain by the *Beach Ridge Facies* that is formed of cross-bedded oolitic calcarenites that also contain root casts and burrows.

No further work was done until Woodroffe *et al.* (1980) divided the Ironshore Formation of Salt Creek area (Fig. 2.2) into the *Oolitic, Lagoonal*, and *Coral Bearing Facies*. The *Lagoonal* and *Coral Bearing Facies* were divisions of the *Lagoonal Facies* of Brunt *et al.* (1973). The *Coral Bearing Facies*, formed of relatively more consolidated rocks than the silts and sands of the *Lagoonal Facies*, contained corals such as *Montastrea, Siderastrea, Diploria*, and *Colpophyllia* sp. along with lesser numbers of *Porites* and *Agaricia*. Woodroffe's *Oolitic Facies*, which correlated with the *Shoal Facies* of Brunt *et al.* (1973), consisted of poorly lithified and cross-bedded ooids cemented by calcite. Jones and Goodbody (1984), who suggested that the ooids from the area around Salt Creek may have formed in quiet water conditions, divided the *Oolitic Facies* of Woodroffe *et al.* (1980) into *Facies A, B, and C* (Fig. 2.3). Each facies consisted of oolitic limestones with *Facies B* being locally cross-bedded and less bioturbated than *Facies A*. *Facies B* also exhibits planar bedding and laminations. *Facies C*, laterally replacing *Facies B*, consisted of cross-bedded oolitic limestones with a few burrows and clasts at its base.

Hunter and Jones (1989b) divided the Ironshore Lagoon into the (1) *Bivalve Facies*, (2) *Ooid Facies*, (3) *Patch Reef and Inter-reef Facies*, and (4) *Reef Tract Facies* (Fig. 2.4, 2.5).

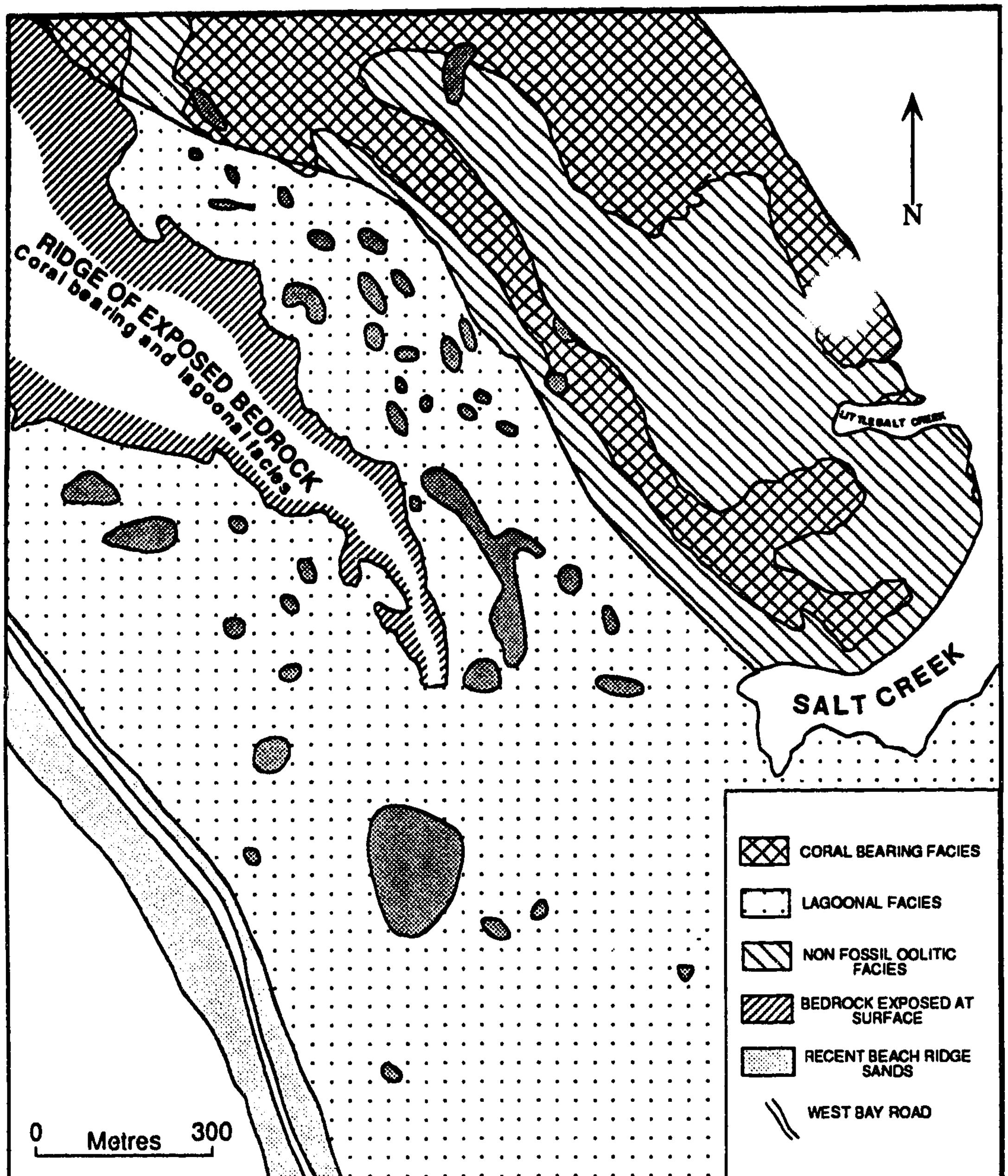


Figure 2.2: Distribution of Ironshore Formation facies in the Salt Creek area (modified from Woodroffe *et al.*, 1980).

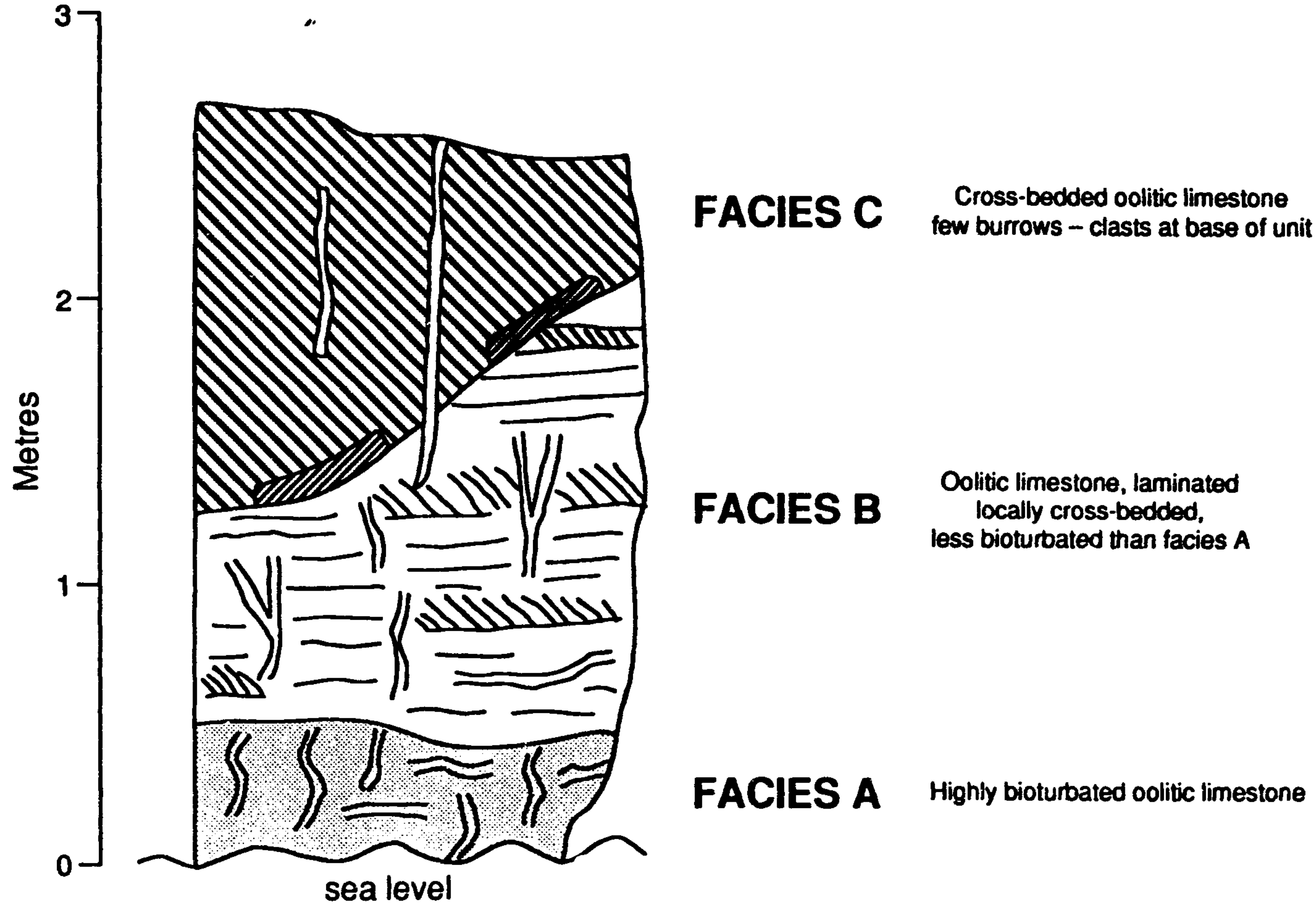


Figure 2.3: Schematic stratigraphic cross-section showing the relationship of facies A, B, and C in the Ironshore Formation south of Salt Creek (modified from Jones and Goodbody, 1984).

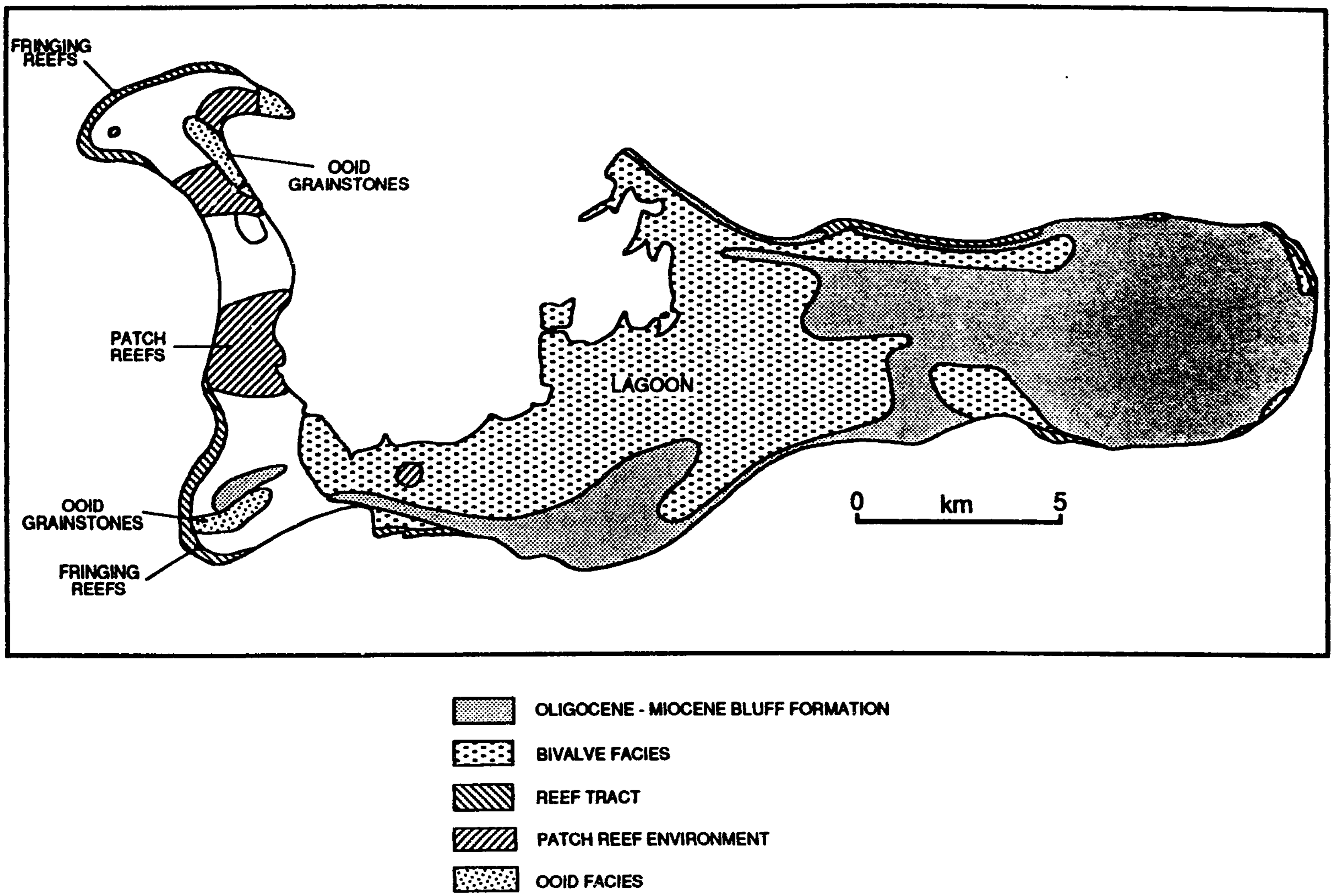


Figure 2.4: Facies of the Ironshore formation (modified from Hunter and Jones, 1989b).

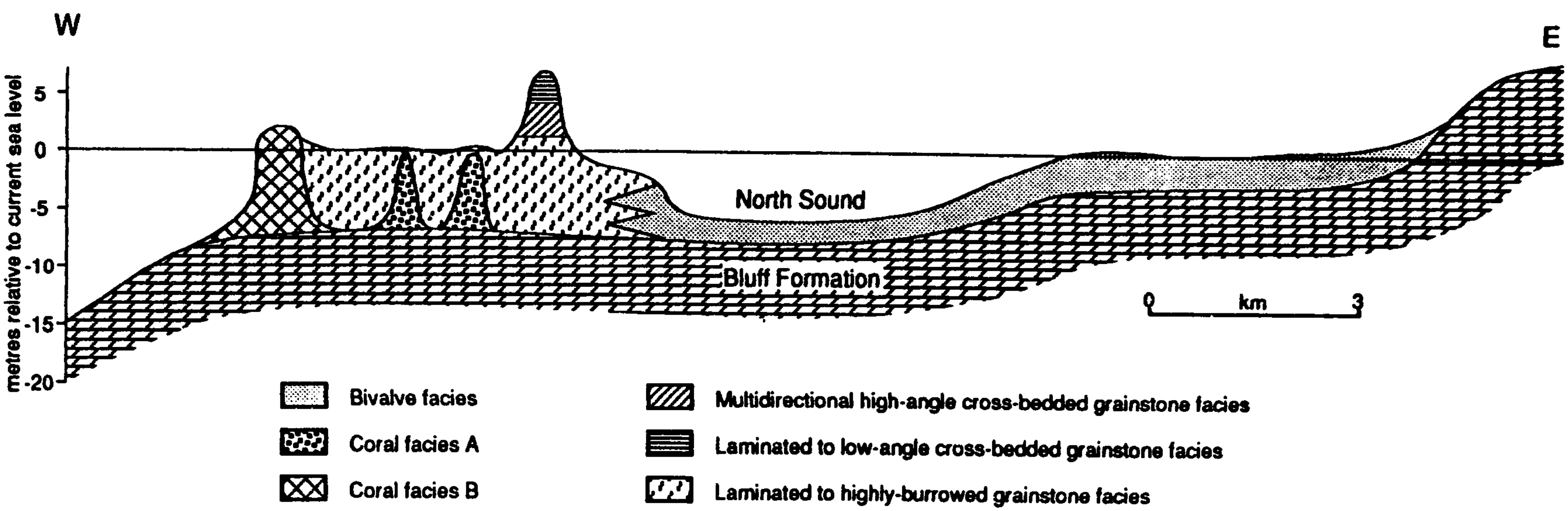


Figure 2.5: Schematic east-west cross-Section across the western half of Grand Cayman showing the lateral and vertical relationships of the main facies in the Ironshore Formation (modified from Jones and Hunter, 1990).

The *Bivalve Facies* consisted of carbonate silts and sands that contained abundant bivalves. It was divided into *Bivalve A* and *Bivalve B Facies* by Hunter and Jones (1989b) on the basis of grain size and the amounts of corals and foraminifera.

Stratigraphically overlying the *Bivalve Facies* were the *Ooid Facies* (*Shoal Facies* of Brunt *et al.* (1973) and *Oolitic Facies* of Woodroffe *et al.* (1980)) formed of oolitic limestones that contain abundant trace fossils (Pemberton and Jones, 1988; Jones and Pemberton, 1989).

In the western part of the Ironshore lagoon (Fig. 2.1), the *Patch Reef Facies* or *Facies C* of Hunter and Jones (1989a) is characterized by a large, diverse coral fauna that includes *Diploria* and *Montastrea* and bivalves such as *Arca* and *Chama*. The areas between these patch reefs were covered by carbonate sands and silts that contained numerous bivalves and trace fossils (*Ophiomorpha*, *Skolithos*, and *Polykladichnus*). This is *Facies D* of Hunter and Jones (1989a).

The *Reef Tract Facies*, formed of different coral communities from the reef, back reef, reef crest, and possibly, the shallow forereef environments, was divided into *Facies E* and *Facies F* by Hunter and Jones (1989a). It included *Montastrea, Diploria, Agaricia, Porites, Meandrina, Pocillopora*, and *Dendrogyra*. These facies were collectively called the *Coral B Facies* by Jones and Hunter (1990).

Further studies undertaken by Jones and Pemberton (1989) concentrated on the lithotype and sedimentary structures in the upper part of the Ironshore Formation exposed near Salt Creek. The seven facies used in that study (Fig. 2.6) were classified on the basis of lithotvpe, sedimentary structures, fossils, and trace fossils. These facies were divisions of the *Ooid Facies* of Hunter and Jones (1988), the *Oolitic Facies* of Woodroffe *et al.* (1980) and *Shoal Facies* of Brunt *et al.* (1973).

Facies A – oolitic limestone, probably of a lagoonal origin, characterized by low-angle to parallel laminations.

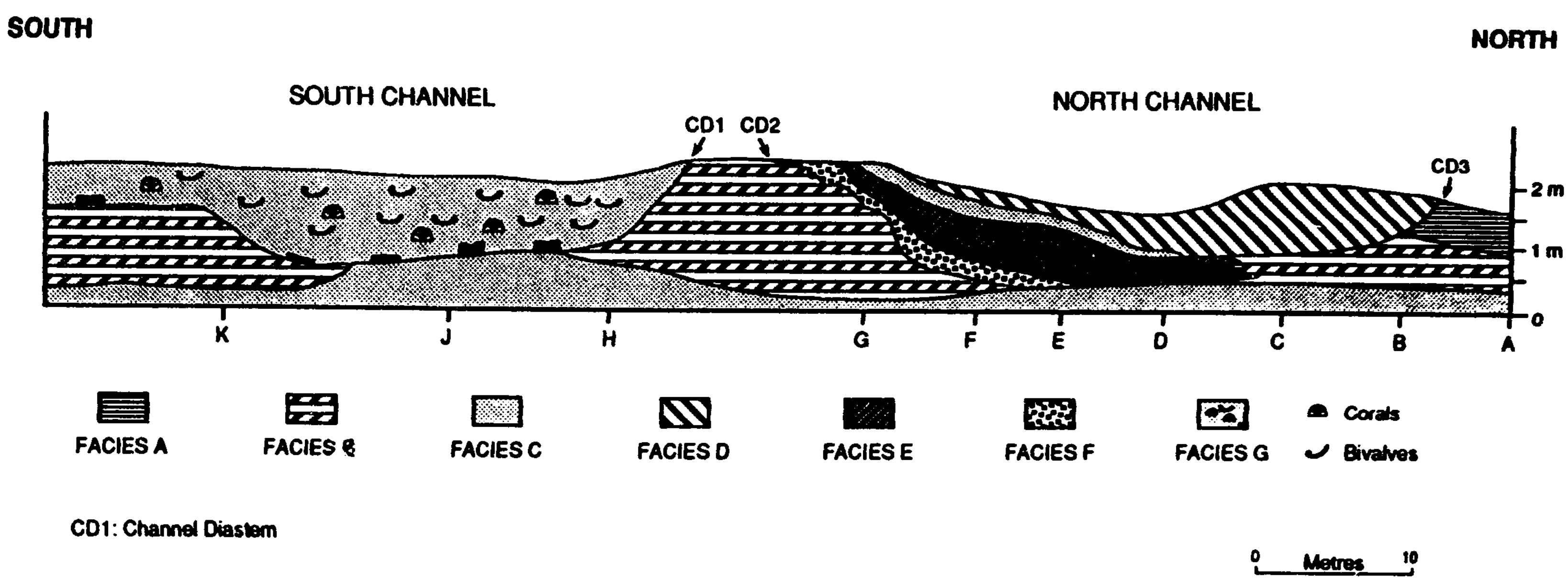


Figure 2.6: Cross-section of the upper part of the Ironshore Formation at Salt Creek showing the distribution of lithofacies (modified from Jones and Pemberton, 1989).

Facies B – oolitic limestone with low-angle to parallel laminations and cross-bedded, that probably originated in the same kind of lagoonal setting as *Facies A*.

Facies C – oolitic limestone, with oosparite as the dominant lithotype, that contains abundant *Ophiomorpha nodosa.*

Facies D – oolitic limestone exhibiting high angle cross-bedding and the presence of lithoclasts at the base.

Facies E – cross-bedded oolitic limestone displaying parallel laminations and passing laterally into *Facies B*.

Facies F – oolitic limestone with numerous large lithoclasts and an *Ophiomorpha-Polykladichnus-Skolithos* assemblage.

Facies G – high-angle cross-bedded oolitic limestone which contain a number of bioclasts (corals and bivalves) with intraclasts at the base. A few articulated and many disarticulated bivalves along with *Siderastrea siderea* occur in this facies. All of these facies were grouped in *Facies G* by Hunter and Jones (1989a).

Hunter and Jones (1989b) named *Facies A* through *G* of Jones and Pemberton (1989) in a different fashion (Fig. 2.4).

Facies A and *B* of Jones and Pemberton (1989) were included in the *Moderately Burrowed Grainstone Facies* whereas *Facies C* was renamed as the *Highly Burrowed Grainstone Facies* by Hunter and Jones (1989b). Both facies were deposited between the patch reefs on the western part of Grand Cayman. The *Unidirectional Cross-Bedded Grainstone Facies*, corresponding to *Facies D* of Jones and Pemberton (1989), was deposited in erosional channels cut into the *Multidirectional Cross-Bedded Grainstone Facies*. It contains numerous marine trace fossils.

The *Lithoclast Rudstone Facies* and *Bioclast Floatstone Facies*, exposed at Salt Creek (SC – Fig. 1.4), were deposited in erosional channels in the *Multidirectional Cross-Bedded Grainstone Facies*. These were *Facies F* and *Facies G* of Jones and Pemberton (1989). Hunter and Jones (1989b) also added the *Laminated Ooid Grainstone Facies* to the list.

This facies, which overlies the *Multidirectional Cross-Bedded Grainstone Facies*, considered to be a foreshore (beach) deposit, was deposited up to 5 m above present day sea level (Fig. 2.5).

In their most recent work, Jones and Hunter (1990) grouped the *Moderately* and *Highly Burrowed Grainstone Facies* into the *Laminated to Highly Burrowed Grainstone Facies* and the *Bioclast Floatstone* and *Lithoclast Rudstone Facies* into the *Rudstone Facies*.

CHAPTER 3
FACIES OF THE IRONSHORE FORMATION

INTRODUCTION

'Facies' is defined as the aspect, appearance, and characteristics of a rock unit, usually reflecting the conditions of its origin; especially as differentiating the unit from adjacent or associated units (Bates and Jackson, 1987). Brown (1943) used the term 'Microfacies' to encompass lithological and biological data evident in thin sections as seen under the microscope. Although supported by Calkins (1943), this term has since been used in different ways. Although Campbell (1944) and Ailling (1945) raised minor objections to the term, their hesitations were overlooked. Thus, Culliver (1952, 1958, 1961) based his microfacies on micropaleontological and petrographic features evident in thin sections. Fairbridge's (1954) attempt to separate these two criteria proved futile and the term was subsequently used by Cloud and Barnes (1957) for minor facies present within facies environments of larger dimensions. The definition of microfacies was broadened by Carozzi (1972, 1989) and Carozzi *et al.* (1976) to include features not visible under the microscope. Thus, he defined microfacies as the '...total of the mineralogic, paleontologic, textural, diagenetic, geochemical and petrophysical features of a carbonate rock'. Other workers, however, have used this term in a different fashion. For example, Shaw and Walton (1963) used this term to define mineral paragenesis (e.g. 'stress-controlled microfacies') whereas Ostry and Deane (1963) applied it to textures in sedimentary boulders (e.g. microfacies analysis of till.)

Flügel (1982, p. 1) defined microfacies as '...the total of all the paleontological and sedimentological criteria which can be classified into thin sections, peels, and polished slabs.'

In the words of Fairbridge (1954, p. 683), '...they (microfacies) display individual characteristics that may be traced over thousands of miles'.

