Surficial carbonate sediments across key rookeries for the northern Great Barrier Reef green turtle population stock.

Report for the Environment Protection Agency

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1. Executive Summary

This report describes the textural and compositional characteristics of surficial carbonate sediments collected strategically from reef islands identified as key rookeries for the northern Great Barrier Reef green turtle, *Chelonia mydas,* population. Sediment samples at each island were classified on the basis of their key textural and compositional traits, and sediment facies discriminated according to this classification. The recognition of particular facies can yield valuable insights for the broader turtle conservation project by characterising the sedimentological traits of key rookeries, and supporting the interpretation of how these rookeries have developed and may change as climate change impacts affect surrounding reefs and reef organisms.

Key findings include:

- Sediment samples from the key rookeries are almost exclusively sand sized, with small (<5%) contributions of pebbles and mud sized sediments at some of the islands. Most rookeries are dominated by coarse well sorted sand, with variations between zones (e.g berm, beach toe) and orientation (North, South, East and West);
- Surficial sediments at the key rookeries are generally similar in their textural traits. However, sorting values are significantly lower at Sandbank 7 and the proportion of coarse sand (>0.25φ fraction) is significantly lower at Raine Island;
- There is significant variation in the constituent composition of biogenic carbonates sediments which comprise the different rookeries:
    - Sediment samples from Raine Island contain more foraminifera than sediments from all the other nesting sites;
    - Sediment samples from Moulter Cay and Sandbank 7 contain more molluscan-derived material than those collected from Raine Island and Sandbank 8;
    - Sandbank 8 and Raine Island samples contain more coral-derived sediment than samples from Moulter Cay and Sandbank 7.
    - Samples from Sandbank 8 contain more *Halimeda* than all the other rookeries.

2. Introduction

2.1. Background and objectives

The green turtle population in the northern Great Barrier Reef and Torres Strait (nGBR/TS) is the largest in the world. It has enormously important ecological, social and cultural value. Turtle nesting data collected by Queensland Parks and Wildlife Service (QPWS) since 1976 suggest an average of 50,000 females in this population nest each year (Limpus et al. 2003). Approximately 90% of this nesting occurs on two small sand cays in the northern GBR; Raine Island and Moulter Cay. Most of the remaining 10 or so percent of nesting occurs on Milman Island and Sandbanks 7 and 8 in the northern GBR, and on Bramble Cay and the Murray Islands (Mer, Dauer and Waer) in Torres Strait (Limpus et al. 2003) (Figure 1).

The nGBR/TS nesting population has been systematically studied since the mid 1970s. Declines in the average size of turtles (carapace length) breeding each year, high recruitment rates and shifts in remigration intervals revealed by these studies have been suggested as indicative of a population in early stages of decline (see Limpus et al. 2003). Since 1996, poor hatchling production has emerged as another major threat to the nGBR/TS population (Limpus et al. 2003). QPWS data indicate that both nesting success (the % of females able to successfully lay eggs each night) and hatchling production are low. Accelerated erosion of the beach, changes in biogenic sediment production and delivery, alterations to the beach rock formation, and a range of other geomorphologic processes may be contributing to this decline.

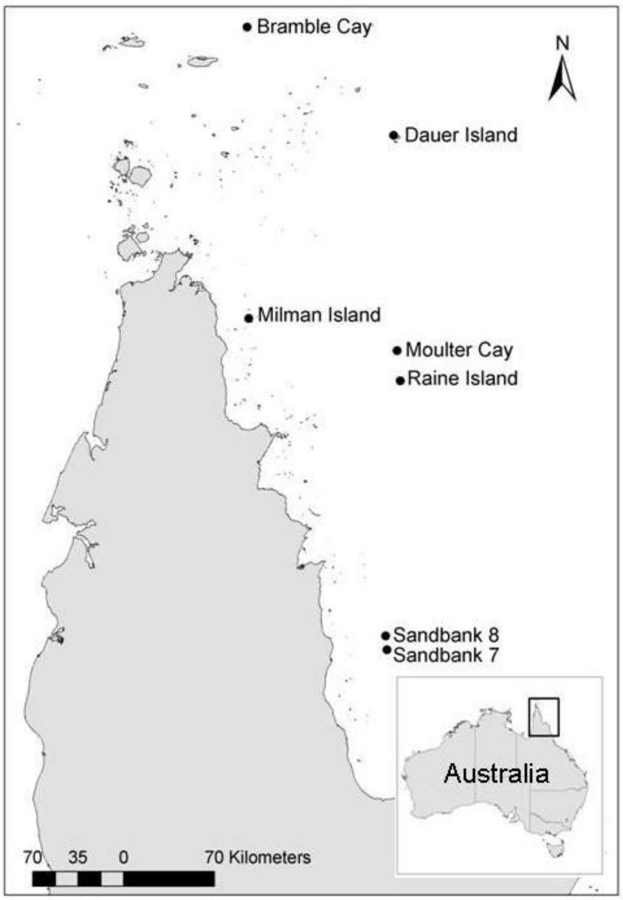


Figure 1. Locations of main nesting grounds for the northern Great Barrier Reef green turtle population.

Increased storm intensity, frequency and sea level are predicted in the future by the most recent climate change projections (IPCC 2007), which may further affect beach morphology and thus turtle nesting success. Understanding how these key rookeries will be affected by climate change is crucial to provide insights into how the nGBR/TS green turtle population will be affected as climate change progresses. This project characterized the sedimentological traits of key rookeries to provide the basis of later interpretation of island response to projected climate changes.

2.2. Report overview

This report describes the textural and compositional characteristics of each key rookery. Investigating these surficial characteristics allows identification of sediment deposits with specific textural and compositional traits, termed facies (Smithers 1994). Identification of these characteristics is important since they reflect the combined influences of: a) the sites of biogenic sediment production and deposition; b) the hydrodynamic environment and processes involved in structuring the habitats of contributing organisms and in redistributing derived sediments; and c) the physical and hydrodynamic characteristics of the carbonate material being produced (Dawson 2006; Kennedy and Woodroffe 2004; Li *et al.* 1998). The spatial distribution of different facies may be used to infer sediment sources and transport to and from key green tutle rookery locations.