Thin section analysis is of utmost importance for the identification of microfacies. The prerequisites for thin section analysis are fieldwork, with special emphasis being laid on facies criteria such as lithology, rock colours, bedding and lamination, sedimentary structures and textures, fossil content, stratigraphic relationships and geometry of the rock bodies (Flügel, 1982). The microfacies can then be grouped in order to interpret the depositional and ecological conditions in terms of sedimentary environments. This interpretation may lead to the recognition of the geology of a large scale or local area depending upon the number and extent of the area from which the samples were collected. Wilson (1975) designated 24 standard microfacies types, which he considered of prime sedimentological importance, based on the carbonate rock types of Dunham (1962) and Flügel (1972) later differentiated many basic microfacies types by considering sedimentological criteria in addition to the paleontologic criteria used by other European researchers.

In this study, the term facies includes all features evident in outcrop and thin section. This would assign a broader perspective to the differentiated facies and thus provide a simpler scheme of naming them. For example, a facies based on all the paleontological and sedimentological criteria visible in outcrop and under the microscope provides a simpler and clearer understanding of the large scale geology of an area. This is entirely a matter of scale.

FACIES

Seventeen facies have been delineated in the Pleistocene Ironshore Formation of Grand Cayman (Table 3.1). The facies are identified and classified into a hierarchical classification scheme through the use of a flow diagram (Fig. 3.1). This scheme allows the facies to be progressively grouped into larger entities that encompass deposits over wider areas.

LITHO-TYPE	ALLOCHEM TYPE	FACIES	LOCALITIES	SORTING	GRAIN SIZE	SEDIMENTARY STRUCTURES	FOSSILS: DOMINANT	FOSSILS: MINOR	FOSSILS: RARE	TRACE FOSSILS	ENVIRONMENT
GRAINSTONE TO PACKSTONE	SKELETAL	Well Sorted Skeletal Grainstone	ACF,ABB,ACB,TFB, SBB,SBD,MS	Good	Fine to Medium	N/O	Corals	Bivalves Red algae *Halimeda*	Foraminifera	N/O	Reef Channel
		Poorly Sorted Red Algae-Coral Grainstone/Packstone	ACF,QRD,SBD, ABB	Moderate to Poor	Fine to Coarse	N/O	Red Algae Bivalves	Gastropods Corals	*Halimeda* Echinoids	N/O	Reef Channel
		Poorly Sorted Skeletal Grainstone/Packstone	H,GC,U,SD,PWA, PWD,ABD,MOA, MOC,MON	Moderate to Poor	Fine to Coarse	Moderate Burrowing	None	Corals Bivalves Gastropods	*Halimeda* Red Algae Foraminifera	*Polykladichnus* *Skolithos*	Inter reef
	NON-SKELETAL (OOIDS)	Laminated Ooid Grainstone	LSC,PBQ,PBA,BQ, SBA	Good	Fine to Medium	Laminated to low-angle cross-bedding	None	None	None	None	Foreshore-Backshore
		Unidirectional Cross-Bedded Ooid Grainstone	SC	Good	Fine to Medium	Unidirectional high-angle cross-bedding, Low burrowing	None	None	None	*Polykladichnus* *Skolithos* *Conichnus* *Bergaueria* *Psilonichnus*	Subtidal
		Multidirectional Cross-Bedded Ooid Grainstone	SC,LSC,PBQ,PBA, PMP,SB,SBA,SBF, ACA,ACH,WRS,BQ, ABD,BLK	Good	Fine to Medium	Multidirectional high-angle cross-bedding, Moderate burrowing	None	None	None	*Ophiomorpha* *Skolithos*	Upper Shoreface
		Moderately Burrowed Ooid Grainstone	SC,L,M,N,PBQ,BQ, MHA,TS,DP,DPQ	Good	Fine to Medium	Laminated, Moderate burrowing	None	None	None	*Ophiomorpha* *Skolithos* *Polykladichnus* *Conichnus*	Subtidal
		Highly Burrowed Ooid Grainstone	SC,LSC,BQ,PBQ, PBA	Good	Fine to Medium	High burrowing	None	None	None	*Ophiomorpha* *Skolithos* *Polykladichnus* *Planolites*	Subtidal

Table 3.1: Facies of the Ironshore Formation, Grand Cayman, British West Indies.

LITHO-TYPE	ALLOCHEM TYPE	FACIES	LOCALITIES	SORTING	GRAIN SIZE	SEDIMENTARY STRUCTURES	FOSSILS: DOMINANT	FOSSILS: MINOR	FOSSILS: RARE	TRACE FOSSILS	ENVIRONMENT
WACKESTONE TO PACKSTONE	SKELETAL	Peneroplid-Miliolid Bivalve Wackestone/Packstone	MA,TSE	Poor	Silt to Very Fine	N/O	Bivalves Foraminifera	Gastropods	*Halimeda* Red Algae	N/O	Lagoon
		Nummulitid-Bivalve Wackestone/ Packstone	BEA,BEB,PCQ, NSE	Poor	Silt to Fine	N/O	Bivalves Foraminifera	Gastropods	*Halimeda* Red Algae	N/O	Lagoon
		Poorly Sorted *Halimeda*-Bivalve Wackestone/Packstone	TG,DSB,EOR,SDA, SDB,SDC,NSE, HSB,LSC	Moderate to Poor	Very Fine to Coarse	N/O	*Halimeda* Bivalves	Gastropods	Foraminifera Red Algae	N/O	Lagoon
	NON-SKELETAL (PELOIDS)	Peloidal-Bivalve Wackestone/ Packstone	BWD,MOS,B,GC, CNP,SDC,PWA, MOC,MON,CYB, SD,G,OGA,FSF,FSH	Poor	Silt to Fine	N/O	Bivalves *Halimeda*	Corals Gastropods	Foraminifera	N/O	Lagoon
FLOATSTONE TO FRAMESTONE		Coral A Floatstone/ Framestone	WKR,C,D,E,F,CD, DS,MH,PSI,VV,YY, CYB,CYC,CYD, CYG,CYH,CYL, DPA,DPB,I,PBA, PBQ,A,B,G,J,K	Poor	Fine to Coarse	N/O	Corals	Bivalves Gastropods *Halimeda*	Foraminifera Red Algae Echinoids	*Gastrochaenolites* *Entobia* *Trypanites*	Patch reefs
		Halimeda-Coral Floatstone/ Framestone	BTD(?),YY,MOA, MOS,CYA,CYB, SDB	Poor	Fine to Coarse	N/O	*Halimeda*, Corals	Gastropods	Bivalves	N/O	Patch reefs
		Coral B Floatstone/ Framestone	ACC,BTD,DP,EOT, CDS,TJU,OL,GTP, LSP,SPB,RWP,CPA, HMB,TG,SBJ,IP,ML, PP,SB,SH,TOT,PL, AS,MS,AB,AC,DP, ER,DP,WB,TF,BT	Poor	Fine to Coarse	N/O	Corals	Bivalves, Gastropods Foraminifera *Halimeda*	Echinoids	N/O	Reef tract
		Bioclast Floatstone	SC	Moderate	Fine to Medium	High-angle cross-bedding, Moderate burrowing	None	Corals Bivalves	None	*Ophiomorpha* *Polykladichnus* *Skolithos*	High Energy Subtidal
RUD-STONE		Lithoclast Rudstone	SC	Moderate	Fine to Medium	High burrowing	None	None	None	*Ophiomorpha* *Polykladichnus* *Conichnus*	High Energy Subtidal

Table 3.1 (contd.): Facies of the Ironshore Formation, Grand Cayman, British West Indies.

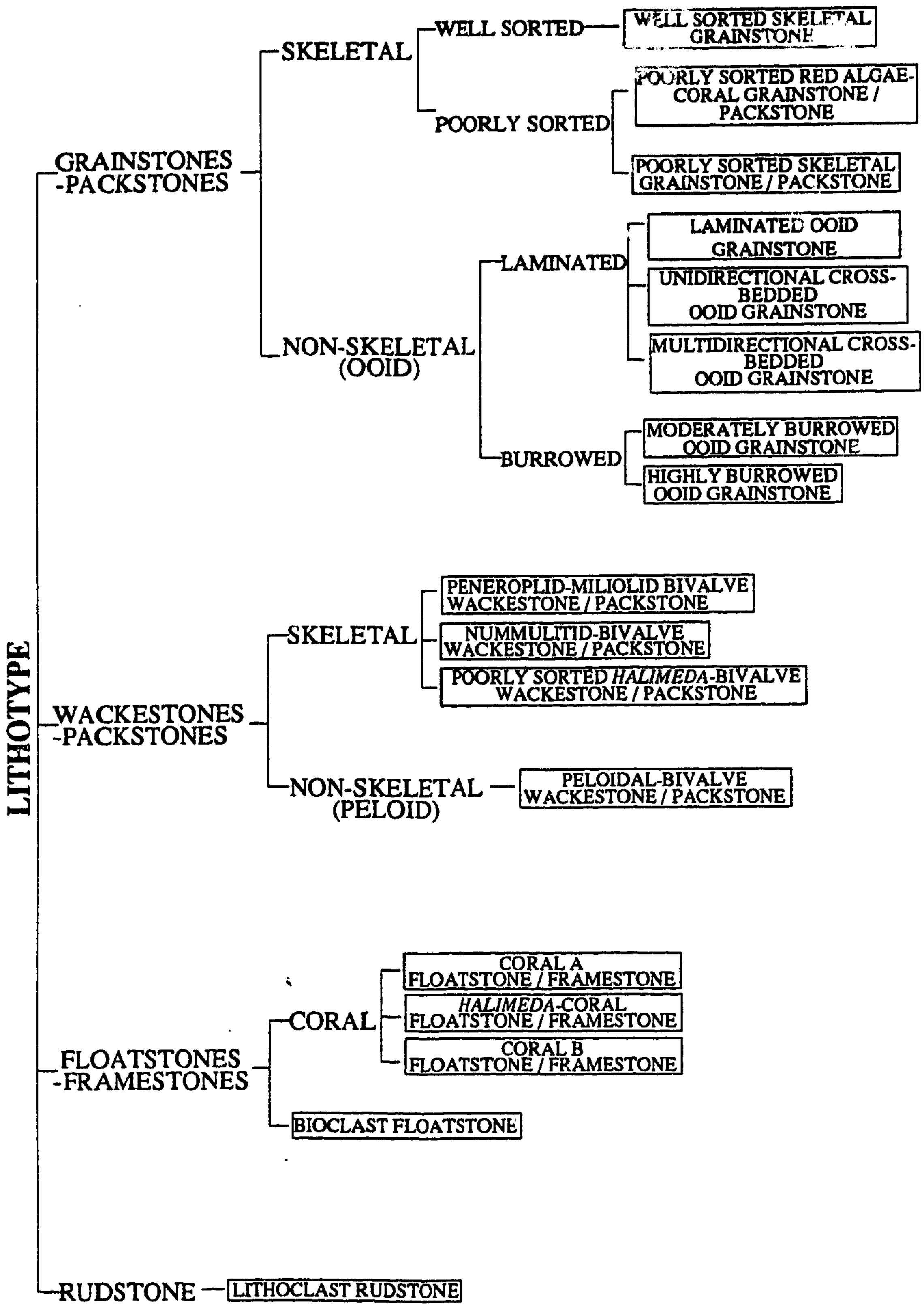


Figure 3.1: Flow diagram showing the hierarchical classification of the facies of the Ironshore Formation on Grand Cayman.

Initial divisions, based on lithotypes, are first divided according to the skeletal and non-skeletal allochem content and then by the type of allochem (Fig. 3.1, Table 3.1).

Mollusc identifications and occurrence are based on Cerridwen (1989) and Cerridwen and Jones (1991). Coral identifications are from Hunter and Jones (1988, 1989b) and Jones and Hunter (1990). Ichnofossils have been identified from Pemberton and Jones (1988) and Hunter and Jones (1989b).

Well Sorted Skeletal Grainstone Facies

This facies, well exposed along the reef tract at Smith's Barcadere (SBB, SBD), West Bay (ACF [illegible] CF, ABC), Milk Shake locality (MS), and Turtle Farm (TFB – Fig. 1.5), consists mainly of well sorted skeletal and ooid grainstones (Plate IA).

The ooids, which have coral fragments, mollusc fragments, and micritized skeletal grains as their nuclei, have thick cortical layers with a radial fabric (Hunter and Jones, 1989). Other allochems include corals and lesser numbers of bivalves, red algae, *Halimeda* fragments and foraminifera. Some gastropod and bivalve shells are filled with spar calcite.

Poorly Sorted Red Algae - Coral Grainstone / Packstone Facies

This facies, which occurs at West Bay (ACF), Queen's Road (QRD), and Smith's Barcadere (SBD – Fig. 1.5), is characterized by red algae and coral fragments held in a poorly sorted grainstone to packstone matrix (Plate IB). Other allochems include gastropod and bivalve fragments along with rare *Halimeda* and echinoid fragments.

Poorly Sorted Skeletal Grainstone / Packstone Facies

This facies (Plate IC) is exposed at the Golf Course (GC), locality U, Selkirk Drive (SD, SDC), Paul Bodden's Quarry (PBA), West Bay (ABD), The Shores (TS), and Canal

PLATE I

Facies of the Ironshore Formation

(A) Photomicrogaph of the *Well Sorted Skeletal Grainstone Facies* (# 2731, Loc. ACB).

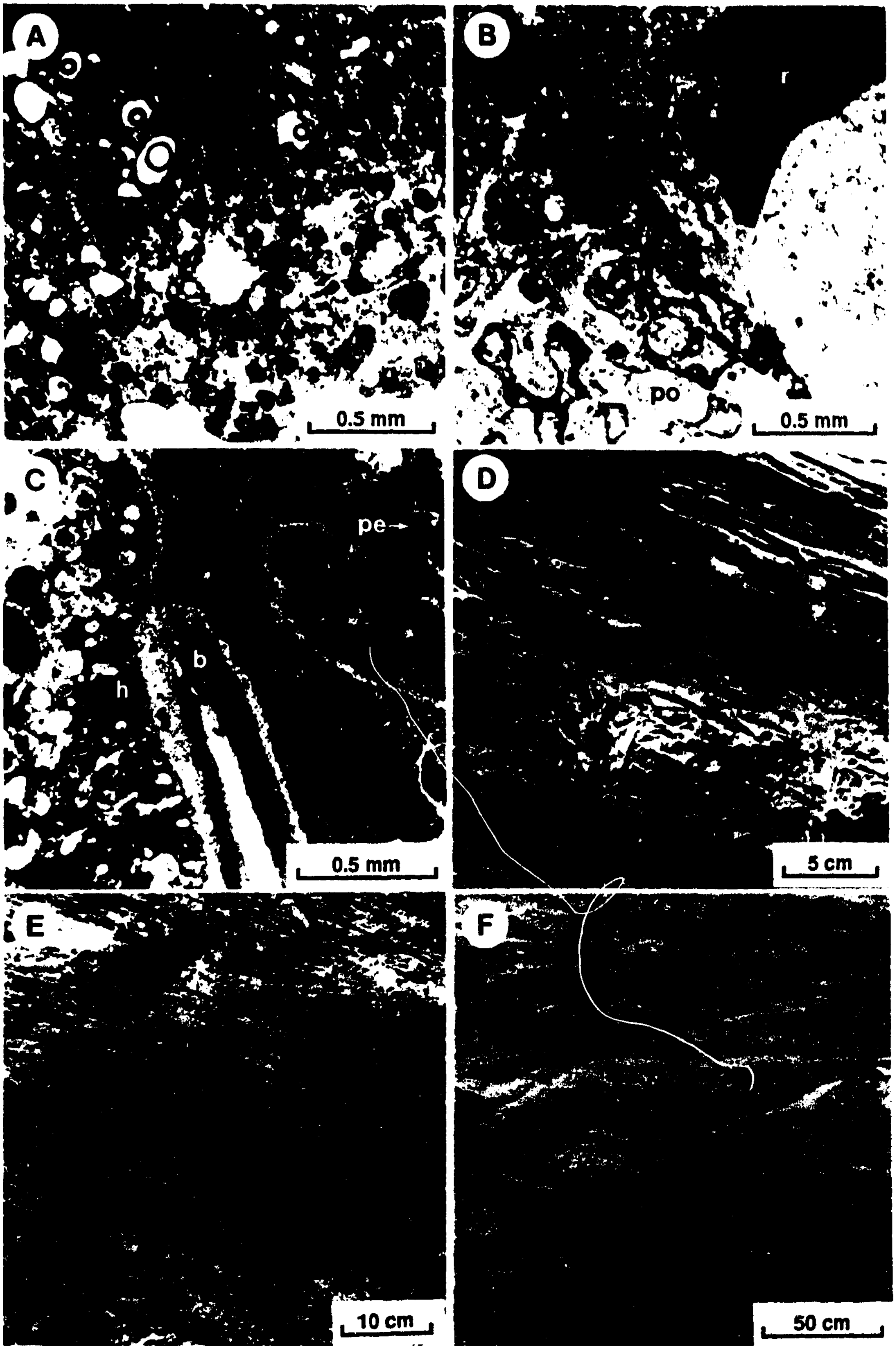
(B) Photomicrogaph of the *Poorly Sorted Red Algae - Coral Grainstone / Packstone Facies* (# 2801B, Loc. SBD). The coral *Porites porites* (po) and red algae (r) occur in a wackestone / packstone matrix.

(C) Photomicrogaph of the *Poorly Sorted Skeletal Grainstone / Packstone Facies* (# 3778, Loc. MOC) showing *Halimeda* (h), bivalves (b), and peloids (pe) in a grainstone / packstone matrix.

(D) Outcrop photograph of the *Unidirectional Cross-Bedded Ooid Grainstone Facies* exposed at Salt Creek (SC – Fig. 1.5). *Conichnus* (c) occurs in these ooid grainstones. Photo courtesy of Brian Jones.

(E) Outcrop photograph of the *Multidirectional Cross-Bedded Ooid Grainstone Facies* exposed at Salt Creek (SC – Fig. 1.5). Photo courtesy of Brian Jones.

(F) Outcrop photograph of the *Laminated Ooid Grainstone Facies* exposed at Paul Bodden's Quarry (PBA – Fig. 1.5) showing the transition from the highly burrowed (hb) ooid grainstones at the bottom to the multidirectional (md) cross-bedded ooid grainstones to the laminated (l) ooid grainstones at the top. Photo courtesy of Brian Jones.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Point (CNP – Fig. 1.5). It generally occurs between the patch reefs and consists of moderately to poorly sorted skeletal grainstones to packstones that have been moderately burrowed (5-6 on the scale of Frey and Pemberton, 1985).

This facies contains 118 species of well preserved and generally articulated molluscs (Cerridwen, 1989), the dominant ones being *Chione* spp., *Codakia* spp., *Crasinella martinicensis*, *Linga pensylvanica*, and *Cerithium* sp. Other allochems include scattered coral fragments along with minor amounts of peloids, red algae, *Halimeda*, foraminifera, echinoid, and worm tube fragments. The amount of *Halimeda* present is lesser than that in the *Peloidal Bivalve Wackestone / Packstone Facies*. Some of the *Halimeda* and gastropod fragments have been partly micritized. Ichnofossils include *Polykladichnus* and *Skolithos*. The limestones of this facies are locally bioturbated (3-4 on the scale of Frey and Pemberton, 1985).

Unidirectional Cross-Bedded Ooid Grainstone Facies

This facies, which occurs at locality SC (Salt Creek – Fig. 1.5), is formed of well sorted ooid grainstones that exhibit high angle cross-bedding with localized back flow ripples (Plate ID) (Jones and Pemberton, 1989). The ooids are of the tangential type. Ichnofossils include *Polykladichnus*, *Skolithos*, *Conichnus*, *Bergaueria*, and *Psilonichnus* sp. Burrowing is low (1-2 on the scale of Frey and Pemberton, 1985).

Multidirectional Cross-Bedded Ooid Grainstone Facies

This facies, which occurs at Botabano Quarry (BQ), Little Salt Creek (LSC), Salt Creek (SC), Paul Bodden's Quarry (PBQ, PBA), Palmetto Point (PMP), Smith's Barcadere (SB, SBA, SBF), West Bay (ACA, ACH, ABD), Walker's Road School (WRS), and Blakes (BLK – Fig. 1.5) is formed of well sorted ooid grainstones. Other allochems include rare broken fragments of gastropods, bivalves, foraminifera, and a few peloids. These grainstones, which display high angle cross-bedding (both planar and tabular) and planar laminations (Plate IE), exhibit low burrowing (3 on the scale of Frey and Pemberton, 1985). The ichnofossil assemblage includes *Ophiomorpha*, *Conichnus*, and *Skolithos*.

Laminated Ooid Grainstone Facies

This facies, occurring at LSC (Little Salt Creek), PBA, PBQ (Paul Bodden's Quarry), BQ (Botabano Quarry) and Smith's Barcadere (SBA – Fig. 1.5), consists of well sorted, laminated ooid grainstones. The ooid grainstones, which occur between the patch reefs, display horizontal to low-angle laminations (Plate IF). Rare bivalve fragments occur between the ooid grainstones. No burrows have been observed in this facies.

Moderately Burrowed Ooid Grainstone Facies

This facies, which occurs at Salt Creek (SC), localities L, M, N, Paul Bodden's Quarry (PBQ), Botabano Quarry (BQ), Half Moon Bay (MHA), The Shores (TS), and Dolphin Point (DP, DPQ – Fig. 1.5), comprises well sorted ooid grainstones that have been moderately burrowed (5 on the scale of Frey and Pemberton, 1985) and exhibit low angle to parallel laminations (Plate IIA). The ooids, which average 0.125-0.150 mm (maximum 0.55 mm) in diameter, have a matt surface and few cortical laminae (Jones and Goodbody, 1984; Hunter and Jones, 1989b). The ooids, are of the tangential type like those of the *Unidirectional Cross-Bedded Grainstone Facies*. Their large nuclei, formed of dense, dark coloured masses of cryptocrystalline calcite or aragonite, probably originated as fecal pellets (Jones and Goodbody, 1984). Other allochems include peloids and rare fragments of bivalves, gastropods, and *Halimeda*.

PLATE II

Facies of the Ironshore Formation

(A) Outcrop photograph of the *Moderately Burrowed Ooid Grainstone Facies* exposed at Salt Creek (SC – Fig. 1.5). *Ophiomorpha* (o) are common in these ooid grainstones. Photo courtesy of Brian Jones.

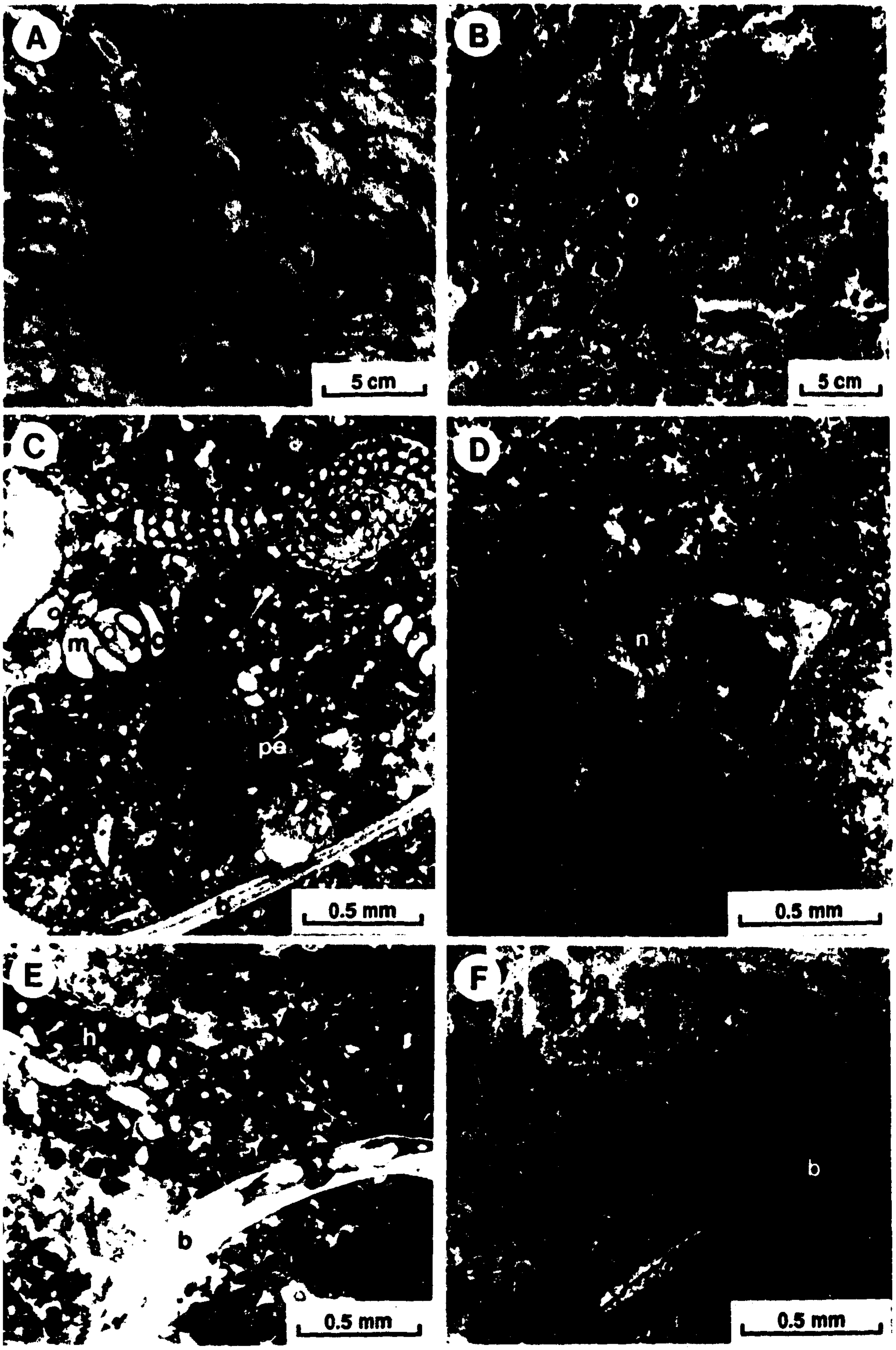
(B) Outcrop photograph of the *Highly Burrowed Ooid Grainstone Facies* exposed at Salt Creek (SC – Fig. 1.5) with numerous *Ophiomorpha* (o). Photo courtesy of Brian Jones.