This report describes the textural and compositional characteristics of Raine Island, Moulter Cay and Sandbank 7 and 8. Environmental interpretations are ongoing and will be published in peer-reviewed journals.

3. Methods

3.1 Sediment sampling strategy

Sediment samples were systematically collected following a sampling design stratified by bio-geomorphic zones identified along shore-normal transects. Four bio-geomorphic zones were identified: cliff, berm, toe of beach, and reef flat. Brief descriptions of each zone are provided below:

- a) the 'cliff' zone which is only present at Raine Island and Moulter Cay, is a high area above and landward of the berm, usually separated by a distinct break in slope (Stoddart et al. 1981).
- b) the 'berm' zone is the often broad low relief area extending from the top of the swash limit to the base of the cliff zone.
- C) the "toe of the beach" is where the sloping beach face intersects the more horizontal reef flat.
- d) the "reef flat" is the quasi horizontal surface extending from the toe of the beach toward the reef crest, usually at an elevation close to the MLWS tide level.

A total of 60 sediment samples were collected from 20 shore normal transects at the four rookeries investigated. The number of transects and samples varied according to the size of the islands. Information on the total number of transects and samples for each island are summarized on Table 1. At each transect a sample was collected for each representative zone. All sample locations were recorded with a GPS, using GCS_Australian_1984 geographic coordinate system or UTM WGS_84 as indicated in Appendix 1.

Table 1. Summary of sampling activity at each rookery.

Rookery	Transects	Number of samples	Zones of which samples were collected
Raine Island	8	32	Cliff, berm, beach toe, and reef flat
Moulter Cay	4	12	Cliff, berm and beach toe
Sandbank 7	4	8	Berm and beach toe
Sandbank 8	4	8	Berm and beach toe
Total	**20**	**60**	**Cliff, berm, toe of beach, and reef flat**

3.2. Textural analysis

The textural characteristics or grain-size distributions for each sediment sample were determined with a Rapid Sediment Analyser (RSA), which effectively calculates grain sizes using settling velocities (Kench 1997). This is the most appropriate method for textural analysis of carbonate sediments which can have diverse size, shape and density. The RSA outputs provide a more realistic indication of hydraulic traits than can be derived from traditional sieving methods (Dawson 2006; Kench 1997; Kench and McLean 1997).

Preparation for RSA analyses involved air-drying samples, before splitting into sub-samples of 10 – 15 g, following the method of Ingram (1971). A RSA 'settling' runtime of 10 minutes was consistently used. Log files generated by the RSA were transferred into SedRep (Microsoft Excel ® based data reporter developed by the school of Geography and Environmental Science, University of Auckland, New Zealand). SedRep calculates grainsize statistics based on the settling velocities of sediment grains, using Gibbs et al.'s (1971) equation. Derived grain statistics included mean grain-size, sorting, skeweness and kurtosis. A grain-size distribution and cumulative frequency curve based on Folk and Ward's (1957) the graphic method are also given. An example report sheet is provided in Appendix 2. Grain sizes are expressed as phi (φ) categories based on Krumbein's (1934) equation:

$$\Phi = -\log^2 d, \text{ where } d = \text{grain size in mm}$$

This report will focus on mean grain-size and sorting of each sample and the range of grain size identified for each zone. Grain size is the most fundamental physical property of sediment. Information on grain size can be used to study dynamic processes of transportation and deposition of sediments. Modal size classes are also identified and discussed for polymodals samples. The D50 grain size (mm) was also calculated for samples from Raine Island as requested by the EPA (Appendix 3). These values were calculated from a script workbook provide by the e-book: Gary Parker. 1D Sediment transport morphodynamics with applications to rivers and turbidity, available online at: http://cee.uiuc.edu/people/parkerg/excel_files.htm. The D50 data are not discussed.

3.3. Compositional analysis

Compositional analyses identify the skeletal constituents which comprise each sediment sample. Samples were dry sieved into 1.5φ, 1.0 φ, 0.5 φ, 0.0 φ, -0.5 φ and >/ -1.0 φ (0.35, 0.50, 0.71, 1.00, 1.41 and >/2mm) size fractions and then point counted under a binocular microscope using the 'ribbon method' (Galehouse (1971; p. 391-392). 100 grains (or if the sample was small – all grains) were counted for each sieve fraction. The organism from which each grain was derived was identified using a photographic key produced by Dawson (2006). 17 component categories are included in this key (Table 2).

The total composition of each sample was calculated by multiplying the composition counts of each grainsize fraction by the weight percent of that fraction of the total sample (Collen and Garton 2004; Dawson 2006; Smithers 1994). The proportion of each size portion to the overall sample weight was acquired from the raw textural data generated by the RSA and SedRep.

Table 2. List of skeletal constituent categories identified from carbonate sediments**.**

Coral	Other Foraminiferans
Coralline Algae	*Halimeda*
Bivalves	Echinoids plates and spines
Gastropods	Alcyonarians spicules
Undetermined Molluscs	Bryozoans
Amphistegina sp.	Serpulids
Baculogypsina sp. + Calcarina sp.	Crustacean
Marginopora vertebralis	Indeterminate
Homotrema rubra	

4. Results

4.1 Raine Island

4.1.1 Textural Analysis

Sediments from Raine Island are predominantly moderately well sorted to well sorted (0.26 to 0.96 φ) very coarse to coarse sands (-0.59 to 0.89 φ). Fine sands and mud are rare. For textural information and for grain size distribution of each sample collected at Raine Island see Appendix 4 and 5 respectively.

4.1.1.1 Cliff

Moderately well-sorted coarse sands dominate the cliff zone at Raine Island. The modal size class is 0φ to 1 φ (Figure 2)

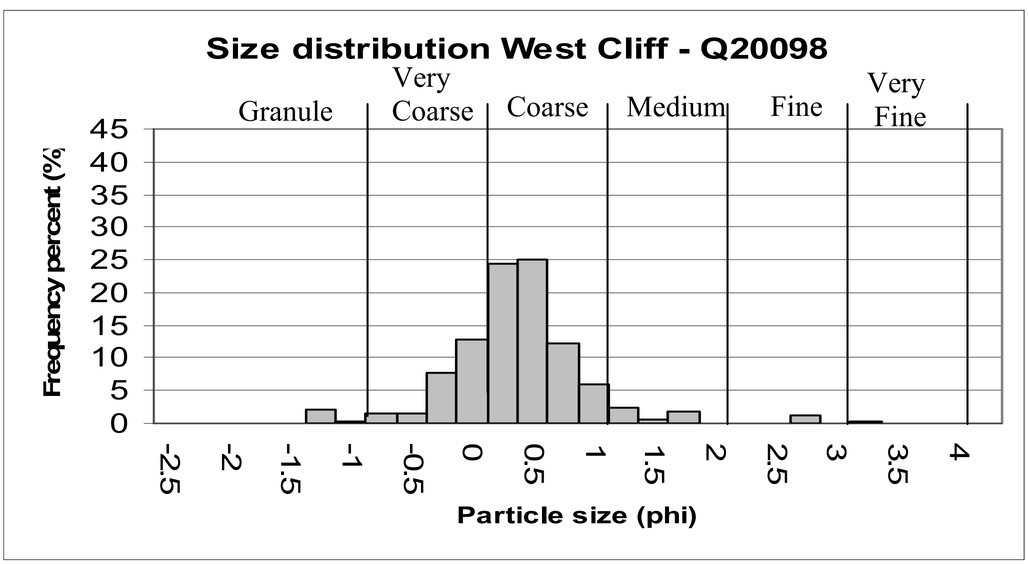


Figure 2. Typical histogram of grain size distribution for the cliff zone at Raine Island (sample Q20098). See histogram for all cliff samples collected from Raine Island at Appendix 5.

4.1.1.2. Berm

The berm zone is dominated by coarse sand. The modal size class is 0φ to 1φ (Figure 3) with grain size varying from well sorted to moderately well-sorted (0.36 to 0.57 φ).

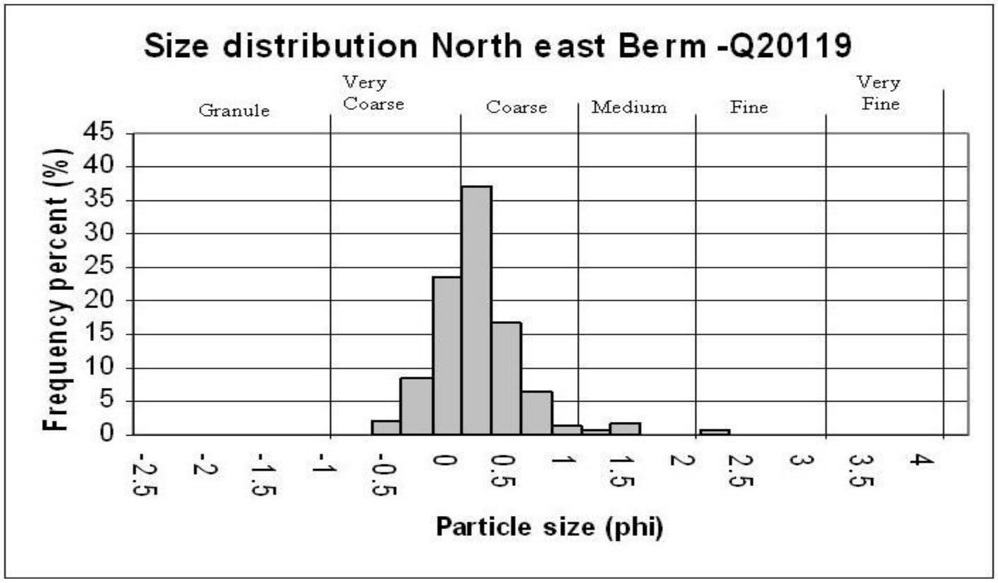


Figure 3. Typical histogram of grain size distribution for the berm zone at Raine Island (sample Q20119). See histogram for all berm samples collected at Raine Island at Appendix 5.

4.1.1.3. Toe of beach

Toe of the beach sediments vary from very coarse sand (-0.2 φ) to coarse sand (0.75φ). The majority of sediment belongs to the -1 to 0 φ modal size class (Figure 4), with most sediment samples from this zone being well sorted

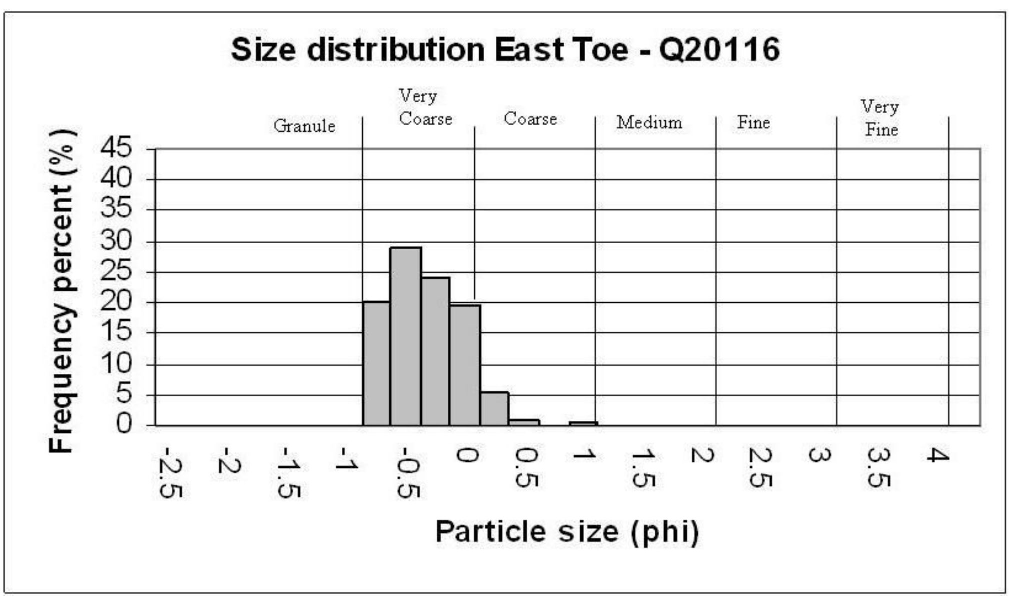


Figure 4. Typical histogram of grain size distribution for the toe of the beach zone at Raine Island (sample Q20116). See histogram for all toe of the beach samples collected from Raine Island at Appendix 5.