(C) Photomicrogaph of the *Peneroplid-Miliolid Bivalve Wackestone / Packstone Facies* (# 2210, Loc. TSE) showing peneroplids (p), miliolids (m), bivalves (b), and peloids (pe) in a wackestone / packstone matrix.

(D) Photomicrogaph of the *Nummulitid-Bivalve Wackestone / Packstone Facies* (# 4615, Loc. BEB) showing the foraminifera *Nummulities* (n) surrounded by a wackestone / packstone matrix.

(E) Photomicrogaph of the *Poorly Sorted Halimeda-Bivalve Wackestone / Packstone Facies* (# 3777, Loc. EOR) showing *Halimeda* (h) and bivalves (b) in a poorly sorted wackestone / packstone matrix.

(F) Photomicrogaph of the *Peloidal-Bivalve Wackestone / Packstone Facies* (# 1965, Loc. MOS) showing bivalves (b) surrounded by peloids (pe) in a poorly sorted wackestone / packstone matrix.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Ichnofossils include *Ophiomorpha*, *Polykladichnus*, *Skolithos*, and *Conichnus*. The *Ophiomorpha* show a change from a vertical to horizontal alignment from the upper to the lower part of the facies (Hunter and Jones, 1989b).

Highly Burrowed Ooid Grainstone Facies

This facies, exposed at Salt Creek (SC), Little Salt Creek (LSC), Botabano Quarry (BQ), and Paul Bodden's Quarry (PBQ, PBA – Fig. 1.5), is formed of well sorted and highly burrowed (8 on the scale of Frey and Pemberton, 1985) ooid grainstones (Plate IIB). Although vaguely laminated in places (Hunter and Jones, 1989b), most of the original sedimentary structures were completely obliterated by burrowing. Ichnofossils include *Ophiomorpha*, *Polykladichnus*, *Skolithos*, and *Planolites*.

Peneroplid - Miliolid Bivalve Wackestone / Packstone Facies

This facies, exposed at Midland Acres (MA) and Tarpon Spring Estates (TSE – Fig. 1.5) in the southern part of Grand Cayman, consists of numerous burrowing bivalves and foraminifera held in a poorly sorted wackestone to packstone matrix (Plate IIC). The sediment surrounding the skeletal grains is usually of a silt to very fine sand size. Micritized skeletal grains, up to 30-125 μm in diameter are also present. As the name suggests, the rock contains numerous benthic foraminifera (10-20%) dominated by peneroplids and miliolids. The large molluscan assemblage is dominated by *Bulla striata*, *Cerithium* spp., *Tellina candeana*, *Linga pensylvanica*, and *Anodontia alba*. The bivalves are articulated, show no evidence of abrasi ., and some have retained their original colour. Rare *Halimeda* fragments, red algae, coral, and echinoid fragments occur in the matrix. Some *Halimeda* plates are outlined by micrite envelopes.

Rare, small colonies of *Siderastrea radians*, *Porites divaricata*, and *Manicina areolata* occur locally.

Nummulitid - Bivalve Wackestone / Packstone Facies

This facies, exposed at Belford Estates (BEA, BEB) and North Sound Estates (NSE – Fig. 1.5) in the southeastern part of Grand Cayman, is coarser grained than the *Peneroplid-Miliolid Wackestone-Packstone Facies*. This facies is typified by and abundance of nummulitids (*Nummulites* and *Amphistegina* sp. form up to 8-20% of the rock) in a silt to fine sand size wackestone to packstone matrix (Plate IID). Other allochems include rare gastropod, *Halimeda*, bivalve, and red algae fragments. Corals are not present in this facies.

Poorly Sorted *Halimeda* - Bivalve Wackestone / Packstone Facies

This facies, exposed at Tropical Gardens (TG), Duck Sound Bight (DSB), End of Road (EOR), Selkirk Drive (SDA), and Head Sound Barcadere (HSB – Fig. 1.5), is formed of bivalve and *Halimeda* (12-20%) fragments held in a moderately to poorly sorted wackestone to packstone matrix (Plate IIE). Some *Halimeda* plates have been partly micritized. Other allochems include rare gastropods, peneroplids, miliolids and peloids.

The diverse assemblage of molluscs is dominated by *Chione* spp., *Codakia* spp., *Anodontia alba*, *Crassinella martinicensis*, and *Cerithium* spp. Micrite occurs in patches. The body cavities of bivalves have been completely filled by mud that contains a few peloids and skeletal fragments. Corals have not been found in this facies. This facies is transitional to the *Peloidal-Bivalve Wackestone / Packstone Facies*.

Peloidal - Bivalve Wackestone / Packstone Facies

This facies, occurring at Bowseland (BWD), Barkers (MOS, MOC, MON), localities B, G, Golf Course (GC), Canal Point (CNP), Selkirk Drive (SD, SDC), Cayman Yacht Club (CYA), Fire Station (FSF, FSH) and Paul Bodden Quarry (PBA – Fig. 1.5), consists of numerous peloids and bivalves held in a poorly sorted wackestone to packstone matrix (Plate IIF). Micrite is restricted to small patches. The large molluscan fauna is dominated by *Chione* spp., *Codakia* spp., *Anodontia alba*, *Crassinella martinicensis*, and *Cerithium* spp. Peloids generally form about 25-35% of the rock (locally up to 50%). Other skeletal allochems include gastropods, corals, *Halimeda* plates, and rare foraminifera. The scarcity of *Halimeda* is the main reason for separating this facies from the *Poorly Sorted Halimeda-Bivalve Wackestone / Packstone Facies*.

Coral A Floatstone / Framestone Facies

This facies, exposed at Cayman Yacht Club, (CYB, CYC, CYD,CYG,CYH, CYL, CYM), Pump Station (PSI), Barker's (MOS), Morgan's Harbour (MH), localities K, A, B, C, D, E, F, VV, YY, Walker's Road (WKR), Paul Bodden's Quarry (PBQ, PBA) and Selkirk Drive (SDB – Fig. 1.5), is restricted to irregular ovate patches up to 300 m in diameter. These poorly sorted floatstones and framestones, which have a grainstone matrix, are dominated by *Diploria*, *Porites*, *Montastrea*, *Siderastrea*, and *Agaricia*.

The cores of the larger patch reefs are formed of massive and hemispherical corals (such as *Montastrea*, *Diploria* and *Siderastrea*) and give way laterally to branching corals (*Porites*) (Plate IIIA) and cementing bivalves (*Chama* and *Pseudochama*) in the peripheral regions (Hunter and Jones, 1989b). Many corals have been extensively bored by bivalves, sponges and worms (Jones and Pemberton, 1988). Corals in this facies were capable of sediment rejection (Hunter and Jones, 1988).

Faunal diversity is highly variable in this facies. For example, only one species of coral (*Porites porites*) occurs at Walker's Road (WKR) and Paul Bodden's Quarry (PBQ – Fig. 1.5) whereas 21 species occur at the Cayman Yatch Club (CYA – Fig. 1.5) (Hunter and Jones, 1989b). The molluscan assemblage in this facies is dominated by *Chama* sp., *Pseudochama radians*, *Arca* spp., and *Barbatia cancellaria*. Molluscs found in the sediments around the patch reefs include *Americardia guppyi*, *Chione* spp., *Codakia* spp.,

PLATE III

Facies of the Ironshore Formation

(A) Outcrop photograph showing *Porites porites* (po) in the *Coral A Floatstone / Framestone Facies* exposed at Paul Bodden's Quarry (PBA – Fig. 1.5). Photo courtesy of Brian Jones.

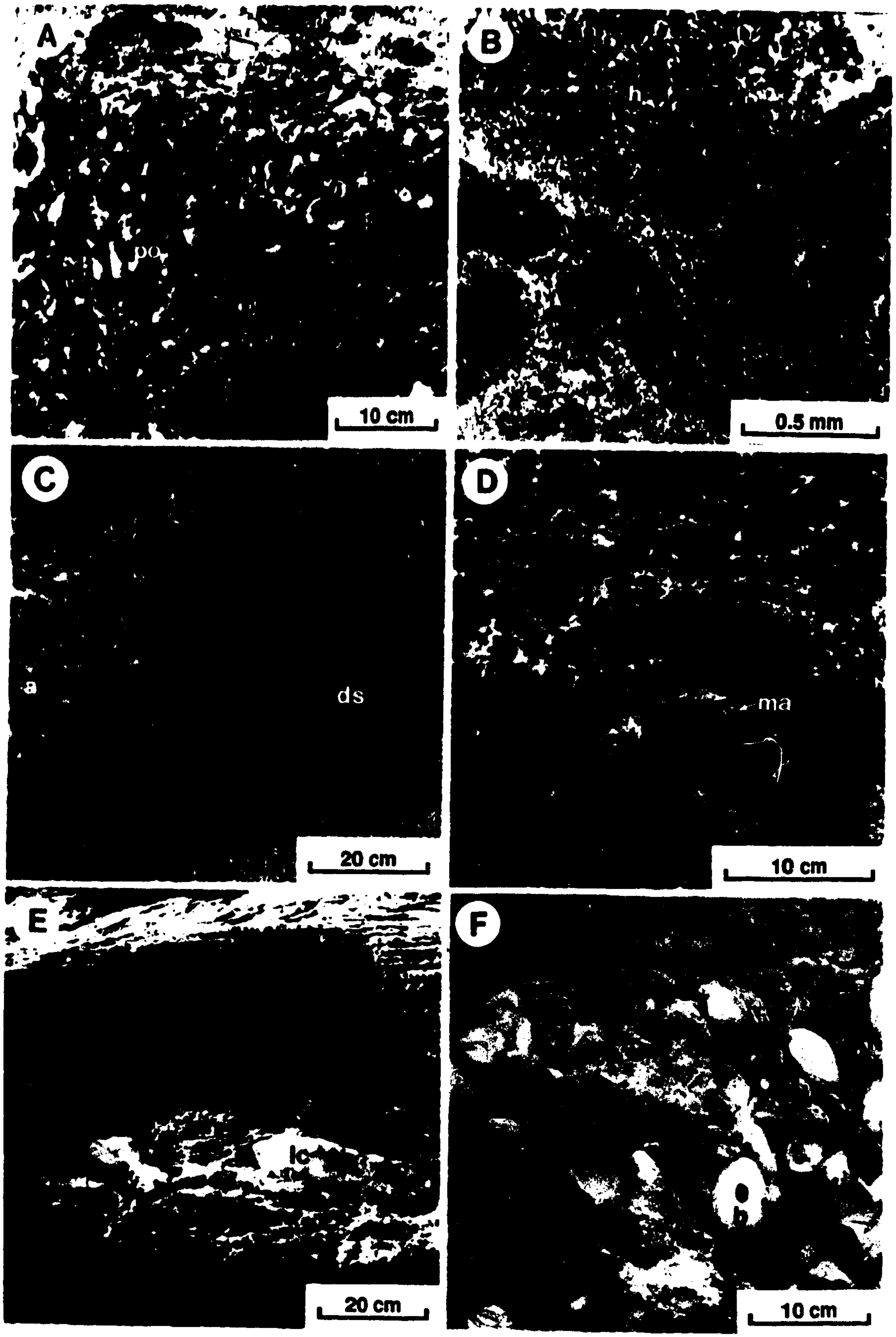
(B) Photomicrogaph of the *Halimeda-Coral Floatstone / Framestone Facies* (#2851, Loc. SDB) showing *Halimeda* (h) plates that occur between the corals.

(C) Outcrop photograph of the *Coral B Floatstone / Framestone Facies* exposed at Dolphin Point (DP – Fig. 1.5). A large head of *Diploria strigosa* (ds) is surrounded by *Acropora cervicornis* (a). Photo courtesy of Ian Hunter.

(D) Outcrop photograph of the *Bioclast Floatstone Facies* exposed at Salt Creek (SC – Fig. 1.5). *Montastrea annularis* (ma) occurs in an ooid grainstone matrix.

(E) Outcrop photograph showing the large tabular lithoclasts (lc) at the base of a channel at Salt Creek (SC – Fig. 1.5). Photo courtesy of Ian Hunter.

(F) Abundant bivalves (b) in the Ironshore Formation exposed at the Omega Gardens (OG – Fig. 1.5). Photo courtesy of Brian Jones.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F
10 cm

Ervilia concentrica, Crassinella martinicensis, Linga pensylvanica, Pitar fulminatus, and *Cerithium* spp. (Cerridwen, 1989). Other allochems include bivalves, gastropods, foraminifera, red algae, echinoids, worm tube fragments, and crustacean pellets. The bivalves dominating the patch reefs are of the nestling / boring, cementing, and byssate suspension-feeding types (Cerridwen and Jones, 1991). The ichnofossil assemblage includes *Gastrochaenolites, Entobia*, and *Trypanites* (Jones and Pemberton, 1988).

Halimeda-Coral Floatstone / Framestone Facies

This facies, exposed in patches at localities VV, YY, Barker's (MOA, MOS), Cayman Yacht Club (CYA, CYB), and Selkirk Drive (SDB Fig. 1.5), is dominated by *Diploria, Porites, Montastrea, Siderastrea* and *Agaricia* along with numerous *Halimeda* fragments (Plate IIIB).

Other allochems include gastropods, bivalves, foraminifera, rare echinoid fragments and peloids. Many of the corals contain *Gastrochaenolites, Entobia*, and *Trypanites*.

Coral B Floatstone / Framestone Facies

This facies, which occurs as a belt along a reef tract on the west, northwest and southwest coasts of Grand Cayman, is exposed at Birch Tree Hill (BTA, BTB, BTC, BTD, BTE, BTF), Georgetown (BK, MS, AS), Dolphin Point (DP, DPA, DPB, DPC, DPD, DPE, DPF, DPQ), West Bay (WBA, WBB), Turtle Farm (TF, TFA, TFB, TFN), Spotts Bay Jetty (SBJ, SBK), Frank Sound (ML), Half Moon Bay (HMA, HMB), Prospect Point (PP, TJU), Cottage Point (CPA), Tortuga Club (TC), Ironshore Point (IP), Spotters Bay (SPB), Little Spot Point (LSP), Rogers Wreck Point (RWP), Eden Rock (ERN, ERS), Cayman Diving School (CDS), Parrot's Landing (PL), Sunset House (SH, SHA), Esso Oil Tanks (EOT), Texaco Oil Tanks (TOT), Smith's Barcadere (SB, SBA, SBB, SBC, SBD, SBE, SBF, SBG), and West Bay (ABA, ABB, ABC, ABD, ACA, ACB, ACC, ACD, ACE, ACF, ACG, ACI – Fig. 1.5). This floatstone – framestone – packstone, which has a grainstone matrix, is dominated by corals (Plate IIIC).

The corals are unevenly distributed with some areas being characterized by a single species (monospecific patches of *Porites porites*, *Pocillopora*, or *Dendrogyra cylindrus* at Smith's Barcadere (SBA – Fig. 1.5)) whereas other areas have a variety of species (21 different species at Dolphin Point (DP – Fig. 1.5) (Hunter and Jones, 1989). Only a few of the corals have been bored. Corals occurring in this facies but not in the Coral *A Floatstone/Framestone Facies* (e.g. *Meandrina meandrites*, *Dendrogyra cylindrus*, *Pocillopora* sp., *Acropora cervicornis*, and *A. palmata*) are ineffective at sediment rejection (Hubbard and Pocock, 1972).

This facies also contains small numbers of bivalves, gastropods, *Halimeda* plates, micritized skeletal grains, rare foraminifera, red algae, and echinoid fragments. It has a greater concentration of skeletal grains than the *Coral A Floatstone / Framestone Facies*.

Many coral fragments (e.g. *Pocillopora* sp. and *Acropora cervicornis*) acted as nuclei for stromatolites that are up to 10 cm long and 3 cm thick. These stromatolites are formed of alternating layers of carbonate silt and micrite. Some of these layers contain foraminifera (*Homotrema* or *Carpentaria*) or red algae encrustations (Hunter and Jones, 1989b, Jones and Hunter, 1991).

Bioclast Floatstone Facies

This facies, which occurs at Salt Creek (SC – Fig. 1.5), is formed of coral and mollusc fragments in a moderately sorted ooid matrix (Plate IIID). The cross-bedded to planar laminated limestones are intensely burrowed (8 to 9 on the scale of Frey and Pemberton, 1985 – Jones and Pemberton, 1989). Large tabular lithoclasts similar to those in the *Unidirectional Cross-Bedded Grainstone Facies* occur at the base of this facies. Ichnofossils include *Ophiomorpha*, *Polykladichnus*, and *Skolithos*.

Lithoclast Rudstone Facies

This facies, which only occurs at Salt Creek (SC – Fig. 1.5), is composed of large lithoclasts held in an ooid grainstone matrix (Plate IIIE). The lithoclasts, up to 10 cm x 10 cm x 10 cm in size (Jones and Pemberton, 1989), are formed of well sorted ooids cemented by spar calcite cement. Some lithoclasts contain bivalve and coral fragments held in an ooid grainstone matrix. Intense burrowing (8 on the scale of Frey and Pemberton, 1985) has destroyed all the original sedimentary structures. Ichnofossils include *Ophiomorpha*, *Polykhladichnus*, and *Conichnus*.

CHAPTER 4
PALEOGEOGRAPHIC FRAMEWORK AND DISTRIBUTION OF FACIES

PALEOGEOGRAPHIC FRAMEWORK

The general paleogeographic configuration of Grand Cayman during deposition of the Ironshore Formation is relatively well known through the work of Jones and Hunter (1990) who integrated their data with information from Doran (1954), Brunt *et al.* (1973) and Hunter and Jones (1988, 1989a, 1989b).

Doran (1954) suggested that North Sound (Fig. 1.2) was a remnant of an older and larger lagoon. Brunt *et al.* (1973) followed his suggestion by stating that during the Late Pleistocene, a large lagoon up to 10 m deep covered the western part of Grand Cayman surrounded by a reef. According to Brunt *et al.* (1973), the lagoon decreased in size because of the fall in sea level at the end of Pleistocene. They also noted a conspicuous submarine feature off the coast of West Bay (Fig. 1.5) that connected two distinct patches of the *Reef Facies* of the Ironshore Formation. It may be the remains of a long and continuous reef which had undergone extensive erosion for some period of time.

Further work by Hunter and Jones (1988) led to refinement of the paleogeographic framework for the Ironshore Formation. They suggested that following Middle Miocene times, erosion of the Bluff Formation produced an irregular karst topography that had a relief of up to 30 m. The Sangamon transgression, which produced a highstand of 6 m above present day sea level 120,000 to 130,000 years ago, led to flooding of large areas of Grand Cayman. Most of the limestones of the Ironshore Formation were deposited in a large lagoon, termed the 'Ironshore Lagoon' (Hunter and Jones, 1988), which covered the central and western parts of Grand Cayman. Outcrops of the Bluff Formation formed the eastern, western and the northern margins of the 'Ironshore Lagoon'. Hunter and Jones

(1988) suggested that the Pleistocene Ironshore Lagoon was far more open than the present day North Sound (Fig. 1.4).

SEA LEVEL

One of the most important constraints in reconstructing the paleogeography of the Ironshore Formation is the fact that the sea level in the Caribbean during the last interglacial was 5.5 to 6 m above present-day sea level (Matthews, 1973; Steinen *et al.*, 1973; Neumann and Moore, 1975; Szabo *et al.*, 1978; Harmon *et al.*, 1981; Woodroffe *et al.*, 1983; Carew *et al.*, 1984; Brasier and Donahue, 1985; and Woodroffe, 1988). Thus, there is a strong inference that sea level should also have been at 5.5 to 6 m above sea level on the Cayman Islands during the 125,000 year highstand. Woodroffe *et al.* (1983) and Woodroffe (1988), however, argued that the last interglacial sea level on Grand Cayman was only 2 to 3 m above present day sea level. This suggestion was based on their data which indicated that (1) "*Coral Facies*" (Woodroffe *et al.*, 1983) was only present below 2 m above sea level, (2) limestones exposed above 2 m were of subaerial origin, and (3) the best preserved erosional surface occurred at +2 m.

Jones and Hunter (1990) questioned their assumptions and interpretations for the following reasons.

(1) The "*Coral Facies*" are not accurate indicators of sea level because the corals that Woodroffe *et al.* (1983) considered indicative of the reef crest environment can occur in water up to 10 m deep.

(2) Limestones of the Ironshore Formation that occur higher than 2 m above sea level did not form in a subaerial setting. For example, limestones of a lagoonal origin occur at elevations of up to 3.8 m above sea level, Upper Shoreface deposits up to 5 m, and Foreshore-Backshore deposits up to 6.5 m above sea level (Jones and Hunter, 1990). At Paul Bodden's Quarry (PBA – Fig. 1.5), *in situ* colonies of *Porites porites* occur up to 3.8 m above sea level.

(3) The dating of the erosional surface at 2 m is questionable because the ages of the corals in the terrace are indicative of their time of deposition, not the time of erosion.

Jones and Hunter (1990) showed that the boundaries between the Upper Shoreface to Foreshore-Backshore and the Foreshore-Backshore at localities BQ, LSC, PBQ, and PBA (Fig. 1.5) were consistent with a sea level highstand of +6 m and thus similar to that recorded from other Caribbean islands. Also, a wave-cut notch with its mid-point at 6 m occurs on the northeastern part of Grand Cayman (locality QRB – Fig. 1.5). As such, it correlates with the wave-cut notch on Cayman Brac that occurs at a similar elevation.

The basic point in the reconstruction of the paleogeography of the Ironshore Formation is that any part of the Bluff Formation that is presently above 6 m above sea level on Grand Cayman must also have been above sea level 125,000 years ago. There has been little or no vertical tectonic movement on the Cayman Islands in the last 125,000 years (Jones and Hunter, 1990). The Bluff Formation is exposed to the south, east and north of the 'Ironshore Lagoon' (Fig. 1.4). Its presence as a thin ridge in the north is not immediately evident at the present day. Hunter and Jones (1988), however, reconstructed the ridge by joining a thin ridge of the Bluff Formation present along the north coast (Fig. 1.4) with the Bluff Formation exposed on Fisherman's Rock (Fig. 1.5) and that outcropping at Hell (Fig. 1.5). This ridge was probably similar to the one exposed along the south coast of Grand Cayman.

THICKNESS OF THE IRONSHORE FORMATION

The Ironshore Formation shows a great variation in thickness. Brunt *et al.* (1973) indicated that the Ironshore was more than 17 m thick in the area around Georgetown (Fig. 1.5) because boreholes did not penetrate the Bluff Formation even at this depth. Also, boreholes to the south of West Bay (Fig. 4.1) penetrated 14 m of the Ironshore Formation (Brunt *et al.*, 1973). The variation in thickness is exhibited at the Golf Course (GC – Fig. 1.5), where samples of the Bluff Formation were obtained from dredged material 3 m

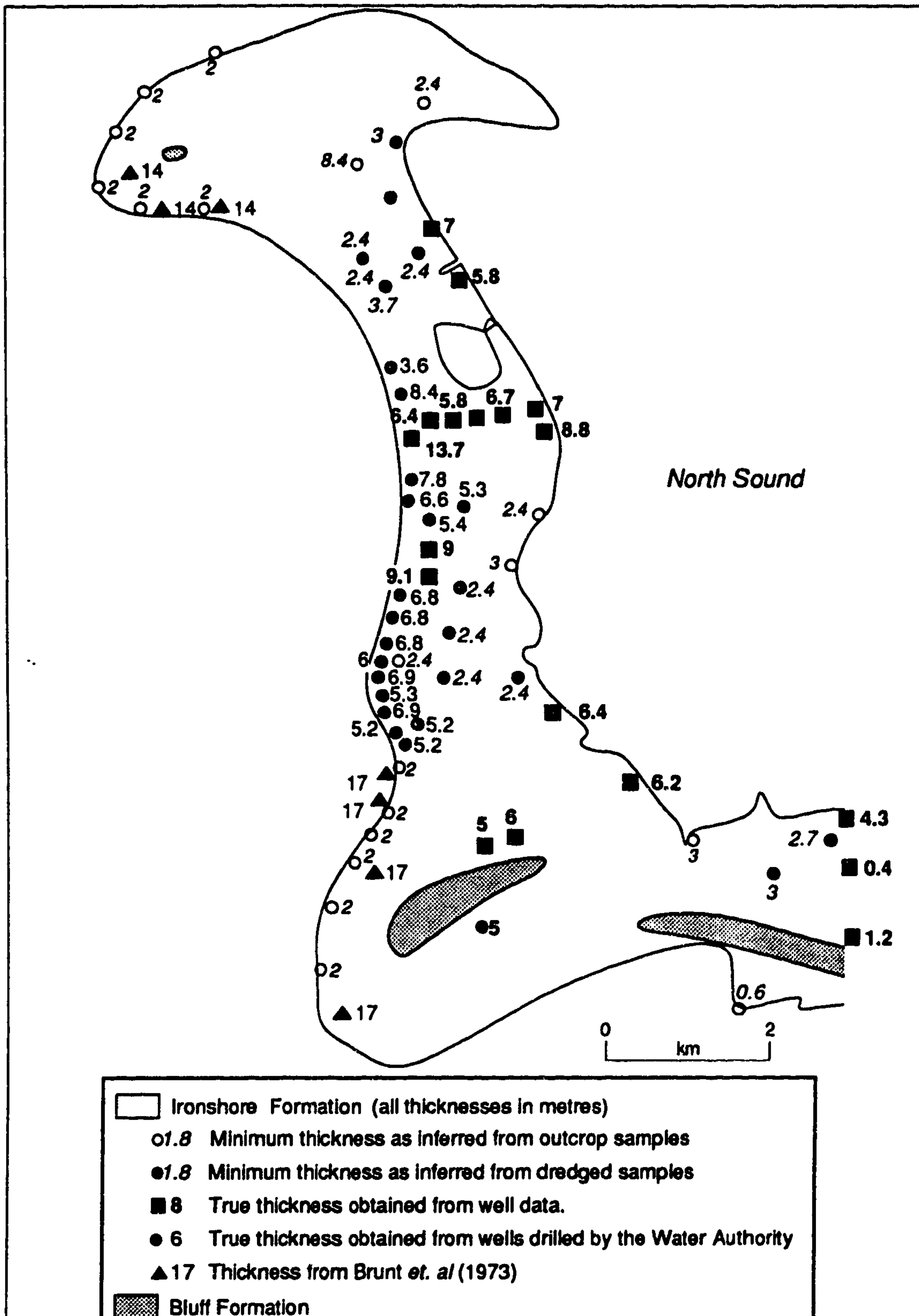

Figure 4.1: Thicknesses of the Ironshore Formation on the western part of Grand Cayman.

below sea level whereas 1.5 km to the west, the top of the Bluff Formation is found at a depth of 20 m (Jones and Hunter, 1990). Wells drilled in various parts of the western Grand Cayman provide a considerable amount of information concerning the thicknesses of the Ironshore Formation on the western part of Grand Cayman.