4.1.1.4 Reef

The reef is predominately composed of very coarse sand, modal size class -1 to 0 φ. With the majority of samples containing a small proportion of granules (Figure 5).

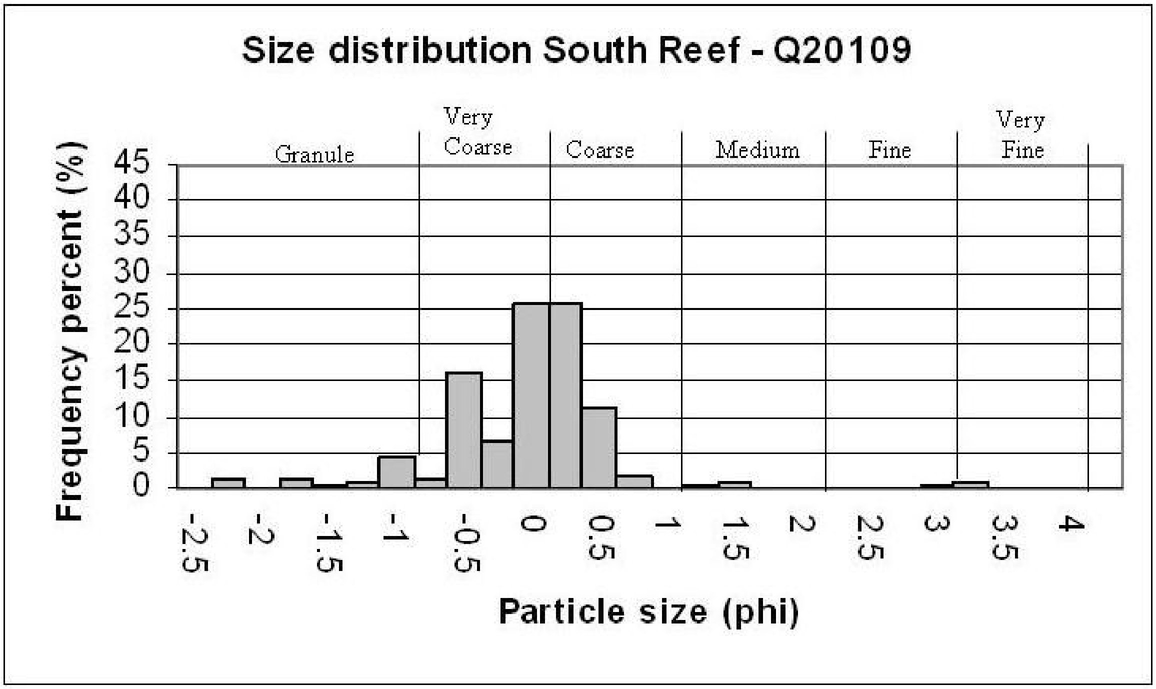


Figure 5. Typical histogram of grain size distribution for the reef zone at Raine Island (sample Q20109). See histograms for all reef samples at Appendix 5.

4.1.2 Compositional Analysis

Foraminiferans and molluscs were the most dominant constituents of sediments at Raine Island, representing 34.0% and 25.1% of the sediment respectively (Figure 6). Coral and coralline algae were also important components with abundances of 17.5% and 15.1% respectively (Figure 6).

Sediment composition at Raine Island is generally similar across the different zones; however a higher abundance of corals occurs on the toe of the beach (Figure 7). For additional information on each sample collected from Raine Island see Table 3.

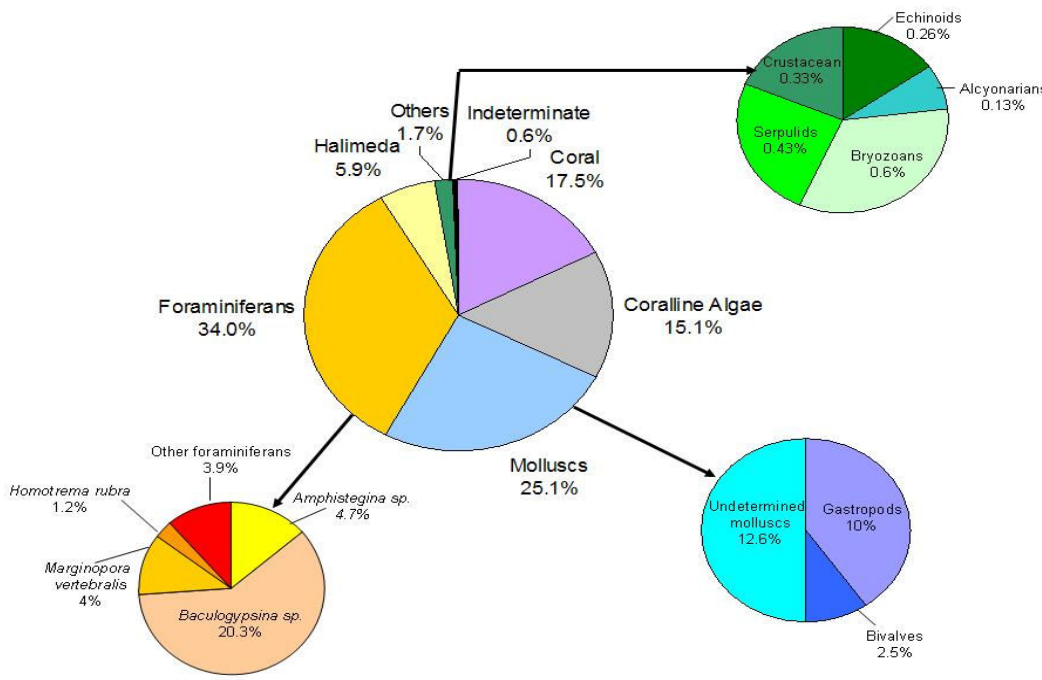


Figure 6. The skeletal constituent composition of surficial biogenic carbonate sediment samples collected at Raine Island, December 2006

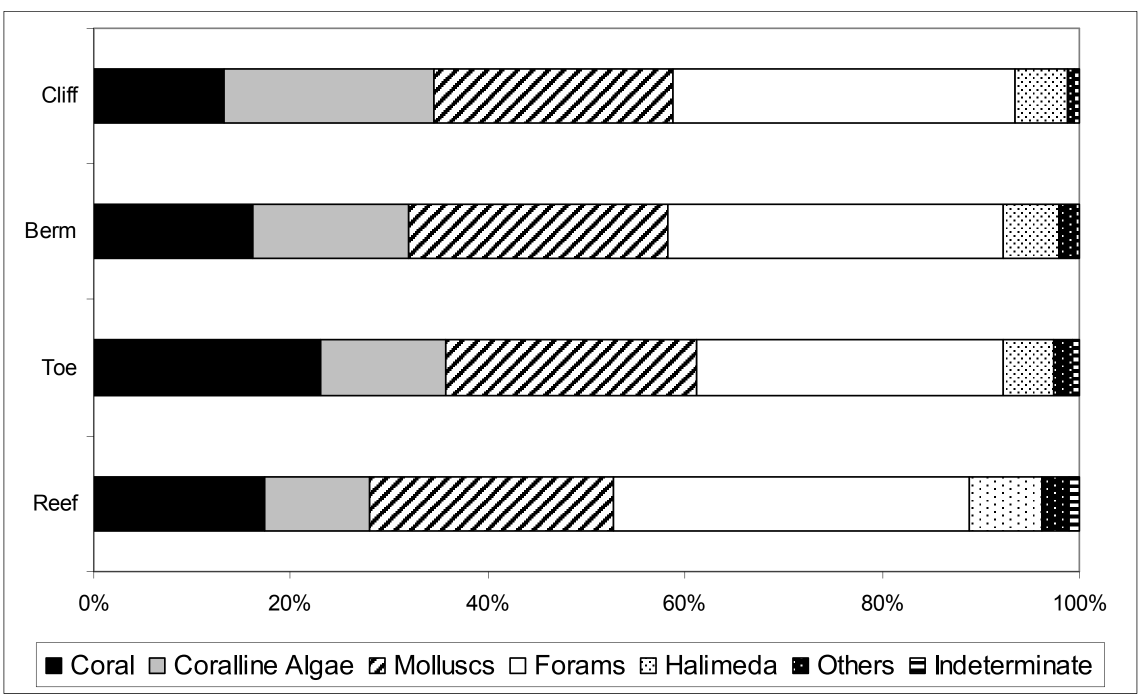


Figure 7. Constituent composition of sediment samples collected from the different zones at Raine Island.

Table 3.Constituent composition of samples collected at Raine Island, December 2006.

Sample	Environment	Coral	Coralline Algae	*Halimeda*	Molluscs	Forams	Others	Undetermined
Q20117	Reef (E)	11.4	24.2	6.1	23.0	34.2	1.2	0.0
Q20125	Reef (N)	39.1	4.9	3.7	31.6	18.1	1.5	1.9
Q20109	Reef (S)	9.9	3.1	7.8	23.5	46.9	8.2	0.9
Q20101	Reef (W)	9.3	11.0	12.2	20.9	46.1	0.5	0.0
Q20116	Toe (E)	39.6	2.6	4.2	25.5	27.2	0.6	1.6
Q20124	Toe (N)	15.2	25.1	2.4	21.1	35.3	0.9	0.0
Q20108	Toe (S)	23.4	3.5	3.9	38.0	25.7	4.3	1.1
Q20100	Toe (W)	14.5	19.6	10.8	17.4	36.2	1.5	0.2
Q20115	Berm (E)	17.2	20.8	5.6	16.2	39.3	0.9	0.0
Q20123	Berm (N)	16.1	28.6	3.5	21.5	30.3	0.1	0.0
Q20107	Berm (S)	13.3	4.8	7.1	37.8	31.4	4.6	1.6
Q20099	Berm (W)	17.9	9.4	6.5	29.6	35.9	0.7	0.0
Q20114	Cliff (E)	13.6	23.8	2.7	16.7	42.7	0.4	0.0
Q20122	Cliff (N)	13.7	34.5	4.7	13.4	32.7	0.9	0.0
Q20106	Cliff (S)	9.7	0.1	1.1	51.8	35.5	0.8	1.1
Q20098	Cliff (W)	16.3	26.6	12.9	15.3	28.2	0.8	0.0

E= east, N= north, S= south and W= west

4.2 Moulter Cay

4.2.1 Textural Analysis

The surficial sediments collected at Moulter Cay are coarse sand and vary from very well sorted (0.2 φ) to moderately well sorted (0.65 φ). Sediments are mostly sand-sized (97.3%), with pebble and mud sized sediments contributing only to 2.5% and 0.3% respectively. For further textural information and grain size histogram on each sample collected see Appendix 6 and 7 respectively.

4.2.1.1 Cliff

The cliff zone at Moulter Cay is composed mainly of coarse sand with only a small variation in grain size (-0.25 to 1.5φ). Samples are well and very well sorted (0.29 to 0.49 φ) (Figure 8).