Essentially, there are three types of values available for the thickness of the Ironshore Formation.

1. Thicknesses from measured sections:

These give the minimum thickness of the formation because the unconformity separating it from the underlying Bluff Formation is usually not exposed and the upper surface is the present day erosional surface. For example, at Little Salt Creek (LSC – Fig. 1.5, 4.1), the formation is exposed up to 6.1 m above sea level and for at least 7 m below sea level, giving a minimum thickness of 13.1 m.

2. Thicknesses obtained from drilling:

These represent the most reliable thickness data because they are obtained from wells drilled at different localities in the western part of Grand Cayman. In the northwestern part, the Bluff formation is exposed at the surface at Hell (Fig. 1.5). A well drilled at Little Salt Creek (LSC1 – Fig. 1.5), at the western margin of North Sound, penetrated 7 m of the Ironshore Formation. Further south, a number of wells (Fig. 1.5) drilled at Safe Haven penetrated 5.8 to 13.7 m of the Ironshore Formation (Fig. 4.2). Wells WB1 and WB2 (Fig. 1.5) drilled at the Golf Course gave thicknesses of 9 m and 9.1 m for the Ironshore Formation. Another recently drilled well (SHT1 – Fig. 1.5) at the Sewage House and Treatment Plant showed the Ironshore Formation to be 6.4 m thick. Wells CF and CF1 drilled at the Cricket Field (CF – Fig. 1.5) penetrated 5 m and 6 m of the Ironshore Formation respectively (Fig. 4.1). To the south of the Cricket Field, the Bluff Formation outcrops at the surface. At Paul Bodden's Quarry (PBQ – Fig. 1.5), the Ironshore Formation is at the most 5m thick, because the unconformity between this and the underlying Bluff Formation is

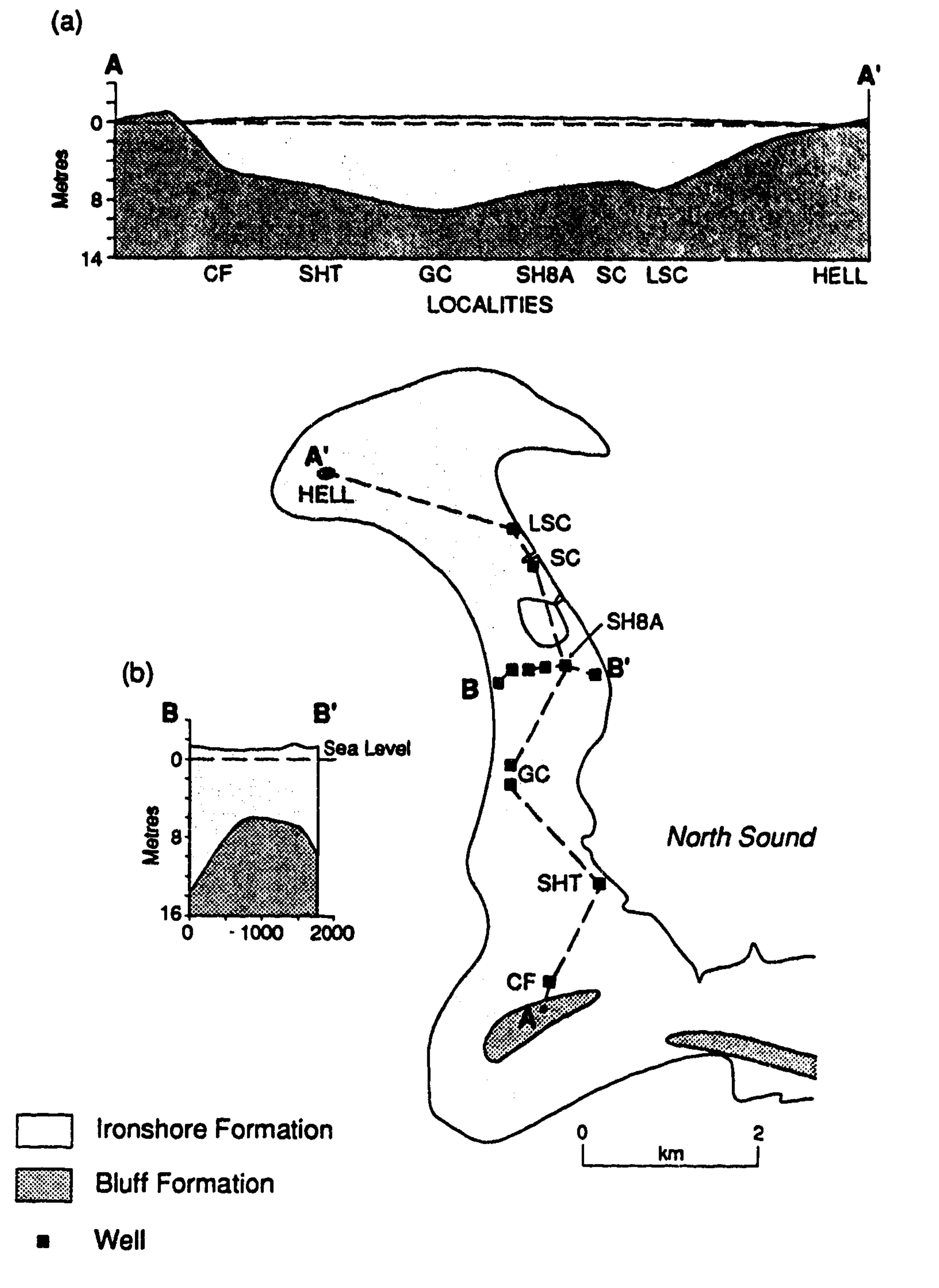

Figure 4.2: (a) South to north cross-section from A to A'.
(b) West to east cross section from B to B' (Safe Haven area).

exposed in the floor of the quarry. In ORA1, (Fig. 1.5), a well drilled at the end of the runway on the airport, the Ironshore Formation is 6.1 m (Fig. 4.1). Three wells (PIL1, PIL2, PIL3) drilled at Patrick's Island (PIL – Fig. 1.5) showed the presence of Ironshore to depths of 0.38 m, 4.3 m and 1.2 m respectively.

Additional information about the thicknesses of the Ironshore Formation along the western parts of Grand Cayman comes from twenty boreholes (BH1 – BH20) drilled by the Water Authority on Grand Cayman (Figs. 1.5, 4.1, App. B). None of these wells reached the Bluff Formation and the thicknesses must therefore be considered as minimums. Nevertheless, the thicknesses in BH6 (6.6 m), BH1 (6.9 m), BH10 (8.4 m), and BH7 (7.8 m) are comparable to those obtained from other wells (Fig. 4.1).

3. Thickness values based on dredged samples obtained at various localities on Grand Cayman:

These values are not accurate but give a general idea of formation thickness. For example, dredged samples of the Ironshore Formation obtained from depths of 2.4 m at Canal Point (CNP – Fig. 1.5) give a minimum thickness of the formation at that locality.

Compilation of all the information shows the variations in the thickness of the Ironshore Formation on Grand Cayman (Figs. 4.1, 4.2). The thicknesses obtained from recently drilled wells at various localities on the west part of Grand Cayman are all lower than the values cited by Brunt *et al.* (1973) to the south of West Bay and in the area around Georgetown (Figs. 1.5, 4.1). The Ironshore Formation is thinnest along the northwest and southwest coasts and thickest in central localities (e.g. SH2, SH4, GC – Fig. 1.5, 4.1) on the western part of Grand Cayman.

DIVISIONS OF THE IRONSHORE FORMATION

The Ironshore Formation is divided into three divisions, X, Y, and Z (Fig. 4.3), according to the practical controls on sampling imposed by the low-lying nature of the

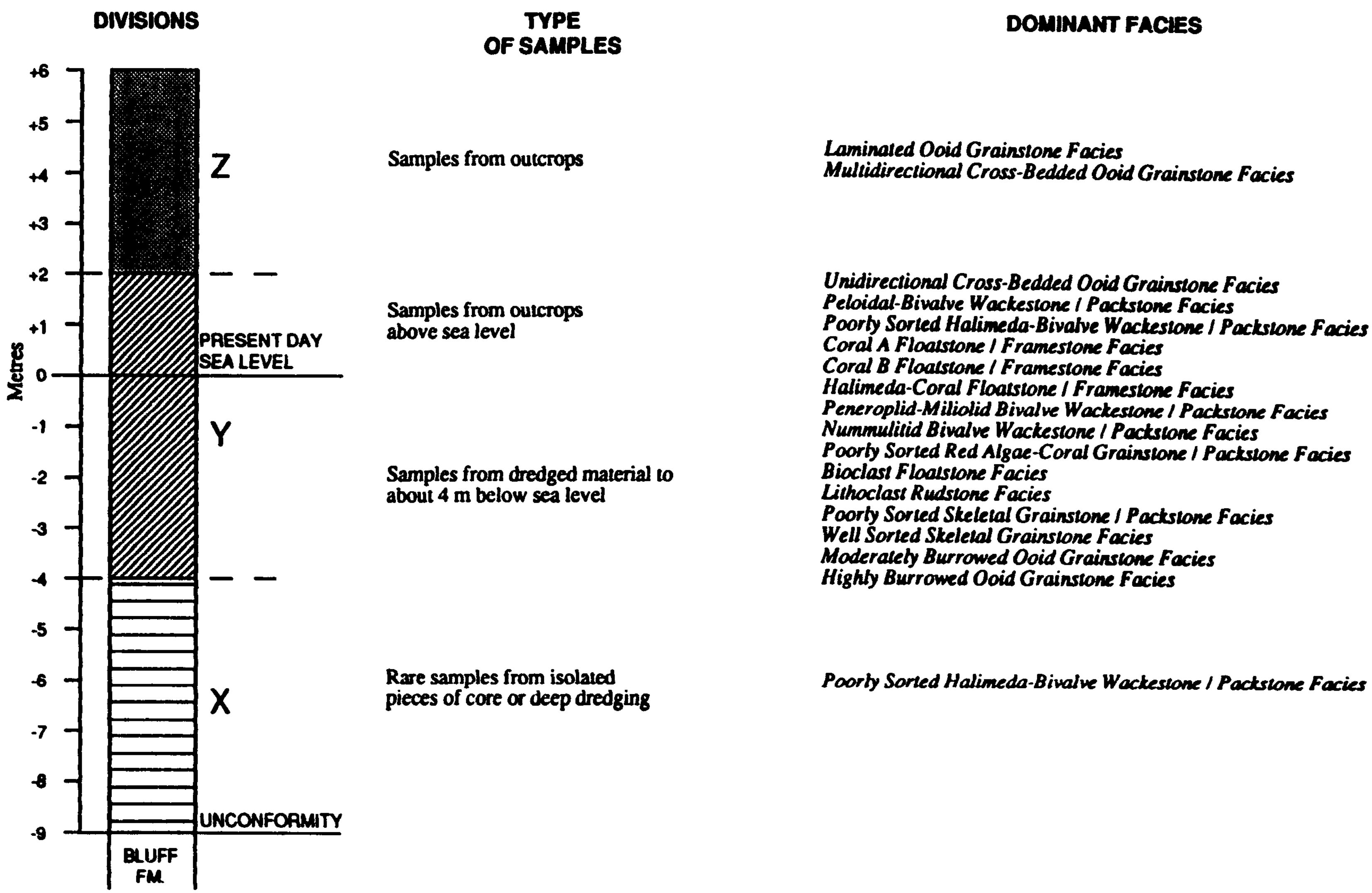

Figure 4.3: Depth controlled divisions of the Ironshore Formation on Grand Cayman.

island. These divisions, however, provide a framework in which the geographic distribution of the facies can be discussed.

Division X, which occurs from 4 m below sea level to the base of the formation, encompasses subtidal facies. There is limited information available for this division due to the lack of exposures and lack of data acquired from drilling. Attempts to drill and core this part of the formation have failed because the friable mudstones are washed away during drilling (Jones, pers. comm., 1992). Scattered samples are available from isolated pieces of core obtained from well cemented layers and material obtained from deep excavations.

Division Y, consisting of facies of the subtidal type, occurs from 2 m above present day sea level to about 4 m below sea level. Above sea level, information is readily available from outcrop. From sea level to -4 m, information must be derived from dredged material. This division contains a wide variety of facies that are exposed at numerous localities on Grand Cayman. Collectively, this data provides a good insight into the facies architecture of Division Y.

Division Z, consisting of shallow subtidal to upper intertidal facies, ranges from approximately 2 m to 6 m above present day sea level. As such, the availability of samples is controlled by the elevation of the land, vegetation cover, and the nature of coastal exposures. Where exposed, detailed sections through the division are easy to obtain (Fig. 4.4).

DISTRIBUTION OF FACIES

The classification of the constituent facies of the Ironshore Formation through the use of a hierarchical flow diagram (Fig. 4.5) means that their geographic and stratigraphic distribution can be viewed at three different levels of refinement. At the coarsest level of division, the entire formation can be viewed in terms of four broadly defined facies (Fig. 4.6). At the other extreme, the formation is divided into seventeen facies (Fig. 4.7). At an intermediate level, the formation can be considered in terms of six facies (Figs. 4.8).

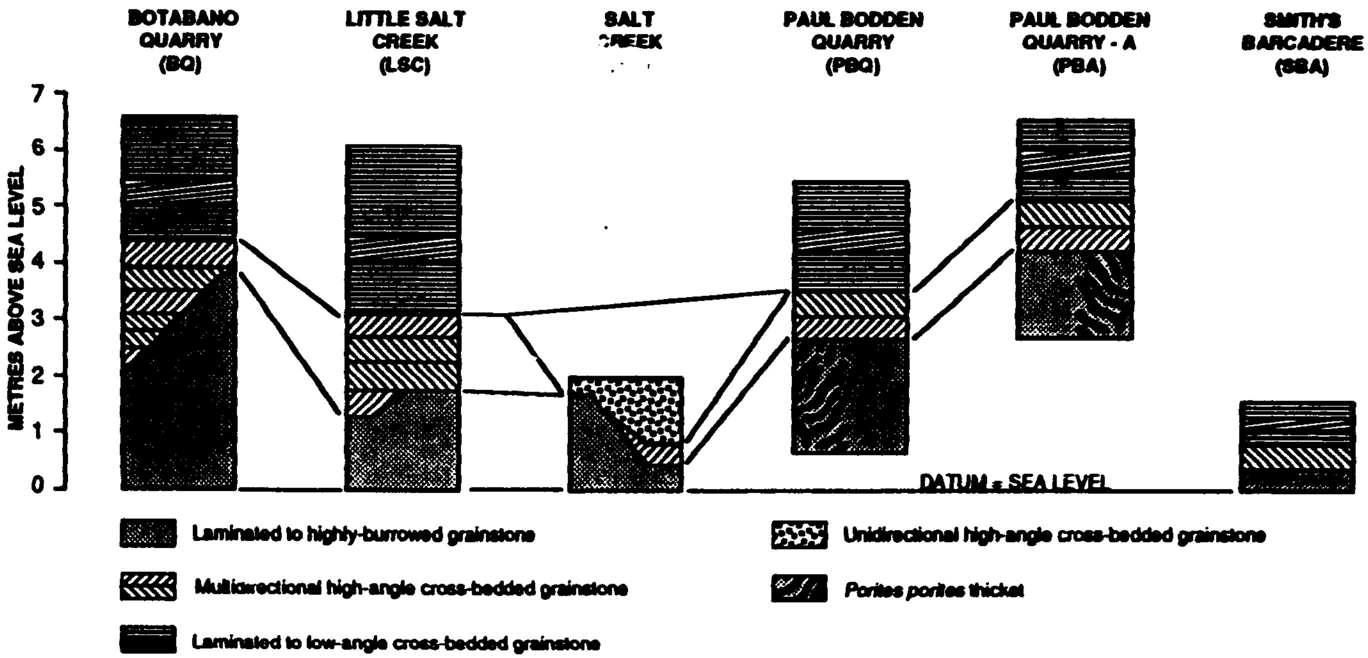

Figure 4.4: Lithostratigraphic correlation of the Ironshore Formation at localities BQ, LSC, SC, PBA, and SBA (Fig. 1.5). (modified from Jones and Hunter, 1990).

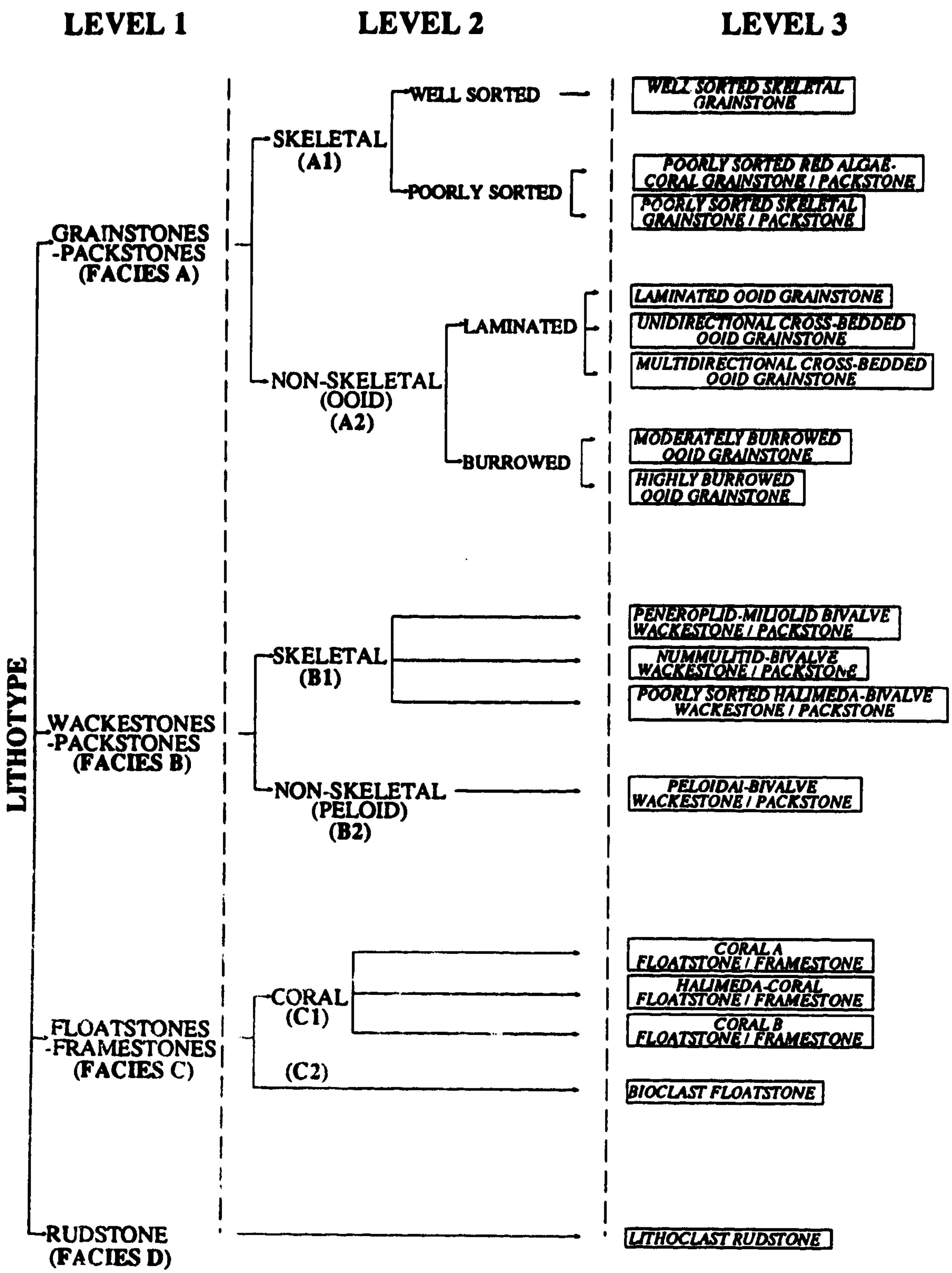

Figure 4.5: Flow diagram depicting the various levels involved in the process of the classification of the different microfacies of the Ironshore Formation on Grand Cayman.

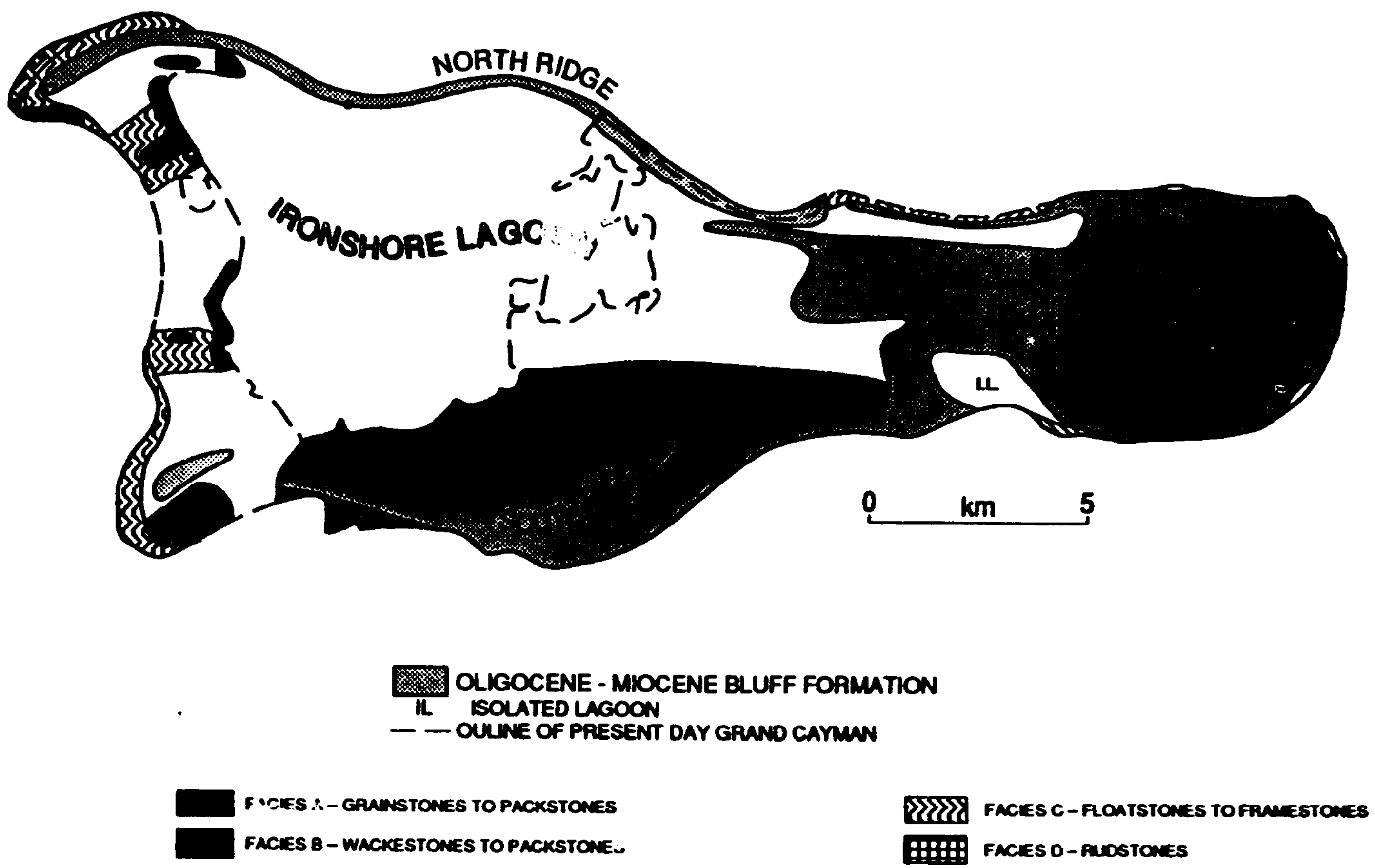

Figure 4.6: Distribution of different rock types of Level 1 occurring in Division Y in the Pleistocene Ironshore Formation at various localities on Grand Cayman.