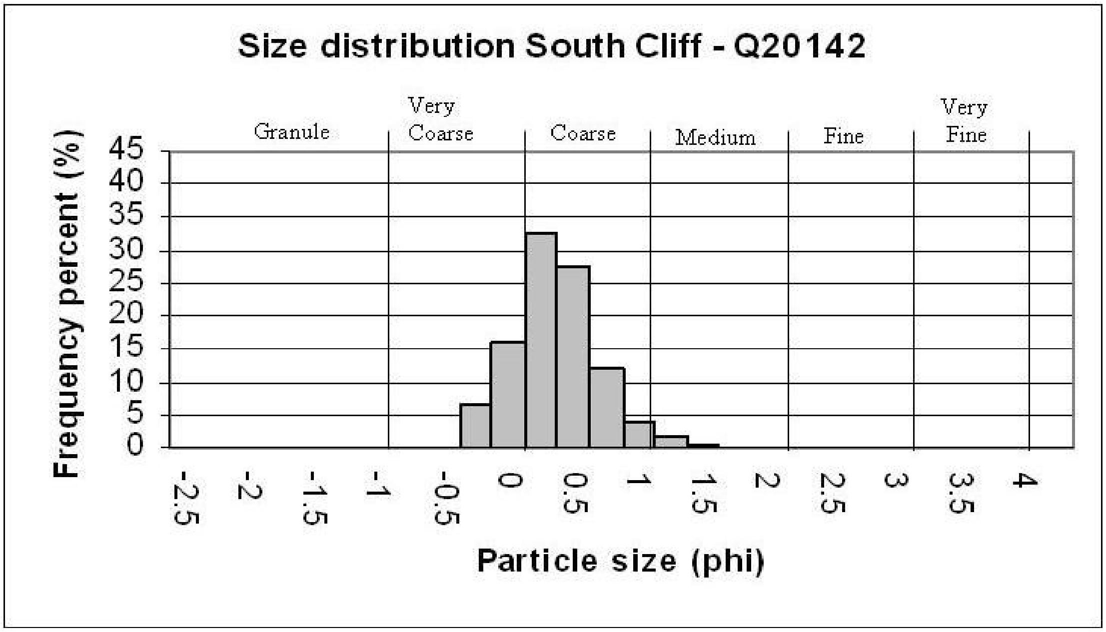


Figure 8. Typical histogram of grain size distribution for the cliff zone at Moulter Cay (sample Q20142). See histograms for all cliff samples at Appendix 7.

4.2.1.2 Berm

The berm is predominately composed of very well sorted coarse sand, but with samples ranging from very well to moderately well sorted sand (0.32 to 0.51 φ). The modal size class is 0 to 1φ(Figure 9).

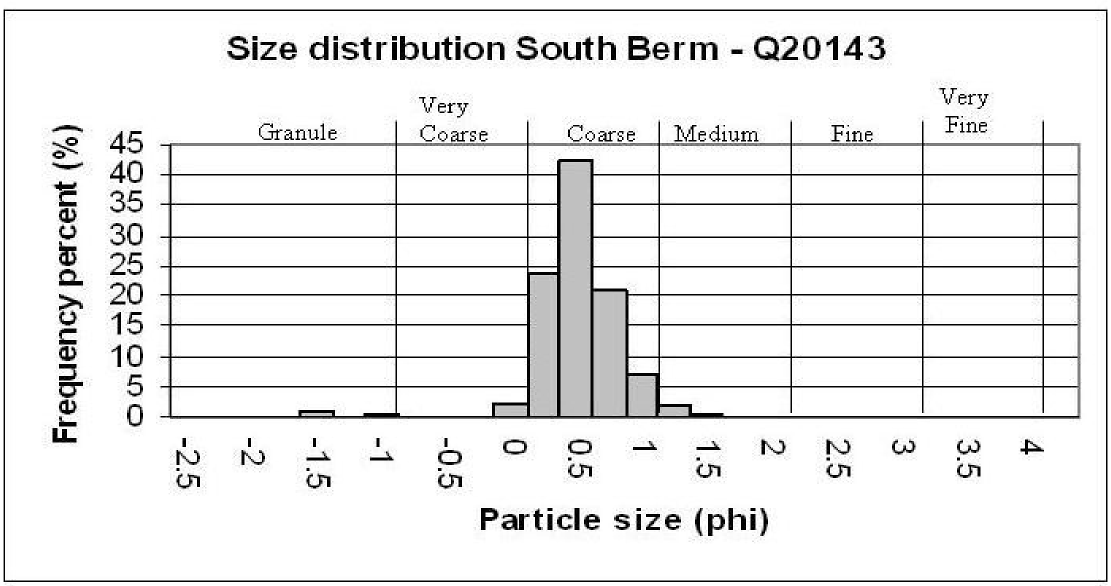


Figure 9. Typical histogram of grain size distribution for the berm zone at Moulter Cay (sample Q20143). See histograms for all berm samples collected from Moulter Cay at Appendix 7.

4.2.1.3 Toe of beach

The toe of beach zone is predominately composed of well sorted very coarse sand with the majority of sediment belonging to the -1 to 0 modal size class (Figure 10).