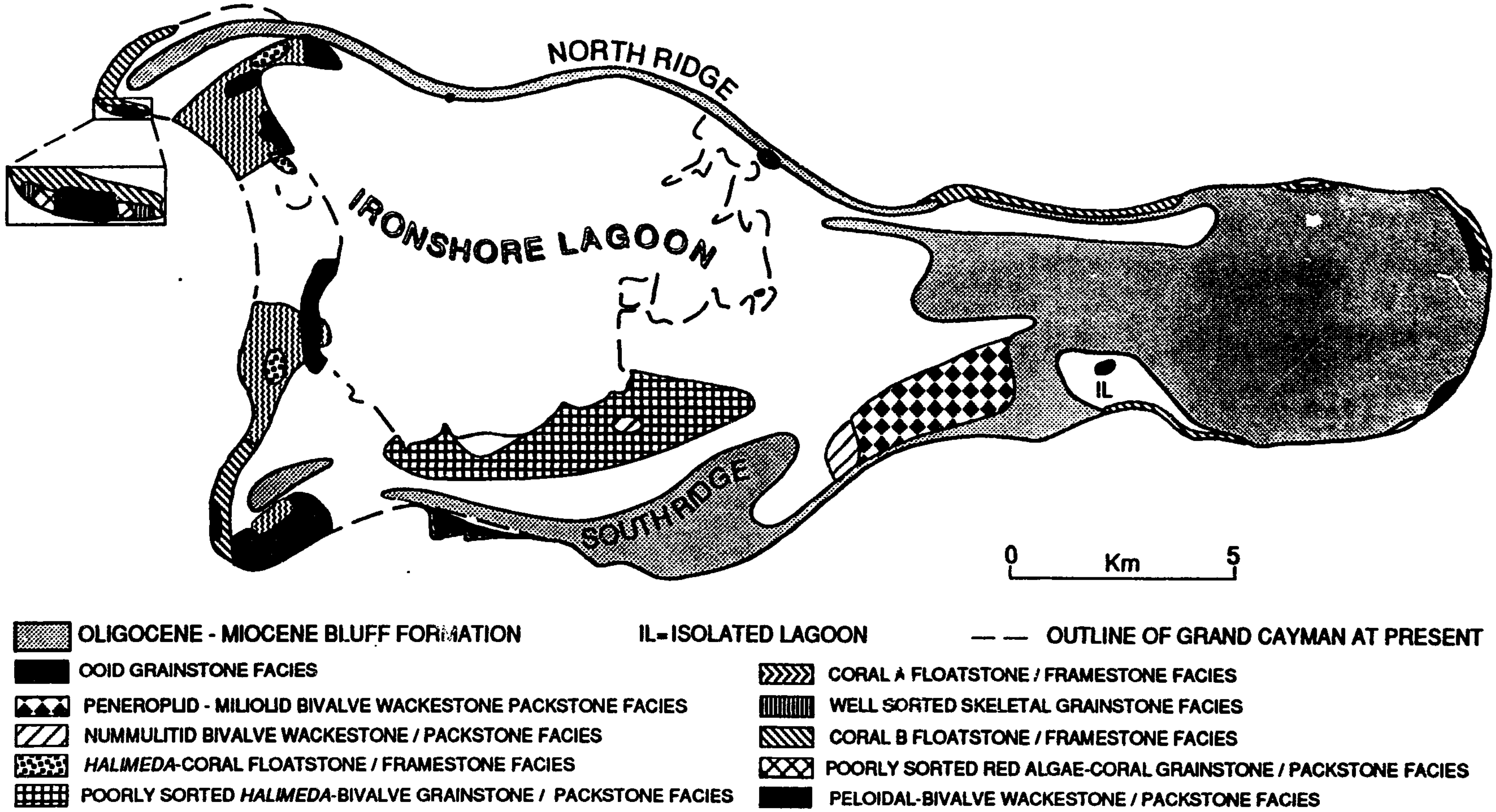

Figure 4.7: Distribution of the microfacies in Division Y of the Ironshore Formation of Grand Cayman, British West Indies. (The ***Multidirectional Cross-Bedded Ooid Grainstone Facies***, ***Unidirectional Cross-Bedded Ooid Grainstone Facies***, ***Laminated Ooid Grainstone Facies***, ***Moderately Burrowed Ooid Grainstone Facies*** and the ***Highly Burrowed Ooid Grainstone Facies*** have been grouped together for the sake of clarity in the above figure.)

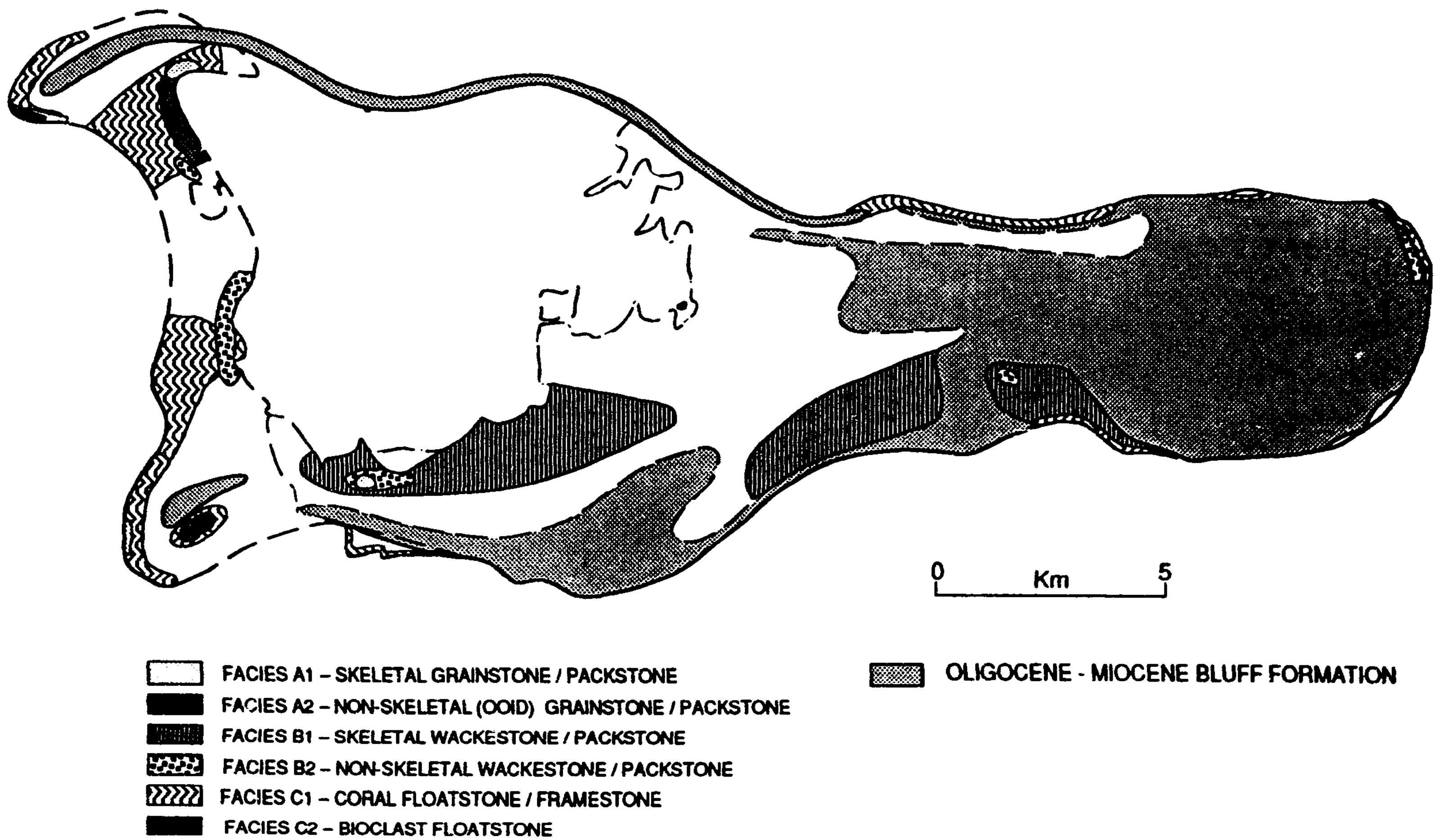

Figure 4.8: Distribution of six facies recognized in Level 2 of facies classification (Fig. 4.5) present in the Ironshore Formation of Grand Cayman.

The level of facies classification chosen determines the resolution at which the depositional architecture of the Ironshore Lagoon can be viewed. Irrespective of the level of facies classification used, their distribution must be viewed from stratigraphic (Figs. 4.9, 4.10) and paleogeographic perspectives (Figs. 4.7, 4.11, 4.12).

Cross-sections I, II, and III (Figs. 4.9, 4.10) clearly show the horizontal distribution of the various facies along the west to east, across the central portion, and from south to north on Grand Cayman.

DIVISION X

The *Poorly Sorted Halimeda – Bivalve Wackestone / Packstone Facies* is the only facies delineated in this division due to the paucity of samples and any other relevant data. Its occurrence at Little Salt Creek (LSC – Fig. 1.5) in the western part of the Ironshore Lagoon (Fig. 4.11), is known from rare core samples obtained during recent drilling (1991). It underlies the ooid grainstones at this locality. This limited data base precludes any further assessment of the lower part of the Ironshore Formation.

DIVISION Y

This division has the best representation of samples among the three divisions of the Ironshore Formation with facies of this division occurring at many localities (Fig. 4.7). The distribution of the different facies is discussed according to the three defined levels of facies division (Fig. 4.5).

Facies Distribution – Level 1

Level 1, involving only four facies (i.e. A, B, C, D – Fig. 4.5), gives a broad view of facies distribution in the Ironshore Lagoon (Fig. 4.6). It does, however, allow identification of major depositional trends. Facies A, consisting of grainstones to

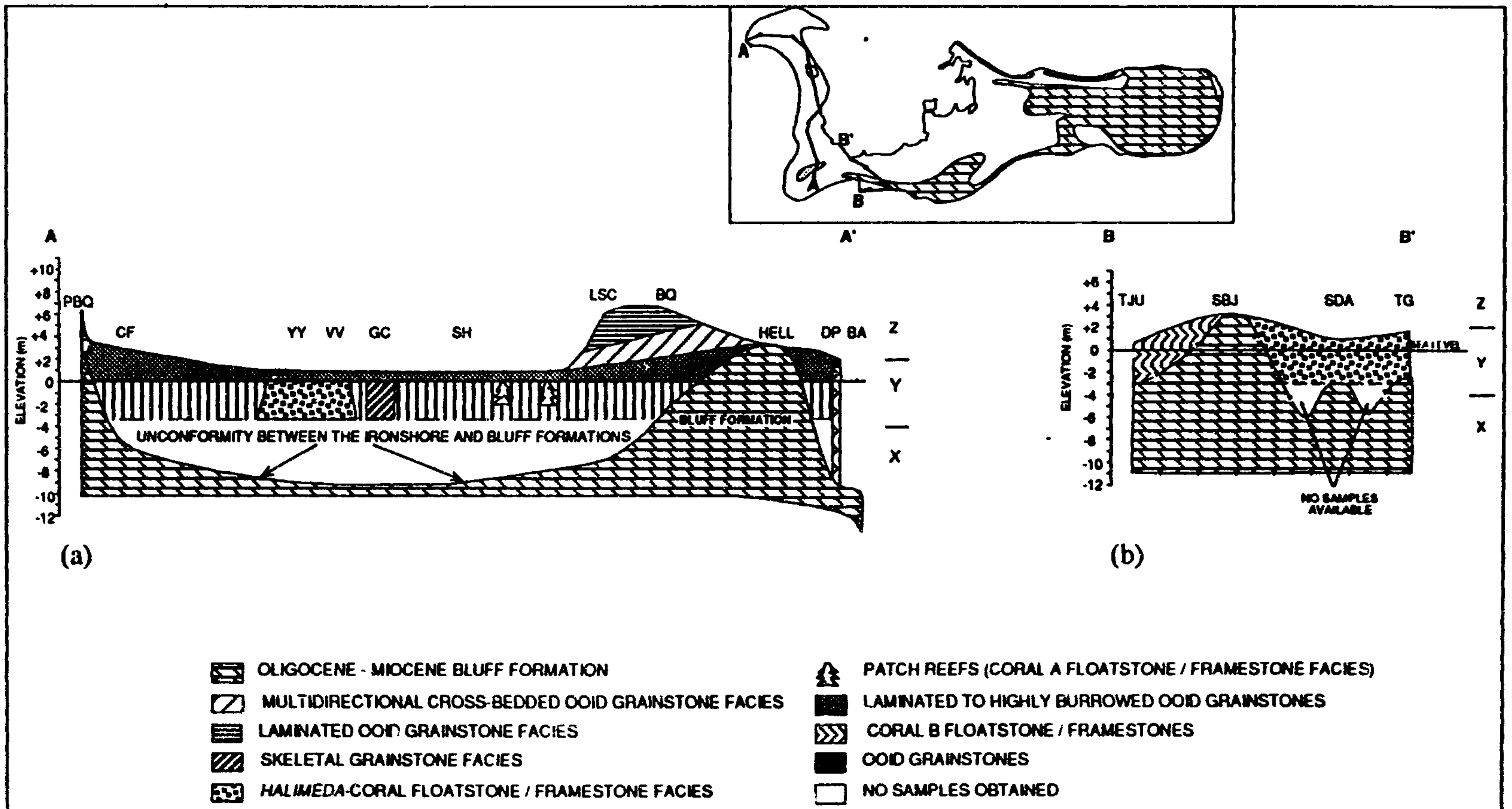

Figure 4.9: (a) Cross-Section I (A-A') across south-north in the western part of Grand Cayman, British West Indies. (b) Cross-section II (B-B') across the central part of Grand Cayman, British West Indies.

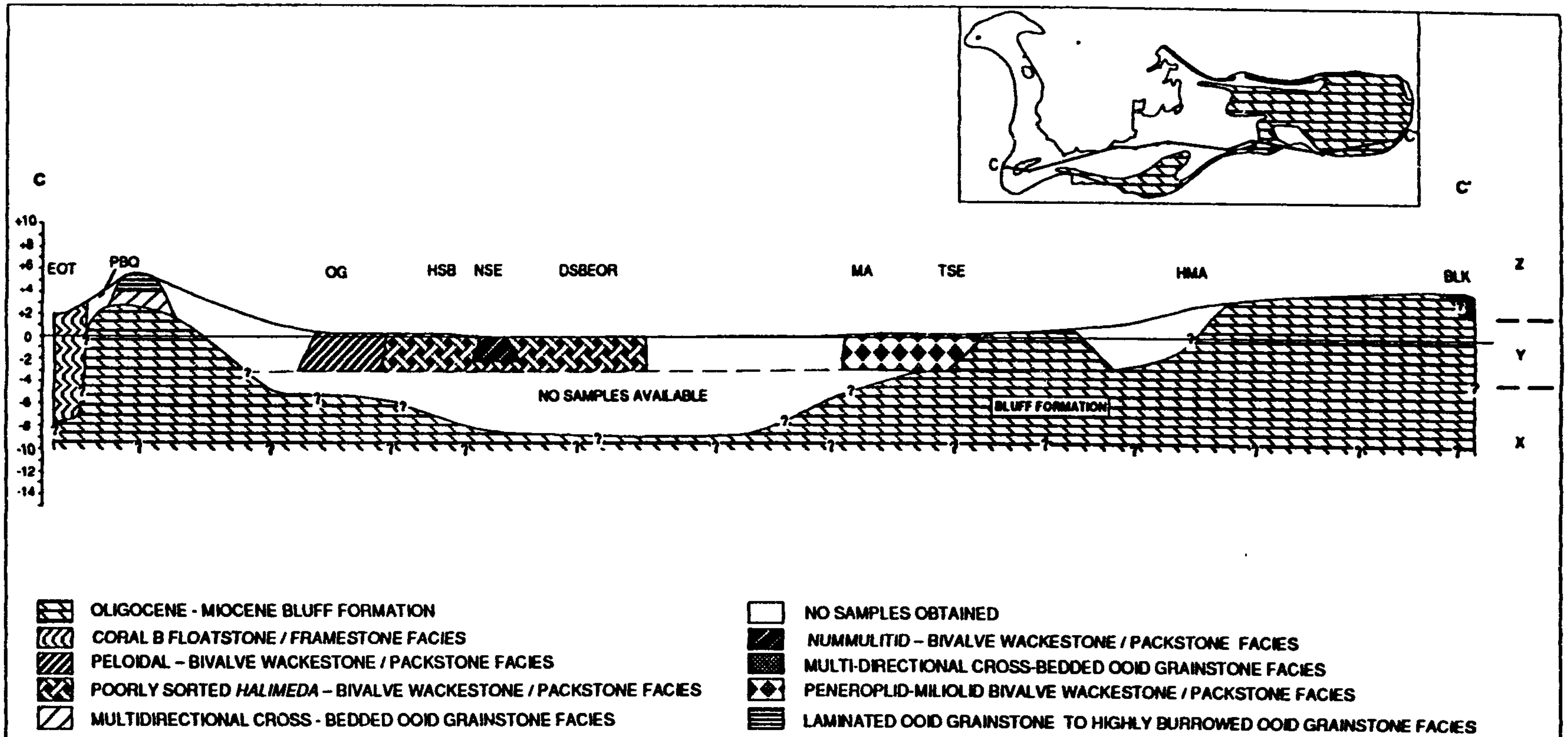

Figure 4.10: Schematic west-east Cross-section III (C-C') across the Ironshore Formation of Grand Cayman.

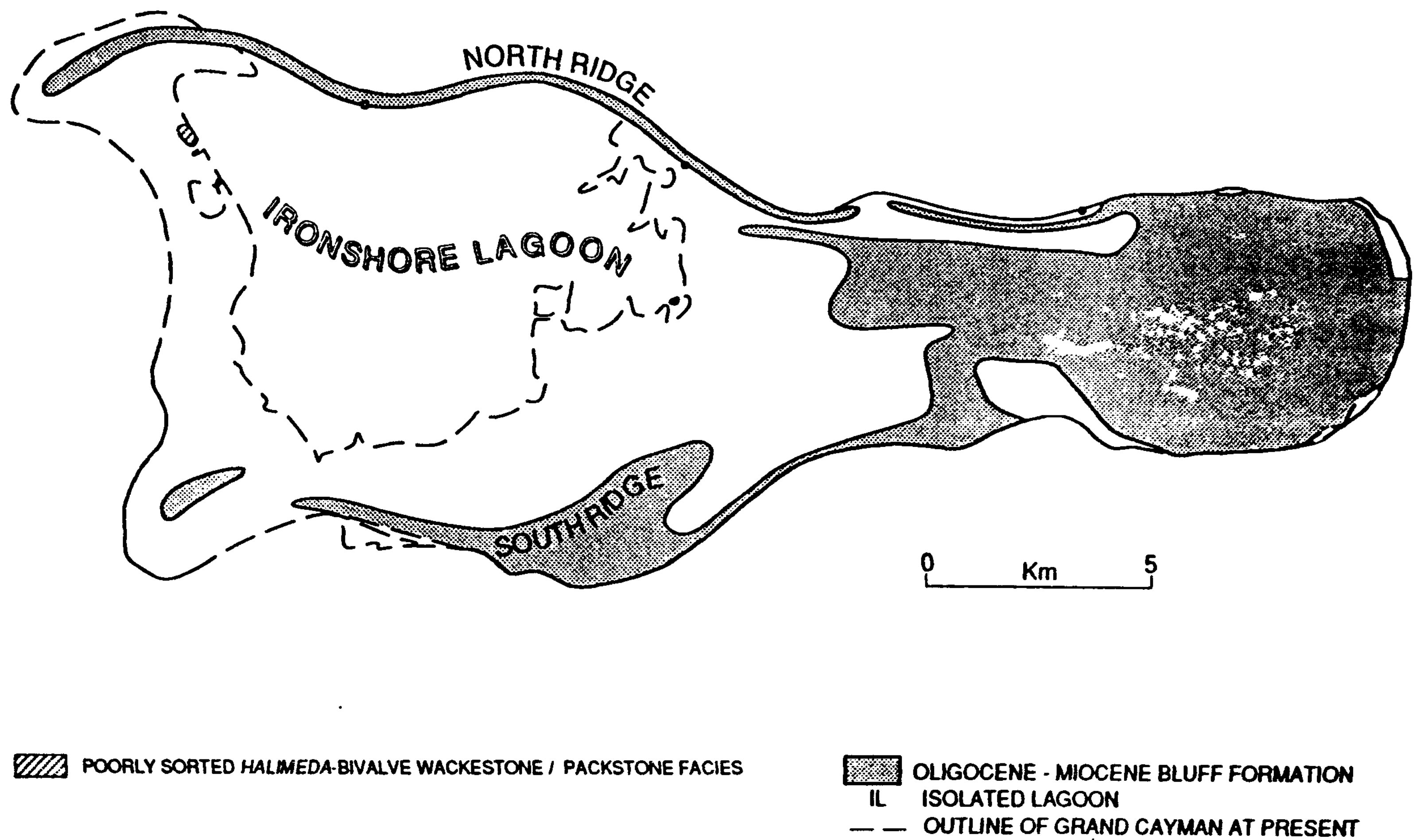

Figure 4.11: Distribution of the facies in Division X of the Ironshore Formation of Grand Cayman.

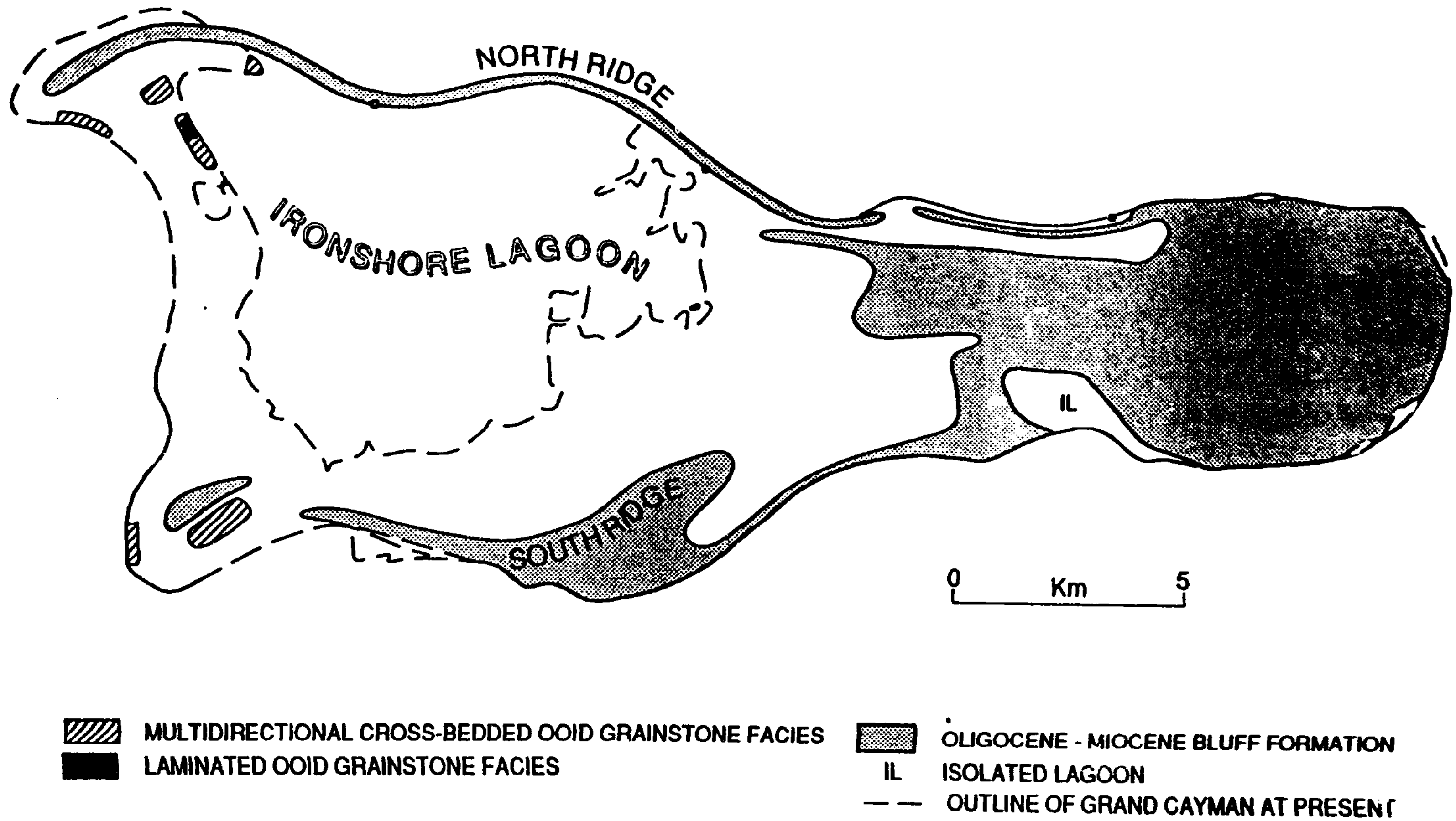

Figure 4.12: Distribution of the facies in Division Z of the Ironshore Formation of Grand Cayman.

packstones, accumulated along the western margin of the Ironshore Lagoon and in some small areas in the eastern part of Grand Cayman (Fig. 4.6). Facies B, consisting essentially of wackestones to packstones, was deposited over most of the central part of the Ironshore Lagoon (Fig. 4.6). The floatstones to framestones of Facies C occur in the west, northeast, and south of Grand Cayman (Fig. 4.6). Facies D, with rudstones as the dominant lithotype, is restricted to a small area around Salt Creek (Fig. 4.6).

Facies Distribution - Level 2

Level 2 divides the facies defined in Level 1 according to the dominant allochem present (Fig. 4.5). Six facies are delineated at this level (Fig. 4.8).

(1) Facies A_1, consisting of skeletal grainstones to packstones, is confined to small areas along the northwest coast.

(2) Facies A_2, dominated by ooid grainstones, occurs at many localities along the northwestern coast of Grand Cayman, and some localities in the west and southwest of Grand Cayman.

(3) Facies B_1, skeletal wackestones to packstones, occurs in the central and southeastern parts of the Ironshore Lagoon and in an isolated lagoon towards the southeast (Fig. 4.8).

(4) Facies B_2, peloidal wackestones to packstones, occurs in a few areas in the central and eastern part and a few localities in the northwestern part of the Ironshore Lagoon.

(5) Facies C_1, coral floatstones to framestones, consists of abundant coral (skeletal) fragments and occurs largely in western Grand Cayman as fringing and patch reefs. It also occurs along the coastline in the northeastern part and along the southern border of an isolated lagoon (Fig. 1.5) towards the southeast (IL – Fig. 4.8).

(6) Facies C_2, occurs at Salt Creek (SC – Fig. 1.5) in the western part of Grand Cayman.

Facies Distribution - Level 3

At Level 3, the Ironshore Formation is divided into 17 facies (Fig. 4.5). As such, it provides a much finer degree of resolution than Levels 1 and 2.

Facies A_1

Facies A_1 is divided into three facies according to the degree of sorting of the allochems (Fig. 4.5). The *Well Sorted Skeletal Grainstone Facies* forms part of an extensive reef tract along the west, northwest, and southwest coasts of Grand Cayman. In contrast, the *Poorly Sorted Red Algae – Coral Grainstone / Packstone Facies* is randomly scattered in small patches in the reef tract along the northwestern and southwestern parts and in a small area in the eastern end of the island (Fig. 4.7). The *Poorly Sorted Skeletal Grainstone / Packstone Facies* shows an irregular distribution between patch reefs on the western and northwestern parts and in the central part of the Ironshore Lagoon (Fig. 4.7).

Facies A_2

This facies is divided into five facies (Fig. 4.5). Three are defined according to lamination style. Of these, the *Unidirectional Cross – Bedded Ooid Grainstone Facies* (Figs. 4.4, 4.9) occurs in this division near Salt Creek (SC – Fig. 1.5). The *Multidirectional Cross – Bedded Ooid Grainstone Facies* and the *Laminated Ooid Grainstone Facies* do not occur in this division. The remaining two facies of Facies A_2 are divided according to the degree of burrowing (Jones and Pemberton, 1989). The *Moderately Burrowed Ooid Grainstone Facies* occurs in the northwestern and southwestern parts of the Ironshore Lagoon whereas the *Highly Burrowed Ooid Grainstone Facies* occurs between the patch reefs in the western part of the Ironshore lagoon.

Facies B_1

This facies is divided into three facies (Fig. 4.5). They are defined on the basis of their dominant skeletal allochems.

The *Peneroplid – Miliolid Bivalve Wackestone / Packstone Facies* occurs in the south-central part and the southeastern end of the Ironshore lagoon (Fig. 4.7, 4.10) whereas the *Nummulitid – Bivalve Wackestone / Packstone Facies* is restricted to an isolated lagoon located southeast of the Ironshore Lagoon (Fig. 4.7). The *Poorly Sorted Halimeda – Bivalve Wackestone / Packstone Facies*, which is the third facies in this group, covers the central part of the Ironshore Lagoon (Fig. 4.7).

Facies B_2

The *Peloidal – Bivalve Wackestone / Packstone Facies* (Fig. 4.5), occurs in isolated patches in the eastern, western and northwestern parts of the Ironshore Lagoon (Figs. 4.7).

Facies C_1

This facies includes three facies (Fig. 4.5). The *Coral A Floatstone / Framestone Facies* and the *Halimeda – Coral Floatstone / Framestone Facies* (Figs. 4.5, 4.7, 4.9, 4.10) form patch reefs in the western part of the Ironshore Lagoon.

Part of the extensive reef tract along the west, northwest, and southwest coasts of Grand Cayman includes the *Coral B Floatstone / Framestone Facies* (Figs. 4.5, 4.7). It directly overlies the Bluff Formation (Fig. 4.10) at locality EOT (Fig. 1.5).

Facies C_2

This facies, the *Bioclast Floatstone Facies*, was deposited on top of the large tabular lithoclasts that occur on the erosional surface at Salt Creek (SC – Fig. 1.5).

Facies D

This facies, the *Lithoclast Rudstone Facies*, is only exposed at Salt Creek (SC – Fig. 1.5).

DIVISION Z

The two facies in Division Z are facies of Facies A_2 (Fig. 4.5). Both facies are exposed at various localities along the western margin of present day North Sound and in the northwestern and southwestern parts of the Ironshore Lagoon. They are restricted in lateral distribution and are not as widespread as those in Division Y. The *Multi-directional Cross – Bedded Ooid Grainstone Facies* (Figs. 4.4, 4.9, 4.10) was deposited on large tabular lithoclasts that lay on erosional surfaces at Little Salt Creek (LSC), Salt Creek (SC), Botabano (BQ) and Paul Bodden's Quarries (PBQ – Fig. 1.5). It overlies the *Poorly Sorted Skeletal Grainstone / Packstone, Moderately Burrowed Ooid Grainstone, Highly Burrowed Ooid Grainstone*, (Figs. 4.9, 4.10), *Coral A Floatstone / Framestone* and the *Coral B Floatstone / Framestone Facies* respectively in different parts of Grand Cayman.

The second facies in this division is the *Lan ıated Ooid Grainstone Facies* (Fig. 4.12) which occurs in the Paul Bodden's (PBQ, PBA – Fig. 1.5) and Botabano (BQ – Fig. 1.5) Quarries, Little Salt Creek (LSC – Fig. 1.5) and Smith's Barcadere (SBA – Fig. 1.5) in the western part of Grand Cayman. The two facies form a part of the '*Ooid Grainstone Facies*' (Fig. 4.7, 4.10) which also includes other ooid facies such as the *Unidirectional Ooid Grainstone Facies* and the *Moderately and Highly Burrowed Ooid Grainstone Facies*.

CHAPTER 5
PALEOECOLOGIC INTERPRETATIONS

INTRODUCTION

The Ironshore Formation consists of a wide array of facies, most of which occur in Division Y. The distribution and thickness of the Ironshore Formation on Grand Cayman places general constraints on the overall nature of depositional conditions during the Late Pleistocene. Paleogeographic reconstruction suggests that most of the Ironshore Formation was deposited in a large enclosed lagoon (the Ironshore Lagoon) that opened to the Caribbean Sea at its western margin. Information on the paleoecological conditions that existed in the Ironshore Formation can be obtained by (a) comparing it with the modern day North Sound, and (b) integrating data derived from interpretation of its lithofacies and biofacies. To facilitate this discussion, the facies architecture of North Sound is briefly discussed.

NORTH SOUND

North Sound, the largest lagoon on Grand Cayman, is a shallow dish-shaped basin with water depths to 5 m (Fig. 5.1). A reef along its northern margin acts as a barrier between the lagoon and the Caribbean sea (Fig. 5.1). Well lithified limestones, similar to those in the Ironshore Formation, form the floor of this sound, on which the modern sediments occur (Roberts, 1976). In general, there is an increase in the concentration of fine-grained sediments towards the centre of North Sound. Near the fringing reef, the sediments are thicker and sand to cobble sized with little mud. In contrast, the southern and western areas are characterized by a thin coating of calcareous mud (Roberts, 1971). Nearly all the sediments, however, display poor to very poor sorting except in the northern part, where they are well to moderately sorted. North Sound also shows a considerable variation in salinity with values up to 42 ‰ in the central part of the sound. In some areas,

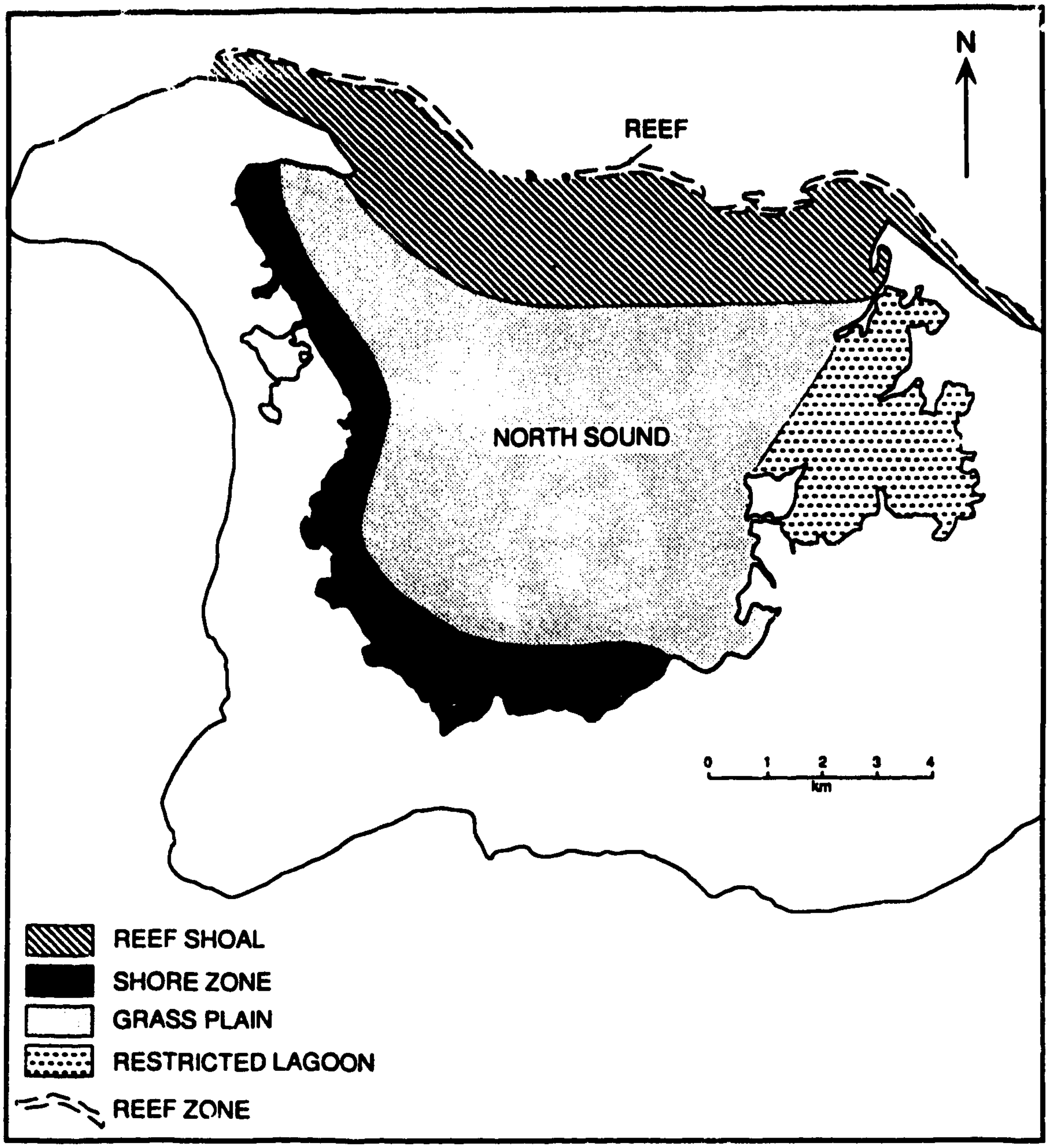

Figure 5.1: Major environmental subdivisions of North Sound (modified from Roberts, 1971).

salinity variations exist due to the influx of brackish to fresh water from the central part of the island. Temperatures are slightly elevated. The waters are moderately clear in all parts of North Sound. Increased turbidity occurs along the southern and western margins, however, due to the concentration of waters rich in organic material from the mangrove swamps that occur around North Sound.

Roberts (1971) divided North Sound into the (1) shore zone, (2) grass plain, (3) restricted lagoon, and (4) reef shoal environments (Fig. 5.1) on the basis of textural properties of sediments, submarine topography, energy conditions, and biota occurrence. The reef at the north edge of North Sound can be regarded as a fifth zone. The distribution of marine organisms is largely controlled by the submarine topography and the substrate conditions (Roberts, 1976).

Shore Zone

The shore zone consisted of small colonies of *Porites* and *Siderastrea* and also showed an abundance of calcareous green algae.

Grass Plain

The grass plain environment is a shallow water, low energy environment. It contains fine sand to mud sized sediments. It has more *Thalassia* than the restricted lagoon and abundant calcareous green algae. The foraminiferal population is dominated by peneroplids and miliolids.

Restricted Lagoon

The restricted lagoon is a deeper, lower energy environment. It is similar to the grass plain in its diversity of organisms and energy conditions. Fine sand to mud sized sediments occur in this environment. The large molluscan population is dominated by the bivalves *Chione* sp. and *Codakia* sp. and the gastropods *Cerithium* sp. and *Astraea* sp.

Reef Shoal

The reef shoal is a shallow water, high energy environment with hard and soft bottom communities. The sediments are cobble to sand sized. A series of small patch reefs formed of *Montastrea*, *Diploria* and *Siderastrea* occur landward of the reef on the northern margin of North Sound. *Acropora palmata* dominates along the southern margin of the reef zone. Brown and green algae are also present.

Reef Zone

The reef zone is a high energy environment with the reef providing hard substrates for the organisms to live on. The dominant corals in this zone are *Acropora palmata*, *Agaricia agaricites*, *Diploria strigosa*, and *Montastrea annularis*. Encrusting coralline algae are common whereas echinoids are rare in this zone.

IRONSHORE LAGOON

Water Depth

The absolute maximum water depth is given by the difference in elevation between the Bluff-Ironshore unconformity and the Late Pleistocene sea level which is known to be 6 m above present day sea level. This would be up to 23 m if the maximum thicknesses of the Ironshore Formation as given by Brunt *et al.* (1973) are accepted (Fig. 5.2). In many areas, however, the maximum absolute water depth must have been on the order of 11 to 14 m (Fig. 5.2). At ORA1, for example, the maximum possible water depth was 11.9 m whereas at SH2, it was 13.8 m. Such figures place a limit on the maximum water depth under which the limestones of the Ironshore Formation were deposited. Such depths, however, do not take into account the rate of sea level rise to its highstand at +6 m or the thickness of sediment that existed on the floor of the Ironshore Lagoon at any given point in time. Collectively, both factors mean that the calculated water depths must be regarded as absolute and probably extreme maxima. Even the 12 to 14 m depth calculated for

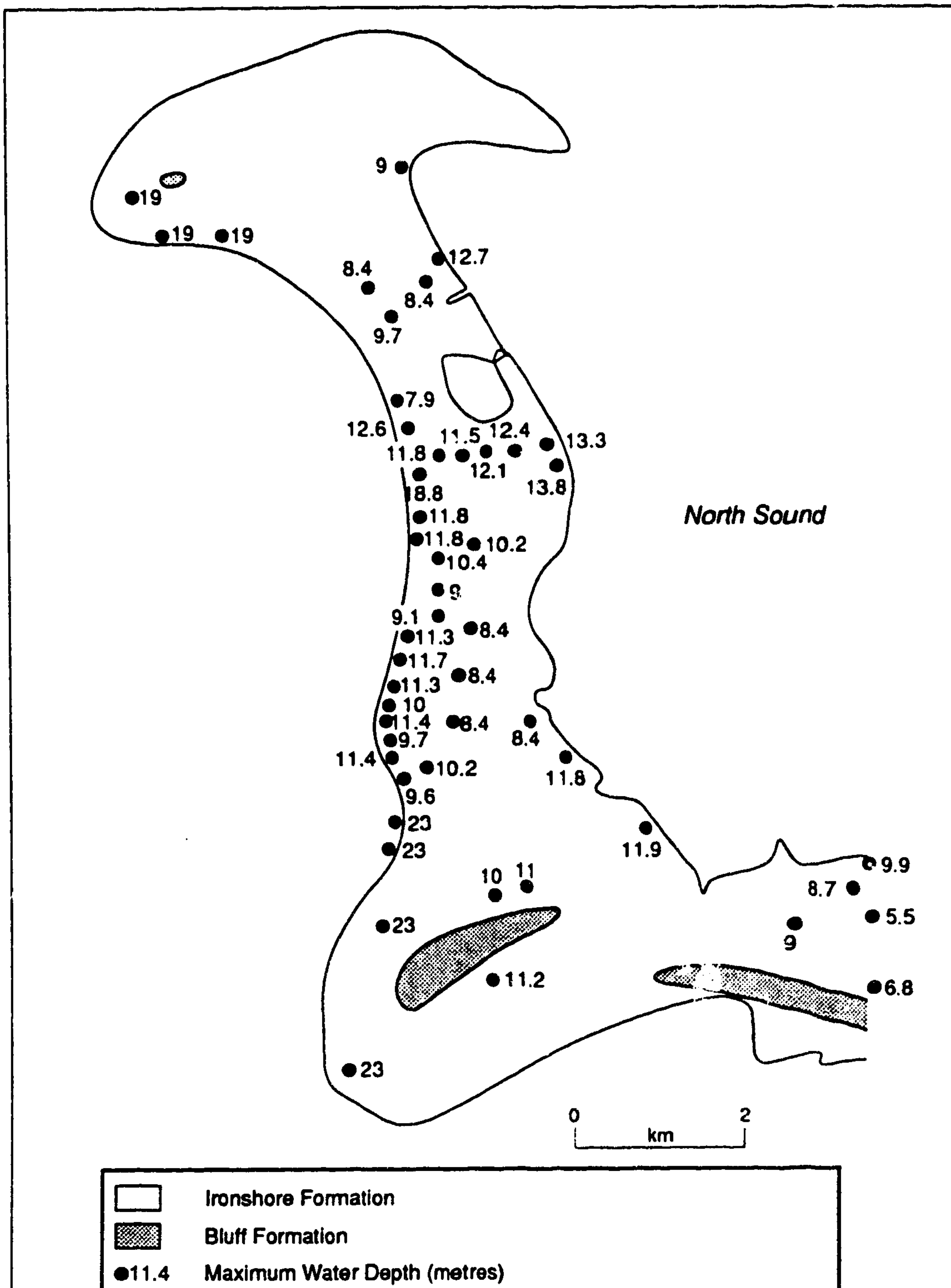

Figure 5.2: Maximum possible water depths present during the Pleistocene highstand of sea level at different localities of the Ironshore Formation in the western part of Grand Cayman.

most localities is probably too high. For example, most of the limestones presently found in Division Y (-4 m to +2 m relative to modern day sea level) must have formed in water that was less than 8 to 10 m deep.

Despite the problems associated with these calculated maximum water depths, they do constrain any discussion concerning depositional conditions of the limestones of the Ironshore Formation.

DEPOSITIONAL ENVIRONMENTS

Analysis of all the available information allows the Ironshore Lagoon to be divided into the (1) Inner Lagoon, (2) Patch Reefs, and (3) Reef Tract (Fig 5.3).

Inner Lagoon

The Inner Lagoon was a low energy, shallow water, protected environment favorable for the accumulation of fine-grained sediments (Fig. 5.3). These sediments were formed almost entirely of skeletal calcium carbonate.

A diverse abundant biota dominated by bivalves and gastropods characterized the Inner Lagoon. Burrowing bivalves dominated the fauna. The bivalves were predominantly infaunal suspension feeders along with lesser numbers of deposit and suspension feeding types. In addition to the carnivorous and grazing gastropods, there were gastropods such as *Tricolia thalassicola* that today live on the leaves of *Thalassia* (Jones and Hunter, 1990). This suggests that *Thalassia* covered much of the seafloor in the Inner Lagoon. In many areas, there must have been large bivalve populations because samples of the Ironshore Formation from localities TSE, OG (Fig. 1.5,) contain thousands of closely packed shells (Plate IIIF). The bivalve population was characterized by *Chione* sp. and *Codakia* sp.

Corals were scarce in the Inner Lagoon. Small colonies of *Siderastrea siderea* and *Porites divaricata* occurred with lesser numbers of *Diploria strigosa*, *Manicina areolata*, and *Agaricia agaricites* (Jones and Hunter, 1990). Foraminifera, with a dominance of

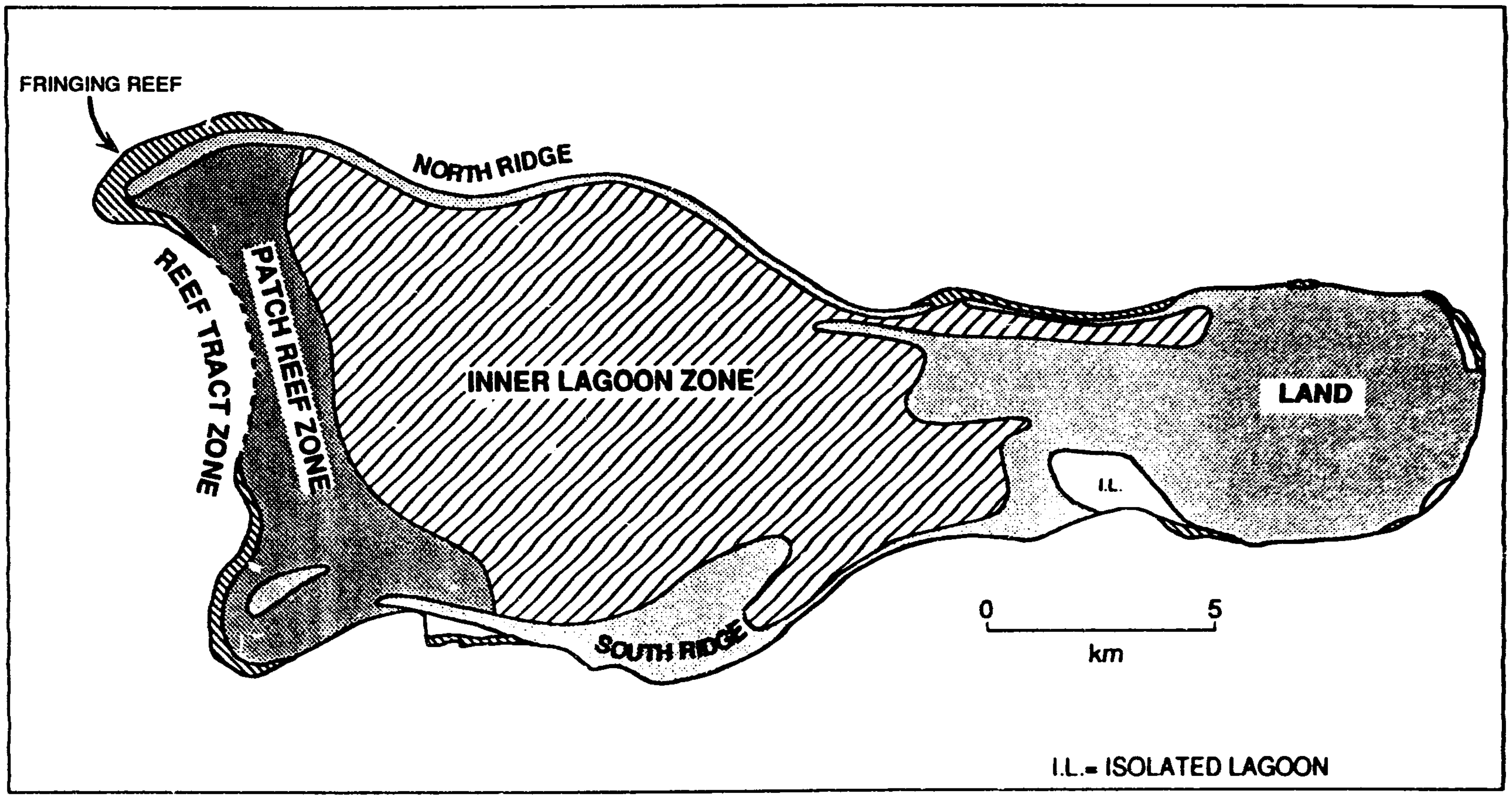

Figure 5.3: Three main depositional zones of the Late Pleistocene Ironshore Lagoon on Grand Cayman (modified from Hunter and Jones, 1988).

peneroplids and miliolids, were abundant in the southeastern part of the Inner Lagoon whereas *Halimeda* was abundant in the central and southern parts. Echinoids were rare.

In the Inner Lagoon, the maximum water depth during the deposition of the different facies was 8 to 10 m. The waters were moderately turbid in the Inner Lagoon except during storms, when turbidity probably increased. Salinity was probably normal marine to slightly elevated in most parts as indicated by the dominant molluscan population and the foraminiferal species present.