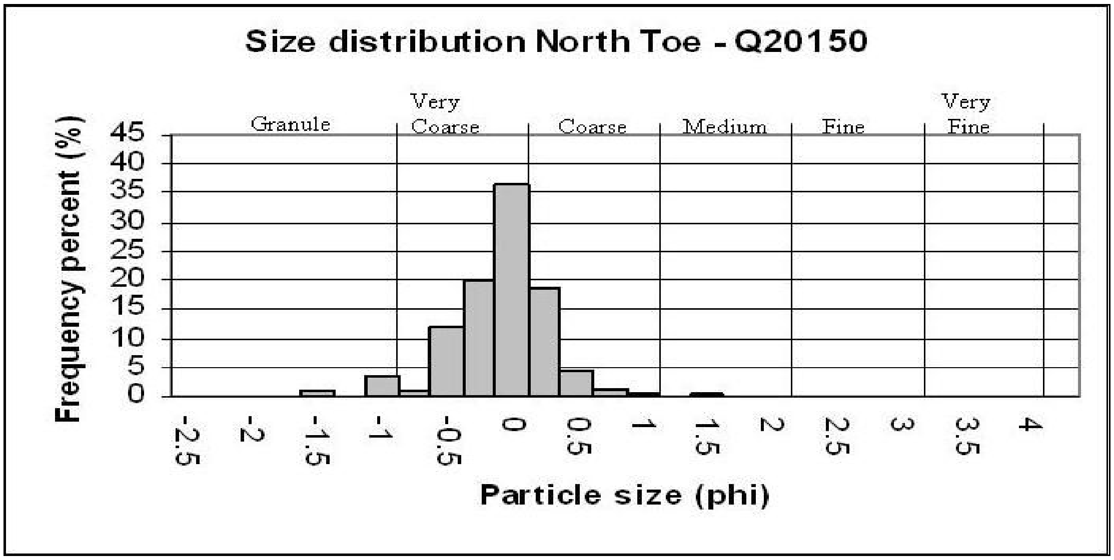


Figure 10. Typical histogram of grain size distribution for the toe zone at Moulter Cay (sample Q20150). See histograms for all toe of the beach samples at Appendix 7.

4.2.2 Compositional Analysis

The sediment samples collected at Moulter Cay are mostly composed of molluscs, foraminiferans, coralline algae, coral and *Halimeda*, representing 44.9%, 25%, 10.9%, 10.7% and 7.7% of the sediment respectively (Figure 11). Constituent composition at Moulter Cay is similar across all orientations and beach zones (Figure 12). For further information on each sample see Table 4.

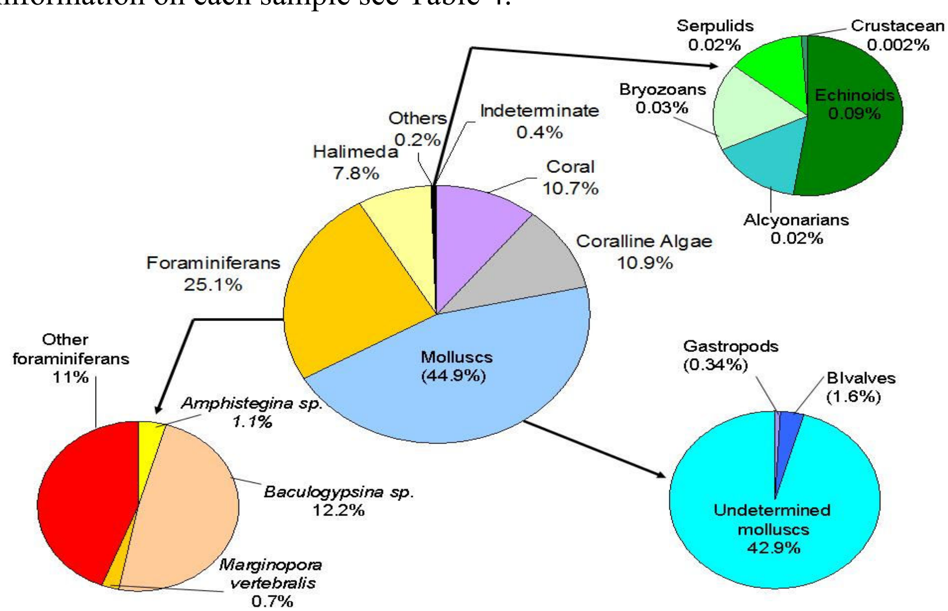


Figure 11. The skeletal constituent composition of surficial biogenic carbonate sediment samples collected at Moulter Cay, December 2006

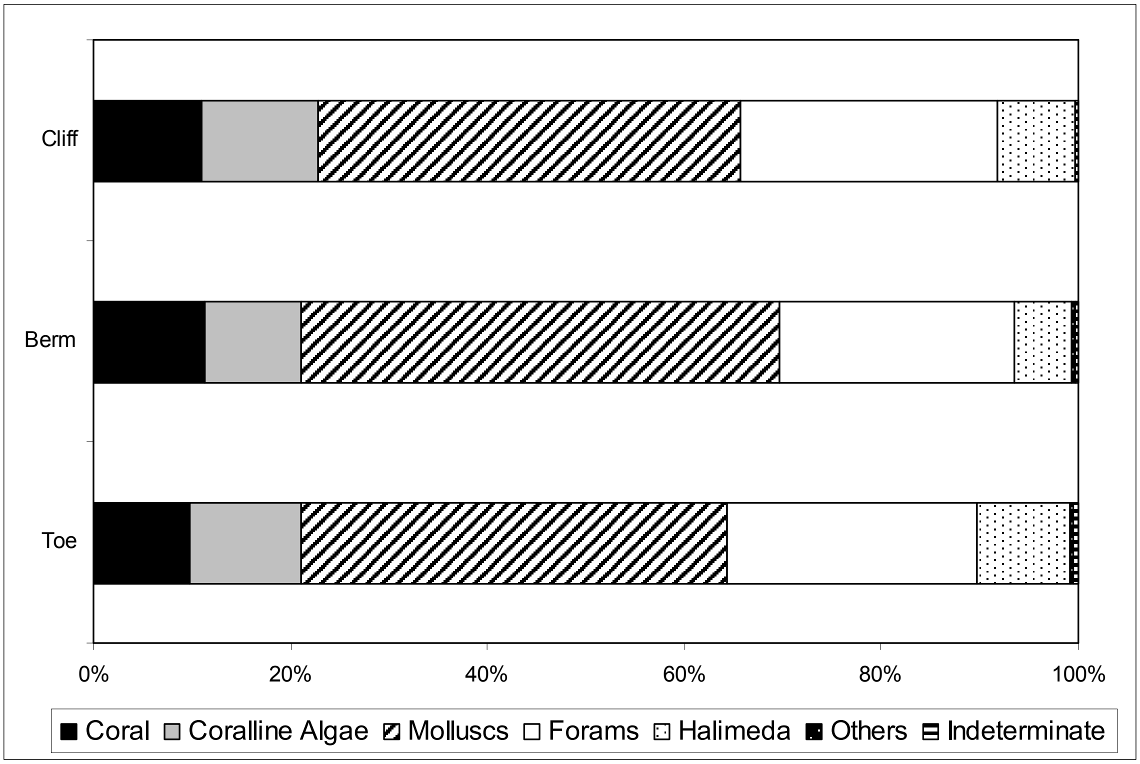


Figure 12. Constituent composition of sediment samples collected from the different zones at Moulter Cay, December 2006