The Inner Lagoon was probably equivalent to the Shore, Grass Plain and Restricted Lagoon zones of North Sound (Fig. 5.3) as shown by the striking similarity in the faunal populations and the abundance of *Halimeda* and *Thalassia*.

Patch Reefs

A zone of patch reefs occurred in the western part of the Ironshore Lagoon (Fig. 5.3). These patch reefs, up to 300 m in diameter, were formed of a diverse coral fauna. The larger patch reefs were dominated by *Diploria*, *Montastrea*, and *Siderastrea*. Small patch reefs and scattered coral colonies occurred in the centr... nd northern part of this zone. The small patch reefs had a less diverse fauna, with some of them consisting of only *Porites porites*. The large patch reefs were zoned whereas the smaller ones were not. The patch reefs were also home for a large assemblage of bivalves which resided in the cavities between the corals (e.g. *Barbatia* sp.) or cemented themselves to the hard substrates (e.g. *Pseudochama radians*).

Some corals (e.g. *Montastrea annularis*, *Porites astreoides*) were bored by the bivalve *Lithophaga* (Jones and Pemberton, 1988). Such boring must have significantly weakened the coral heads and made them more vulnerable to erosion, liberated large amounts of $CaCO_3$, considerably increased the area for erosional activities of sponges, algae, and fungi, strengthened the substrate by binding it with the calcareous linings around the borings, and provided microcavities for sediment accumulation and cement precipitation

(Jones and Pemberton, 1988). Lesser amounts of coral bioerosion can be attributed to the activity of sponges and worms.

The carbonate silts and sands between the patch reefs (Hunter and Jones, 1988) were inhabited by a different biota. Among the molluscan species present, bivalves were commonly of the epibyssate, suspension feeding, boring and nestling types (e.g. *Arca* sp. and *Barbatia* sp.). *Americardia guppyi*, *Chione* sp., *Codakia* sp., *Ervilia concentrica*, *Crassinella martinicensis*, *Linga pensylvanica*, *Pitar fulminatus* and *Cerithium* sp. were common in these areas. Dominance of infaunal suspension feeders at some localities (MOA, CYB, CNP, GC, M, PWA, PWD, SDC, TG, NSE, SD, SDA, SDB, VV – Fig. 1.5) reflects the reduced availability of epifaunal niches compared to the nearby patch reefs (Cerridwen and Jones, 1991). Acrid and chamid bivalves dominated at localities BTD, C, D, F and G (Fig. 1.5). These bivalves were, however, different from the bivalves in the Inner Lagoon (e.g. at Midland Acres (MA) and Tarpon Spring Estates (TSE – Fig. 1.5)). Free-living and grazing gastropods occurred in the sediment between the patch reefs. The abundance of *Ophiomorpha*, *Polykladichnus* and *Skolithos*, suggests that these sediments were actively burrowed by shrimp and various worms.

The water depth in this zone was 4 to 10 m. Energy levels were probably slightly higher than in the Inner Lagoon. The absence of corals, such as *Meandrina meandrites*, *Isophyllia* sp., that were incapable of sediment rejection suggests that the water of this zone was slightly turbid. This zone is probably equivalent to the reef shoal environment in North Sound (Fig. 5.1).

Reef Tract

The reef tract formed the western margin of the Ironshore Lagoon (Fig. 5.3). The diverse biota of this zone was dominated by corals along with fewer bivalves and gastropods. Corals included *Montastrea*, *Diploria*, *Acropora palmata*, *Acropora cervicornis*, *Meandrina meandrites*, *Pocillopora*, and *Dendrogyra cylindrus*. Near Smith's

Barcadere (SB) and Sunset House (SH – Fig. 1.5), the coral community, dominated by *Porites porites*, includes *Acropora cervicornis*, *Montastrea annularis*, *Dendrogyra cylindrus*, and *Pocillopora* (Hunter and Jones, 1988). At Dolphin Point (DP – Fig. 1.5), numerous corals such as *Acropora palmata*, *Montastrea annularis*, *Porites porites*, and *Diploria strigosa* occur in life position. The bivalve population of the reef tract included epifaunal byssate types such as *Barbatia cancellaria* and *Barbatia domingensis* along with lesser numbers of the suspension feeding infaunal bivalves. Burrowing bivalves were scarce because of the lack of soft sediment. Boring bivalves were also rare along the reef tract with the exception of one specimen (*Lithophaga*) at locality BTD (Jones and Pemberton, 1988). The restriction in bivalve numbers was probably related to the higher energy levels in the reef tract compared to the patch reefs. Grazing and carnivorous gastropods also inhabited the reef tract (Cerridwen and Jones, 1991). The fauna at localities TFB, DPQ and EOT (Fig. 1.5), which differs from that of the other reef localities by having *Lithopoma tectum*, *Columbella mercatoria*, *Cypraea* sp., *Latirus carinifer*, *Patelloida pustulata*, and *Lucapina suffusa*, reflects the abundant epifaunal niches that were available.

Foraminifera were common in the reef tract. At Smith's Cove (SB – Fig. 1.5), they occurred in large numbers in the oolitic limestones. Red algae commonly coated the hard coral substrates. Conversely, *Halimeda* was scarce and echinoids rare.

Water depth during deposition [illegible] various facies of the reef tract was 4 to 10 m. The abundance of *Acropora palmata* in the reef tract, which is ineffective at sediment rejection, suggests that the water was clear and had no turbidity. The salinity was probably normal marine in all parts of the reef tract.

This zone is equivalent [illegible] the Reef Zone environment along the northern margin of North Sound (Fig. 5.3) as indicated by the dominance of *Acropora palmata* and the occurrence of *Agaricia*, *Diploria*, *Siderastrea*, and *Montastrea*.

FACIES EVOLUTION THROUGH TIME

Facies in the Ironshore Formation represent subtidal to intertidal to high intertidal depositional settings. The Ironshore Formation exhibits vertical facies changes that record the change in facies through time and therefore provide valuable information on progressive change in depositional conditions. Collectively, the succession represents a shallowing upward sequence (Fig. 5.4). Deposition probably took place with a progressive increase in sea level. The deposits below 4 m below sea level are difficult to characterize from a depositional perspective because of the paucity of data. The information that is available suggests deposition in a subtidal setting.

Most facies in the Ironshore Formation originated in a subtidal setting, probably in water that was 5 to 10 m deep. Near the top of Formation, however, there is evidence for progressive shallowing and a substantial change in the depositional architecture of the area. These changes were initially manifested as erosional features that dissected previous deposited subtidal facies. For example, at Salt Creek (SC – Fig. 1.5), two channels, informally called the north (NC1) and south (SC1) channels, were cut into these subtidal deposits (Hunter and Jones, 1989b; Jones and Hunter, 1990) (Fig. 5.4). Firmgrounds developed on the floors of these channels indicate that little sediment was deposited in these areas for some period of time (Jones and Pemberton, 1989). Periodic high energy events, however, did result in large tabular lithoclasts being brought into the area at the base of NC1 and SC1 channels (Fig. 5.4).

Channel SC1 was subsequently filled with ooid grainstones that underwent considerable burrowing. At some places, numerous bioclasts in a matrix of well sorted ooids covered the tabular lithoclasts that lay on the floor of this channel. Channel NC1 was filled in with multidirectional cross-bedded ooid grainstones which were deposited on top of the large tabular lithoclasts at the base. These show a lateral change to moderately burrowed ooid grainstones (Fig. 5.4). A new channel (NC2 – Fig. 5.4) was produced by

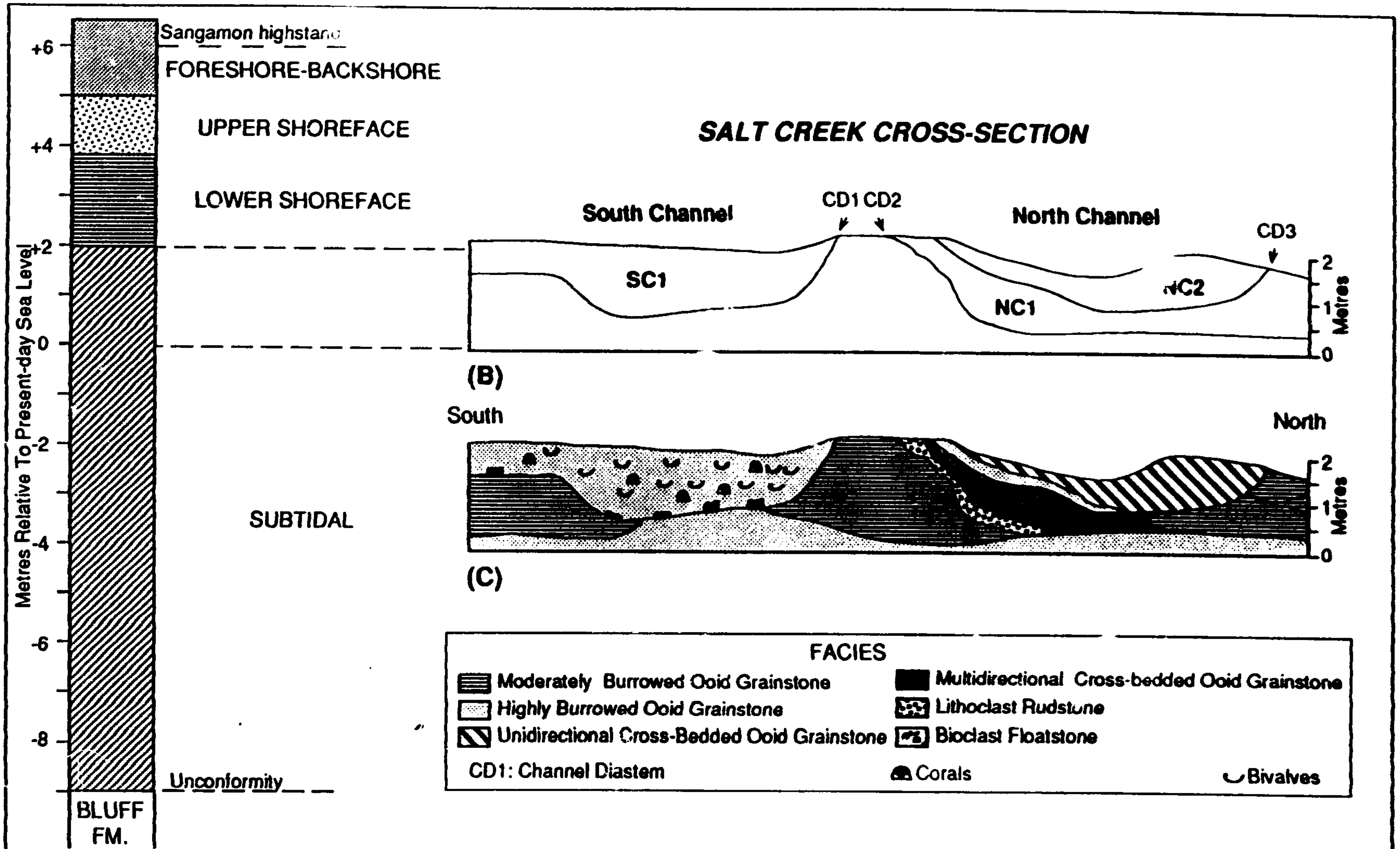

Figure 5.4: (A) Shallowing upward sequence in the Ironshore Formation on Grand Cayman.
(B) Cross-section at Salt Creek showing channels cut into the subtidal deposits.
(C) Various facies deposited into these channels.

a later event of erosion northward of Channel NC1. It was later filled with unidirectional cross-bedded ooid grainstones.

In addition to the above, differentially burrowed ooid grainstones were deposited at Little Salt Creek (LSC), Salt Creek (SC), Botabano (BQ) and Paul Bodden's (PBQ) Quarries, Localities L, M, N, and Morgan's Harbour (MHA – Fig. 1.5) under quiet water conditions (Hunter and Jones, 1989b).

Overlying the subtidal deposits are the Lower Shoreface deposits, which consist of skeletal and ooid grainstones occurring up to 2.2 m below sea level (Jones and Hunter, 1990). The oolitic limestones at Paul Bodden's (PBQ, PBA) and Botabano (BQ) Quarries, The Shores (TS), Salt Creek (SC) and localities L, M, N (Fig. 1.5) are locally cross-bedded and showed variable bioturbation. Many of the sedimentary structures have been destroyed by burrowing.

The Upper Shoreface deposits, which overlie the Lower Shoreface deposits and occur up to 1 m below sea level, are composed of cross-bedded ooid grainstones. These show variable bioturbation on a small scale.

The Foreshore-Backshore deposits, occurring up to 0.5 m above sea level, are composed of cross-bedded ooid grainstones. They display low angle and horizontal laminations.

COMPARISON OF THE PLEISTOCENE IRONSHORE LAGOON WITH PRESENT-DAY NORTH SOUND

North Sound (Fig. 1.5) appears to be a good modern analog for the Ironshore Lagoon (Fig. 1.4). It is smaller in extent than the Ironshore Lagoon. The five environments differentiated in North Sound (Fig. 5.1) are similar to those proposed for the Ironshore Lagoon (Fig. 5.3) although they have a north-south as opposed to a west-east orientation.

Sediment distribution in the Ironshore Lagoon shows a change from coarser sand sized sediments in the Reef tract and Patch reefs zones to mud sized sediments in the Inner

Lagoon (Table 5.1). This trend is similar to the fining of sediments from the outer margins towards the centre of North Sound (Roberts, 1976). Energy levels in the Ironshore Lagoon gradually become higher westwards from the Inner Lagoon towards the Patch reefs and Reef tract zones (Table 5.1). They show a similar change in North Sound, where high energy conditions prevail in the reef shoal environment, but gradually decrease towards the low energy, quiet conditions in the restricted lagoon (Roberts, 1976).

Two more factors which strengthen the comparison between the Ironshore Lagoon and North Sound are salinity and turbidity. Most of the Ironshore Lagoon developed under normal marine conditions although it is possible that some areas of the Inner Lagoon Zone had elevated salinities. Considerable variation in salinity in the waters of North Sound is due to the influx of brackish and fresh water from the central portion of the island along the eastern margin. Turbidity decreases from moderate to high in the Inner Lagoon to being virtually absent in the Reef tract zone of the Ironshore Lagoon (Table 5.1) and follows the same general trend of decrease from the Shore Zone to the Reef Zone environments of North Sound.

Another striking similarity between the Inner Lagoon zone of the Ironshore Lagoon and North Sound is the occurrence of the marine grass *Thalassia* on the seafloor. *Thalassia* covers about 60 % of the floor of North Sound while evidence suggests the floor of the Ironshore Lagoon was also extensively covered by *Thalassia*. Also, the green algae *Halimeda* is concentrated in the Inner Lagoon and shows a decrease towards the Reef Tract Zone. This change in *Halimeda* concentrations from the Inner lagoon to the Reef Tract Zone of the Ironshore Lagoon is similar to the increase in *Halimeda* lagoonward from the reef shoal environment (Fig. 5.1) of North Sound (Table 5.1).

In addition to the common features summarized above, the fauna in the zones of the Ironshore Lagoon bears striking resemblance to that present in the different environments of North Sound.

ZONES OF THE IRONSHORE LAGOON		Inner Lagoon Zone	Patch Reefs Zone	Reef Tract Zone
WATER DEPTH (Below Sangamon sea level)		Maximum=10m	4-10m	4-10m
SALINITY		Normal to slightly elevated	Normal	Normal
TURBIDITY		Moderate to high	Minimal	None
ENERGY LEVELS		Low	Moderate	High
SUBSTRATES		Soft	Soft to Hard	Hard
BOTTOM CONDITIONS		Muddy	Sandy	Sandy
DOMINANT BIOTA	Gastropods	Abundant	Abundant	Scarce
	Bivalves	Abundant	Abundant	Abundant
	Corals	Scarce	Abundant	Abundant
	Foraminifera	Abundant	Rare	Abundant
	Halimeda	Abundant	Scarce	Scarce
	Red Algae	Scarce	Rare	Common
	Echinoids	Rare	Rare	Rare
	Thalassia	Common	Absent	Absent
BURROWING		Common	Scarce	Scarce
ENVIRONMENT		Shallow and Protected	Patch reef	Reef tract

Table 5.1: Summary of depositional conditions and dominant biota present in the three zones of the Ironshore Lagoon on Grand Cayman.

All of the above similarities between the Pleistocene Ironshore Lagoon and the present day North Sound confirm that it is a good modern analog for the depositional conditions and environments that existed in the Ironshore Lagoon during the Pleistocene.

CONCLUSIONS

The Late Pleistocene Ironshore Formation of Grand Cayman formed approximately 125,000 years ago when sea level was approximately 6 m above present day sea level. Detailed analysis of the limestones from this formation allowed the following conclusions to be made.

1. The Ironshore Formation of Grand Cayman contains seventeen facies that are defined on the basis of their sedimentological and paleontological characteristics.
2. The Ironshore Formation is 2 m to 13.7 m thick with the thickest part being on the central part of the western peninsula of Grand Cayman. The variation in the thickness reflects the uneven topography developed on the underlying Tertiary rocks prior to the Late Pleistocene.
3. The limestones in the Ironshore Formation form a gradual shallowing upward sequence that formed in response to progressively shallowing conditions.
4. Sample availability meant that the Ironshore Formation was divided into three defined divisions. The little information available on Division X (from base of the formation to -4 m) suggests deposition in subtidal conditions. Division Y (-4 m to +2 m) includes a broad array of subtidal facies that developed in a wide range of depositional settings. Division Z, well exposed above sea level (+2 to +6 m), includes shallow subtidal to upper intertidal deposits.
5. The Ironshore Formation on the western part of Grand Cayman was deposited in the Ironshore Lagoon that was divided into the Inner lagoon, Patch reefs, and Reef tract zone. The Inner Lagoon, characterized by shallow, quiet-water conditions, was covered by *Thalassia* and was home to a diverse fauna of bivalves and gastropods. The Patch Reef Zone, characterized by slightly higher energy conditions, was characterized by patch reefs formed of various corals and bivalves. The areas between the reefs

were covered by skeletal sands. The reef tract, which formed the barrier to the lagoon, was formed of a diverse coral fauna.

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Appendix A: List of localities on Grand Cayman where samples from the Ironshore Formation have been collected showing the codes and the exact locations. UTM=UNIVERSAL TRANSVERSE MERCATOR.

CODE	NAME	UTM - N	UTM - E
A		2136220	460290
ABA	West Bay Coast	2141810	456950
ABB	West Bay Coast	2141780	457110
ABC	West Bay Coast	2141770	457220
ABD	West Bay Coast	2141780	457160
ACA	West Bay Coast	2141810	456870
ACB	West Bay Coast	2141800	456800
ACC	West Bay Coast	2141790	456720
ACD	West Bay Coast	2141790	456620
ACE	West Bay Coast	2141770	456480
ACF	West Bay Coast	2141780	456360
ACG	West Bay Coast	2141780	456270
ACH	West Bay Coast	2141890	456100
ACI	West Bay Coast	2141820	456080
AIR	Airport	2133200	461890
AS	Atlantis Submarine	2133230	459520
B		2141040	459820
BEA	Belford Estates-A		
BEB	Belford Estates-B		
BK	Burger King	2134060	459710
BLK	Blakes	2134610	489790
BQ	Botabano Quarry	2142700	459300
BTA	Birch Tree - A	2143820	457300
BTB	Birch Tree - B	2143860	457390
BTC	Birch Tree - C	2143910	457070
BTD	Birch Tree - D	2143960	457560
BTE	Birch Tree - E	2144000	457680
BTF	Birch Tree - F	2144040	457810
BTH	Birch Tree Hill	2143790	457210
BWD	Bowseland	2140310	472820
C		2140550	459550
CD	Between C and D	2140500	459800
CDS	Cayman Diving School	2132680	459030
CF	Cricket Field		
CLP	Collier Pond	2137850	490820
CNP	Canal Point	2137550	461450
CPA	Cottage Point - A	2133370	483330
CYA	Cayman Yacht Club - A	2140690	460210
CYB	Cayman Yacht Club - B	2140690	460620
CYC	Cayman Yacht Club - C	2140080	460740
CYD	Cayman Yacht Club - D	2140490	460660
CYE	Cayman Yacht Club - E	2140500	460310
CYF	Cayman Yacht Club - F	2140360	460860
CYG	Cayman Yacht Club - G	2140260	460770

Appendix A: List of localities on Grand Cayman where samples from the Ironshore Formation have been collected showing the codes and the exact locations. UTM=UNIVERSAL TRANSVERSE MERCATOR.

CODE	NAME	UTM - N	UTM - E
CYH	Cayman Yacht Club - H	2140460	460810
CYJ	Cayman Yacht Club - J	2140410	460040
CYK	Cayman Yacht Club - K	2140[illegible]70	460400
CYL	Cayman Yacht Club - L	2140080	460140
D		2140450	459550
DP	Dolphin Point	2141960	455840
DPA	Dolphin Point - A	2142080	455820
DPB	Dolphin Point - B	2142030	455830
DPC	Dolphin Point - C	2142180	455840
DPD	Dolphin Point - D	2142260	455860
DPE	Dolphin Point - E	2142290	455870
DPF	Dolphin Point - F	2141930	455890
DPQ	Dolphin Point Quarry	2142040	455850
DS	South of D	2140400	459550
DSB	Duck Pond Bight	2133800	470920
E		2141180	459020
EEP	East End Post Office	2133510	488640
EOR	End of Road	2134090	472000
EOT	Esso Oil Tanks	2132020	458720
ERN	Eden Rock North	2133040	459320
ERS	Eden Rock South	2132960	459230
F		2141560	459300
FSF	Frank Sound Fire Station-F		
FSH	Frank Sound Fire Station-H		
G		2141400	459830
GC	Golf Course	2136900	461070
GH	Governor's Harbour	2140350	461030
GTP	Grape Tree Point	2139340	476190
H		2140780	459420
HMA	Half Moon Bay - A	2133330	484080
HMB	Half Moon Bay	2133280	484370
HSB	Head Sound Barcadere	2133690	467480
I		2140740	459360
IP	Ironshore Point	2133130	485020
J		2141140	459100
K		2140960	459720
L		2140600	460050
LSC	Little Salt Creek	2141440	460380
LSP	Little Spot Point	2139550	483060
M		2141270	460150
MA	Midland Acres	2133560	476690
MH	Morgan's Harbour	2141920	459620
MHA	Morgan's Harbour - A	2141960	459680
ML	Micrite Locality	2133880	482680

Appendix A: List of localities on Grand Cayman where samples from the Ironshore Formation have been collected showing the codes and the exact locations. UTM=UNIVERSAL TRANSVERSE MERCATOR.

CODE	NAME	UTM - N	UTM - E
MOA	Middle of Anywhere	2143020	460040
MOC	Middle of C	2143620	460180
MON	Middle of Nowhere	2143090	460240
MOS	Middle of Somewhere	2143430	460050
MS	Milkshake Locality	2133740	459740
N		2141150	460200
NSE	North Sound Estates	2133400	469380
OG	Omega Gardens	2132860	465330
OGA	Omega Gardens - A	2132840	465260
OL	Oil Line	2132570	459730
PBA	Paul Bodden Quarry - A	2131420	460170
PBQ	Paul Bodden Quarry	2131900	460550
PL	Parrots Landing	2132850	459150
PMP	Palmetto Point	2143450	461450
PP	Prospect Point	2131020	464940
PSI	Pump Station I	2135780	459700
PWA	Public Works - A	2135380	461280
PWD	Public Works Department	2134920	461680
RWP	Rogers Wreck Point	2139710	489770
SB	Smiths Barcadere	2131330	458820
SBA	Smith's Barcadere - A	2131430	458730
SBB	Smith's Barcadere - B	2131590	458690
SBC	Smith's Barcadere - C	2131690	458680
SBD	Smith's Barcadere - D	2131730	458670
SBE	Smith's Barcadere - E	2131820	458630
SBF	Smith's Barcadere - F	2131230	458830
SBG	Smith's Barcadere - G	2131140	458840
SBJ	Spotts Bay Jetty	2130900	466500
SC	Salt Creek	2140900	460700
SD	Selkirk Drive	2132510	464360
SDA	Selkirk Drive - A	2132560	464350
SDB	Selkirk Drive - B	2132520	464520
SDC	Selkirk Drive - C	2132600	464720
SDD	Selkirk Drive - D	2132790	464760
SH	Sunset House	2132380	458850
SHA	Sunset House - A	2132520	458920
SHB	Sunset House - B	2132550	458930
SPB	Spotter Bay	2139780	489650
TC	Tortuga Club	2139030	490530
TF	Turtle Farm	2142900	456120
TFA	Turtle Farm - A	2143050	456180
TFB	Turtle Farm - B	2143300	456300
TFN	Turtle Farm - N	2142980	456170
TG	Tropical Gardens	2133050	463600

Appendix A: List of localities on Grand Cayman where samples from the Ironshore Formation have been collected showing the codes and the exact locations. UTM=UNIVERSAL TRANSVERSE MERCATOR.

CODE	NAME	UTM - N	UTM - E
TJU	Boonrasri Tongpenyai	2130800	464380
TOT	Texaco Oil Tanks	2132230	458780
TS	The Shores	2142890	459880
TSE	Tarpon Springs Estates	2134320	478660
U		2136570	460380
VV		2135900	460180
WBA	West Bay - A	2142500	455960
WBB	West Bay - B	2142690	456050
WKR	Walker Road	2131340	459150
WRS	Walker's Road School	2131540	460020
YY		2135180	460140

Appendix B: List of wells drilled on Grand Cayman showing the codes and the exact locations.
UTM=UNIVERSAL TRANSVERSE MERCATOR

CODE	WELL NAME	UTM - N	UTM - E
BH1	Borehole-1	2135350	459600
BH2	Borehole-2	2135550	459620
BH3	Borehole-3	2136000	459670
BH4	Borehole-4	2136430	459825
BH5	Borehole-5	2136750	459900
BH6	Borehole-6	2137350	459925
BH7	Borehole-7	2137750	460000
BH8	Borehole-8	2138150	460025
BH9	Borehole-9	2138550	459925
BH10	Borehole-10	2138900	459920
BH11	Borehole-11	2138650	460240
BH12	Borehole-12	2135425	459375
BH13	Borehole-13	2138050	459650
BH14	Borehole-14	2135000	459575
BH15	Borehole-15	2135125	459875
BH16	Borehole-16	2137200	460530
BH17	Borehole-17	2137150	460050
BH18	Borehole-18	2139250	459750
BH19	Borehole-19	2136050	460175
BH20	Borehole-20	2134875	459750
CF	Cricket Field	2132650	461750
CF1	Cricket Field-1	2132750	461075
LSC1	Little Salt Creek-1	2141450	460300
ORA1	Owen Roberts Airport-1	2133400	463350
PIL1	Patrick's Island-1	2132700	465600
PIL1A	Patrick's Island-1A	2132702	465602
PIL2	Patrick's Island-2	2133250	466075
PIL3	Patrick's Island-3	2131700	465900
SH2	Safe Haven-2	2138430	461830
SH3	Safe Haven-3	2138710	461370
SH4	Safe Haven-4	2138275	460350
SH5	Safe Haven-5	2138600	461770
SH6	Safe Haven-6	2138630	460900
SH7	Safe Haven-7	2138700	461170
SH8	Safe Haven-8	2138550	461525
SH8A	Safe Haven-8A	2138552	461527
SHT1	Sewage House and Treatment Plant-1	2135250	460500
WB1	West Bay-1	2136980	459950
WB2	West Bay-2	2136950	459975

Appendix C: List of samples collected from various localities on Grand Cayman and the thin sections used in the study.

LOCALITY	SAMPLE NOS.	THIN SECTION SAMPLES
A	1435,	
ABB	2753-56,3494	2753, 2755
ABC	2758,	2758
ABD	3769,	3769
ACA	2724,2725,2726,	2725
ACB	2727,2728-30,2731,2732,3493,	2727, 2731
ACC	2733,2734,2735,	2733, 2735
ACE	2736,	2736
ACF	2737,2738-39,2740,	2737, 2740
ACG	2741-46,	2746
ACH	2747-52,3492	2752
B	1436-50,1783-85,1907,1970-83,2760,	1436, 1439, 1450, 1976
BEA	4614,	4614
BEB	4615,	4615
BLK	4311-12,	
BQ	1946-48,3804-13,	1947, 3804, 3809, 3811
BRP	3489,3527,	
BTD	1904,2619-36,2637,	2632, 2636
BTH	2639,2640-47,3299,	2639, 2644, 2646, 2647
BWD	1094-97,1099-1101,2885-88	2888
C	1451-95,1649-50,1683,1751-62,1908,	1462, 1987, 1990, 1992, 1996, 2048,
	1984-99,2046-50,2592,2984-92,3444-48,	2592
CD	2993,2994-96,	2993
CDS	1929,2835-50,	1929, 2839
CLP	3770,	3770
CNP	1686-87,1818,1819-25,1923,2118-25,2897,3346-48,3514,	1818, 2122, 2123, 3346-48
CYA	1921,2762-2770,2771-72,2773-76,3511,	1921, 2771, 2772
CYB	1922,2777-86,2921-26,3512,	1922, 2779, 2786, 2924, 2926
CYC	2898,3009,3449,	
CYE	2913-16,2940-44,	
CYG	3023-41,3302-04,3368-70,3414-23,3450-54,3456,	3030, 3302, 3304
CYH	3011-22,3373,3375,3411-13,3457-59,	
CYL	3371,	3371
CYM	3010,3349,3374,	3349
D	1496-97,1730-50,1909,2997-3002,3008,3501-02,	1738
DP	330,1321-22,1537-40,2677,2678-92,2967,3731-32,	2677
DPA	2693-95,	
DPB	2696,	
DPC	2697,2701,	2697
DPD	2698-2700,	
DPQ	3754-61,1906,2702-23,	2719, 2722
DS	3003-05,3006,3007,	3006
DSB	3775	3775
E	1776-82,1910,2051-59,2069,3503-04,	2052, 2056
EOR	3776, 3777	3777
EOT	2810-17,3301,3484,	2811, 2812, 2815, 2816, 2817, 3301
F	1694-1729,1911,2060-62,2063,2064,2065,2066-67,	2063, 2065
G	1765-72,1912,2594-98,2070-81,2082,2761,2979-83,3430-43,3505-06,	2082
GC	2978 ,3330-31,3486,3490,3528,	3330, 3331
H	1774-75,1913,2094,2095,2096-97,2098-2102,3508,	2094, 2096, 2097
HMA	3816,	3816
HSB	3772,3773-74	3772
I	1914,2082-84,2085,2086-93,2219,2220-2226,2593,	2085, 2219, 2593
J	1763-64,1915,2599-2605,	

Appendix C: List of samples collected from various localities on Grand Cayman and the thin sections used in the study.

JB	250-58,259,260-61,262-63	250-58, 260, 261
K	1689-93,1916,1941,2606-08,3509,	1916
L	2609-11,2612-13,3764,	2612, 2613, 3764
LSC	3779,3780,3781-83,	3780
M	1918,2614-15,2616,3510,	2614, 2615
MA	1938,2202,2203,2204,3526,	2202, 2204
MH	1498-25,1920,2103-13,2573-2587,3511,	1500, 2106,2574
MHA	2588-90,2591,	2591
MOA	1786,1893,1894,1902,1955,1956-60,3497,	1893, 1955
MOC	3778,	3778
MON	1787-89,1891-92,1901,1949-50,1951,1952-53,3496,	1951
MOS	1790-98,1903,1961-68,3485,3498,	1795, 1963, 1965, 1968
N	1919,2617-18,2977,	
NSB	2200, 3771	2200, 3771
OG	1935,2190-94,2212,3523,2190-94,3523	
OGA	1843,2195,2196,2197,2198,3481-83	2196, 2198
OL	2964,	2964
PBA	3789-3803,	3795, 3803
PBQ	2889-93,2975-76,3784-89,	2890, 2892, 3785, 3789
PMP	1942-44,1945,	1945
PSI	1527,1528,1529,1530,1531-36,	1528, 1530
PWA	1928, 2141,2144,2145-46,2147,3517,3767,	2144, 2147
PWD	1827,1927,2148-49,2150,2151-52,3516,	2150
QRD	2963,	2963
SB	1826,	
SBA	2792,2793-94,2795,	2792, 2795
SBB	2796,2797,2798,	2797
SBC	2799,	2799
SBD	2800-01,	2800, 2801
3BE	2802-03,2928-30,2958-61,2962	2962
SBF	2804,2805-06,2807,	2804, 2807
SBG	2808,2809,	2809
SC	316-17,331-32,473-76,664-72,717-18,1323-28,1411,1586-88	316,1323-27
SD	1846,1847-49,1931,1940,2164-69,2170,3519,	1846, 2170
SDA	1850-58,1932,2171-80,3520,	1851, 1932, 2177, 2180
SDB	1859,1860-67,1890,1933,	1859
SDC	1934,2856-60,2861,2862-63,2864,3522,	2861, 2864
SHA	2818,2819,	2818
SHB	2820-27,2828,	2828
TFA	2666,2667,	2666, 2667
TFB	1905,2648-65,3300,	2649, 2656, 2659, 2665
TFC	2667,	
TFN	2668-71,3763 ,	3763
TG	1930,2155,2156-57,2158-60,2161-62,2211,3518	2155,2158-60
TJU	2829,2830,2831-34,3762,	2830
TS	3768,	3768
TSE	1844,1939,2205-10,2235-38,2965-66,3322-23	2207-08,2210,2235-38,2965-66,3322-23
U	1799,1924,2126,2127,	2127
VV	1800-07,1925,2128-40,3515,3765,3766,	2129-30, 2134, 2137, 3766
WBA	2672,	2672
WBB	2673,2674-76,	2673
WKR	2968,	2968
WRS	1889,2153,2154,	2154
YY	1808-15,1816,1817,1926,2181-89,2851,2852-54,2855,	1816, 2851, 2855

Appendix D: Thin Section analysis of the samples from the Ironshore Formation on Grand Cayman for the determination of the skeletal and non-skeletal constituents leading to the classification of the different facies.

#	Loc.	Environment	Sorting	Grain Size	Gastropods	Bivalves	Corals	Forams	Halimeda	Red Algae	Echinoids	Peloids	Mud	Ooids	Facies
1325	SC	Upper shoreface	G	Md - Fi	S								VC	VC	Ooid Grainstone
1327	SC	Upper shoreface	G	Md - Fi		R		S	R	C		S			Ooid Grainstone
1528	PSI	Patch reef	P	Fi - Cs	VC	S			S	S		C			Coral A Flts./Frms.
1738	D	Patch reef	P	Fi - Cs			C								Coral A Flts./Frms.
1846	SD	Inter reef	M - P	Fi - Cs	C	S	C	R				C			Poorly Sorted SkeletalG/P
1893	MOA	Inter reef	P	Fi - Cs	C	S			S		R	C	R		Poorly Sorted SkeletalG/P
1921	CYA	Patch reef	P	Fi - Cs	VC	C		R	S			C	VC		Peloidal-BivalveW/P
1922	CYB	Patch reef		Fi - Cs	C	C			C	R	R	C	VC		Halimeda-Coral Flts./Frms.
1932	SDA	Patch reef	P	Fi - Cs	C	VC		R	VC	R		S	C		Poorly Sorted Halimeda-Bivalve W/P
1945	PMP	Upper shoreface	G	Fi - Md		R		S					C	C	Ooid Grainstone
1947	BQ	Upper shoreface	G	Fi - Md									C	VC	Ooid Grainstone
1951	MON	Inter reef	P	Fi - Cs	VC	C			S		S	C			Poorly Sorted SkeletalG/P
1955	MOA	Inter reef	P	Fi - Cs	C	C		R	C		S	C	C		Poorly Sorted Halimeda-Bivalve W/P
1965	MOS	Inter reef	P	Fi - Cs	C	VC	C	S	C			C	VC		Halimeda-Coral Flts./Frms.
1968	MOS	Patch reef	P	Fi - Cs			C								Halimeda-Coral Flts./Frms.
1976	B	Patch reef	P	Fi - Cs	S	C			S			VC	VC		Peloidal-BivalveW/P
1992	C	Patch reef	P	Md - Cs	S		VC		S				VC		Coral A Flts./Frms.
1996	C	Patch reef	P	Fi - Md			VC						VC		Coral A Flts./Frms.
2056	D	Patch reef	P	Md - Cs			C								Coral A Flts./Frms.
2065	E	Patch reef	P	Md - Cs			C								Coral A Flts./Frms.
2065	F	Patch reef	P	Fi - Cs			VC								Coral A Flts./Frms.
2085	G	Patch reef	P	Fi - Cs	S	VC			S			C	C		Peloidal-BivalveW/P
2096	H	Inter reef	M	Fi - Md			VC					C	VC		Poorly Sorted SkeletalG/P
2097	H	Inter reef	P	Fi - Cs	C	S		R	S			VC	VC		Poorly Sorted SkeletalG/P
2106	K	Patch reef	P	Fi - Cs			VC								Coral A Flts./Frms.
2122	CNP	Inter reef	P	Fi - Cs	C	C			S			VC	C		Peloidal-BivalveW/P
2127	U	Inter reef	P	Fi - Cs	R	R		S	S			C	VC		Poorly Sorted SkeletalG/P
2129	VV	Patch reef	M - P	Fi - Cs	S	S		R	C			C	VC		Poorly Sorted Halimeda-Bivalve W/P
2134	YY	Patch reef	P	Fi - Cs	VC				S			C	C		Coral A Flts./Frms.
2137	YY	Patch reef	P	Fi - Cs	S		VC	R	C			S	VC		Halimeda-Coral Flts./Frms.
2144	PWA	Inter reef	M	Fi - Cs	S	C			S			C	S		Peloidal-BivalveW/P
2147	PWA	Inter reef	M	Fi - Cs		S			S			C	VC		Poorly Sorted SkeletalG/P
2150	PWD	Inter reef	P	Fi - Cs	VC	R			C			C	VC	R	Poorly Sorted SkeletalG/P
2154	WRS	Upper shoreface	G	Fi - Md										VC	Ooid Grainstone

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#	Loc.	Environment	Sorting	Grain Size	Gastropods	Bivalves	Corals	Forams	Halimeda	Red Algae	Echinoids	Peloids	Mud	Ooids	Facies
2158	TG	Lagoon	P	Fi - VFi	S	C		R	VC			VC	VC		Poorly Sorted Halimeda-Bivalve W/P
2159	TG	Lagoon	P	Fi - VFi	S	C		S	C			C	VC		Poorly Sorted Halimeda-Bivalve W/P
2170	SD	Inter reef	P	Fi - Cs	C	S	C	S				C	VC		Poorly Sorted SkeletalG/P
2198	OGA	Lagoon	M - P	Si - VFi	S	C		R	C			VC	VC		Peloidal-BivalveW/P
2200	NSE	Lagoon	P	VFi - Fi	C	C		S	R						Peloidal-BivalveW/P
2202	MA	Lagoon	P	Si - Fi	C	VC		S	R	R		C			Peneroplid-Miliolid-Bivalve W/P
2204	MA	Lagoon	P	Si - VFi	C	C	C	C	C	R		VC	VC		Peneroplid-Miliolid-Bivalve W/P
2208	TSE	Lagoon	P	Si - VFi	VC	VC		C	R		R	C			Peneroplid-Miliolid-Bivalve W/P
2210	TSE	Lagoon	P	Si - Fi	VC	VC		VC	R			VC	VC		Peneroplid-Miliolid-Bivalve W/P
2574	MH	Patch reef	P	Fi - Cs			VC								Coral A Flts./Frms.
2591	MHA	Subtidal	G	Fi - Md	S			R					C	VC	Ooid Grainstone
2604	I	Patch reef	P	Fi - Cs			VC					C	C		Coral A Flts./Frms.
2612	L	Subtidal	G	Fi - Md	S	S			S			VC	VC		Ooid Grainstone
2613	L	Subtidal	G	Fi - Md	S	S			S				VC	VC	Ooid Grainstone
2614	M	Subtidal	G	Fi - Md	C	C		R	C			C	VC	VC	Ooid Grainstone
2618	N	Subtidal	G	Fi - Md									S	VC	Ooid Grainstone
2632	BTD	Reef tract	P	Fi - Cs	S		VC			R		C	VC		Coral B Flts./Frms.
2636	BTD	Reef tract	P	Fi - Cs		R	VC		C			C	VC		Halimeda-Coral Flts./Frms.
2644	BTH	Reef tract	P	Fi - Cs	S	S	VC	S	R			C	VC		Coral B Flts./Frms.
2646	BTH	Reef tract	P	Fi - Cs	S		VC	S	S		S	S	VC		Coral B Flts./Frms.
2649	TFB	Reef channel	M - G	Fi - Md	S	R	VC		S	S		C			Well Sorted Skeletal Grainstone
2656	TFB	Reef channel	G	Fi - Md	R	R	VC		R	S		C	VC		Well Sorted Skeletal Grainstone
2659	TFB	Reef channel	G	Fi - Md			VC			R					Well Sorted Skeletal Grainstone
2666	TFA	Reef tract	G	Fi - Md	S	S	C	S	S				S		Coral B Flts./Frms.
2673	WBB	Reef tract	P	Fi - Cs			C	S	S	S		C	VC		Coral B Flts./Frms.
2677	DP	Reef tract	P	Fi - Cs			VC								Coral B Flts./Frms.
2692	DP	Reef tract	G	Fi - Md			VC						VC		Ooid Grainstone
2693	DPA	Reef tract	P	Fi - Cs			VC			R		S	S		Coral B Flts./Frms.
2696	DPB	Reef tract	P	Fi - Md			VC	R		S		C	VC		Coral B Flts./Frms.
2697	DPC	Reef tract	P	Fi - Cs			VC								Coral B Flts./Frms.
2719	DPQ	Reef tract	P	Fi - Md	S	S	VC	S	S	S		C	VC		Ooid Grainstone
2725	ACA	Upper shoreface	G	Fi - Md	R	R		R						VC	Ooid Grainstone
2727	ACB	Reef channel	G	Fi - Md			VC								Well Sorted Skeletal Grainstone
2731	ACB	Reef channel	M	Fi - Md	S	S	VC			S			VC	VC	Well Sorted Skeletal Grainstone

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#	Loc.	Environment	Sorting	Grain Size	Gastropods	Bivalves	Corals	Forams	Halimeda	Red Algae	Echinoids	Peloids	Mud	Ooids	Facies
2733	ACC	Reef tract	P	Fi - Cs	S	S	VC			S		C	VC		Coral B Flts./Frms.
2735	ACC	Reef tract	P	Fi - Cs	S		VC	S	S	S	S	C	VC		Coral B Flts./Frms.
2739	ACF	Reef channel	G	Fi - Md	S	S	S					C			Well Sorted Skeletal Grainstone
2740	ACF	Reef channel	G	Fi - Md	S	S			R	C	R		VC	VC	Poorly Sorted Red-Algae Coral G/P
2746	ACG	Lagoon	P	Fi - Cs	S	C	S	R	S	S	R	C	VC	VC	Ooid Grainstone
2752	ACH	Upper shoreface	G	Fi - V Fi	S	C	R	S	S	S	R		VC	VC	Ooid Grainstone
2755	ABB	Reef channel	G	Md		R	VC			S		C	VC		Well Sorted Skeletal Grainstone
2759	CSG	???	P	Fi - Cs		S	VC		S		R	C	C		???
2772	CYA	Patch reef	P	Fi - Cs	C	S		R	C			C	VC		Halimeda-Coral Flts./Frms.
2779B	CYB	Patch reef	P	Fi - Cs			VC								Coral A Flts./Frms.
2797	SBB	Reef channel	M - G	Fi - Md		S	C		R	S		C	VC		Well Sorted Skeletal Grainstone
2801A	SBD	Reef channel	M	Fi - Md	R		C					S	C		Well Sorted Skeletal Grainstone
2801B	SBD	Reef channel	M	Fi - Md	R	R	C	R	R	C		C			Poorly Sorted Red-Algae Coral G/P
2804	SBF	Upper shoreface	G	Fi - Md	R	R	VC	S	S	R			VC	C	Ooid Grainstone
2807	SBF	Upper shoreface	G	Fi - Md		R				R			VC	C	Ooid Grainstone
2809	SBG	Upper shoreface	P	Si - Fi	S	S	VC			S			VC	C	Coral B Flts./Frms.
2811	EOT	Reef tract	P	Fi - Cs		R	C		R				VC		Coral B Flts./Frms.
2815	EOT	Reef tract	P	Fi - Cs	S	C	VC	R	S	S		C	VC		Coral B Flts./Frms.
2817	EOT	Reef tract	P	Fi - Cs	S		C		S			C	VC		Coral B Flts./Frms.
2830	TJU	Reef tract	P	Fi - Cs	S	S	VC		R			S	VC		Coral B Flts./Frms.
2839	CDS	Reef tract	P	Fi - Cs	S	S	VC					C			Coral B Flts./Frms.
2851	SDB	Patch reef	P	Fi - Cs	S	C	R	R	C		R	C	C		Halimeda-Coral Flts./Frms.
2855	SDB	Patch reef	P	Fi - Cs			VC		S			S	C		Coral A Flts./Frms.
2861	SDC	Inter reef	P	Fi - Cs	S	R			C			VC	VC		Poorly Sorted Halimeda-Bivalve W/P
2864	SDC	Inter reef	P	Fi - Cs	C	C		R	S			VC	VC		Peloidal-BivalveW/P
2888	BWD	Lagoon	P	Si - Fi	C	VC		S				VC	VC		Peloidal-BivalveW/P
2890	PBQ	Upper shoreface	G	Fi - Md		R	S		S	R				C	Ooid Grainstone
2917	CYD	Patch reef	P	Fi - Cs		S	VC						VC		Coral A Flts./Frms.
2940	CYE	Patch reef	P	Fi - Cs											Coral A Flts./Frms.
2963	QRD	???	P	Fi - Cs	S	C	S		R	C		S	VC		Poorly Sorted Red-Algae Coral G/P
2964	OL	Reef tract	P	Fi - Cs			VC								Coral B Flts./Frms.
2968	WKR	Patch reef	P	Fi - Cs	S		VC				R	S			Coral A Flts./Frms.
2993	CD	Patch reef	P	Fi - Cs			VC								Coral A Flts./Frms.
3006	DS	Patch reef	P	Fi - Cs			VC					S	S		Coral A Flts./Frms.

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#	Loc.	Environment	Sorting	Grain Size	Gastropods	Bivalves	Corals	Forams	Halimeda	Red Algae	Echinoids	Peloids	Mud	Ooids	Facies
3009	CYC	Patch reef	M-P	Fi-Cs			VC					C	R		Coral A Flts./Frms.
3011	CYH	Patch reef	P	Fi-Cs			C.		R			S	VC		Coral A Flts./Frms.
3030A	CYG	Patch reef	P	Fi-Cs	S	C	VC		S	S	R	S	VC		Coral A Flts./Frms.
3302	CYG	Patch reef	P	Fi-Cs			VC								Coral A Flts./Frms.
3304	CYG	Patch reef	P	Fi-Cs			VC								Coral A Flts./Frms.
3322	TSE	Lagoon	M-G	Fi-Md	C	C		C	S			C	VC		Peneroplid-Miliolid-Bivalve W/P
3330	GC	Inter reef	P	Fi-Cs	S	C	C	S	S	S		C			Peloidal-BivalveW/P
3331	GC	Inter reef	P	Fi-Cs			?					C	VC		Poorly Sorted SkeletalG/P
3349	CYM	Patch reef	?	?	?	?	?	?	?	?	?	?	?	?	???
3371	CYL	Patch reef	M-P	Fi-Cs	S	S	C	S	S	R	R	C	VC		Coral A Flts./Frms.
3488	PCQ	Lagoon	M-P	Fi-Cs		R				R		C	VC		Nummulitid-Bivalve W/P
3768	TS	Inter reef	b.-G	Fi-Md		R		R	S			S	VC	VC	Ooid Grainstone
3769	ABD	Upper shoreface	P	Si-Fi	R	C		S	S	S	R		VC	VC	Poorly Sorted SkeletalG/P
3770	CLP	Reef Tract	M-G	Fi-Md	C		S	S		S	R	C	VC		Coral B Flts./Frms.
3771	NSE	Lagoon	M-G	Fi-Md				C	S	R		C	VC		Nummulitid-Bivalve W/P
3772	HSB	Lagoon	M-P	Fi-Cs	S	S		R	C			C	VC		Poorly Sorted Halimeda-Bivalve W/P
3775	DSB	Lagoon	M	V Fi-Fi	S	C			C			V	VC		Poorly Sorted Halimeda-Bivalve W/P
3776	VV	Patch reef	G	Fi-Md										VC	Ooid Grainstone
3777	EOR	Lagoon	P	Si-Fi	VC	R		R	C			VC	VC		Poorly Sorted Halimeda-Bivalve W/P
3778	MOC	Inter reef	P	Fi-Cs	C	C			C			C	S		Poorly Sorted SkeletalG/P
3778	MOC	Inter reef	P	Fi-Cs	C	C		R	S			C	C		Poorly Sorted SkeletalG/P
3779	LSC-1	Upper shoreface	G	Md-Fi		R		S	S			C		VC	Ooid Grainstone
3780	LSC-2	Upper shoreface	G	Fi-Md									VC	VC	Ooid Grainstone
3782	LSC-3	Foreshore to	G	Fi-Md	R	R			R	S		C		VC	Ooid Grainstone
		backshore													
3795	PBA	Patch reef	P	Fi-Cs			VC								Coral A Flts./Frms.
3803	PBA	Upper shoreface	G	Fi-Md		R		R		R				VC	Ooid Grainstone
4614	BEA	Lagoon	P	Fi-Cs				C	S'			S	VC		Nummulitid-Bivalve W/P
4615	BEB	Lagoon	M-P	Fi-Cs	S		R	C	R		R	S	VC		Nummulitid-Bivalve W/P
4616	BEC	Lagoon	P	Fi-Cs			VC	S	S			C	VC		Coral A Flts./Frms.
4728	FSF	Lagoon	P	Md-Cs	C	C	S	C				VC			Peloidal-BivalveW/P
4731	FSH	Lagoon	M-P	Md-Cs	C	C	S	C				VC			Peloidal-BivalveW/P

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TYPE OF FRAGMENTS	SYMBOL	PERCENTAGE RANGE
SKELETAL (Gastropods, Bivalves, Corals, Forminifera, Halimeda, Red Algae, Echinoids)	VERY COMMON (VC)	>15%
	COMMON (C)	5-15%
	SCARCE (S)	2-5%
	RARE (R)	<2%
NON-SKELETAL (Peloids, Ooids)	VERY COMMON (VC)	>30%
	COMMON (C)	10-30%
	SCARCE (S)	<10%