Table 4. Constituent composition of samples collected at Moulter Cay, December 2006

Sample #	Environment	Coral	Coralline Algae	*Halimeda*	Molluscs	Forams	Others	Undetermined
Q20147	Toe (E)	8.1	9.9	9.8	48.6	23.6	0.0	0.4
Q20150.	Toe (N)	9.8	12.5	8.7	33.3	34.8	0.2	1.2
Q20144	Toe (S)	10.7	8.4	13.6	46.4	19.3	0.7	0.4
Q20141	Toe (W)	10.7	14.5	5.7	45.0	24.1	0.1	0.4
Q20146	Berm (E)	12.0	7.8	5.3	26.6	5.3	0.2	0.6
Q20149	Berm (N)	7.2	10.9	5.9	48.3	27.2	0.7	0.2
Q20143	Berm (S)	9.7	4.8	4.2	57.7	21.2	0.3	0.5
Q20140	Berm (W)	16.5	15.0	8.4	40.2	19.9	0.0	0.0
Q20145	Cliff (E)	6.6	11.9	6.9	27.5	6.9	0.0	0.2
Q20148	Cliff (N)	10.8	13.4	11.9	35.7	27.8	0.0	0.4
Q20142	Cliff (S)	11.7	8.6	7.4	42.7	28.1	0.0	1.0
Q20159	Cliff (W)	15.0	13.2	5.4	45.8	20.7	0.0	0.0

E= east, N= north, S= south and W = west

4.3 Sandbank 7

4.3.1 Textural Analysis

The surficial sediments collected from Sandbank 7 are predominantly very well sorted coarse sand. Sediment samples vary from very coarse (-0.11 φ) to coarse (0.67 φ) very well sorted (0.24 φ) to well sorted sand (0.43 φ). Muds are absent. For further textural detail and grain size histogram for each specific sample see Appendix 8 and 9 respectively.

4.3.1.1 Berm

The berm is predominately composed of well sorted coarse sand, with grain size ranging from -0.25 to 1.75φ. The majority of the sediment from all berm samples belongs to the 0 to 1φ modal grain size class (Figure 13).

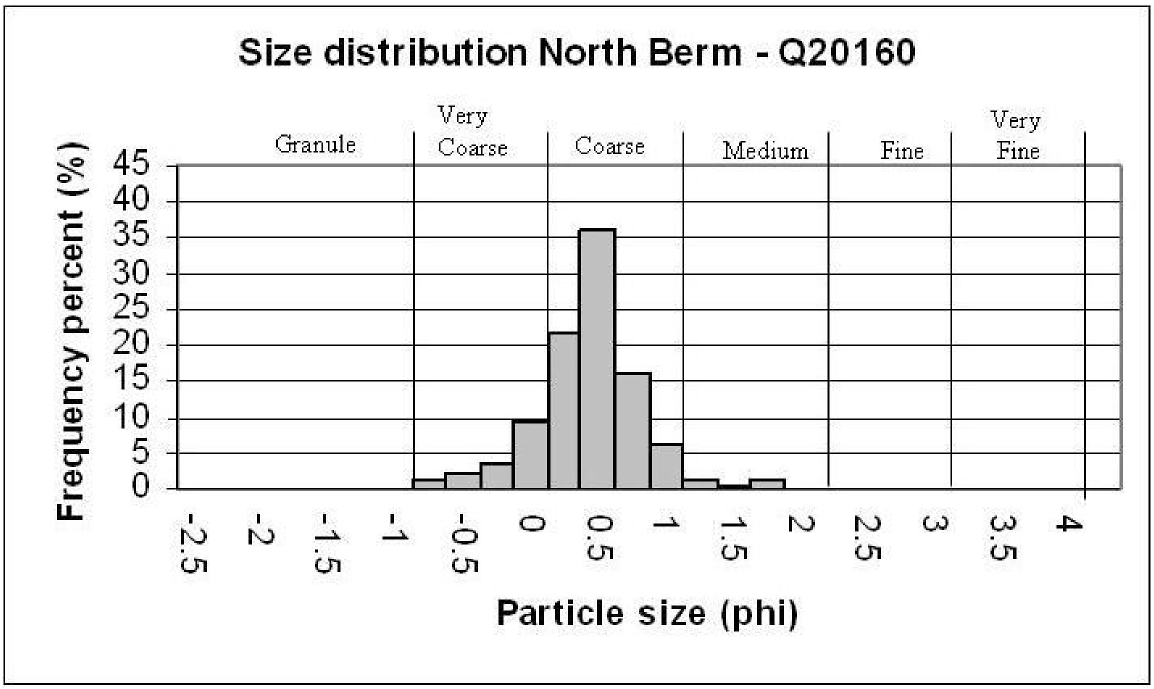


Figure 13. Representative histogram of grain size distribution for the berm zone at Sandbank 7 (sample Q20160). See all grain size histograms from the berm at Appendix 9.

4.3.1.2 Toe of the beach

The toe zone is predominately composed of very well sorted coarse sand with grain size ranging from -0.25φ (very coarse sand) to 1.75 φ (medium sand), with the modal size class being 0 to 1φ (Figure 14).

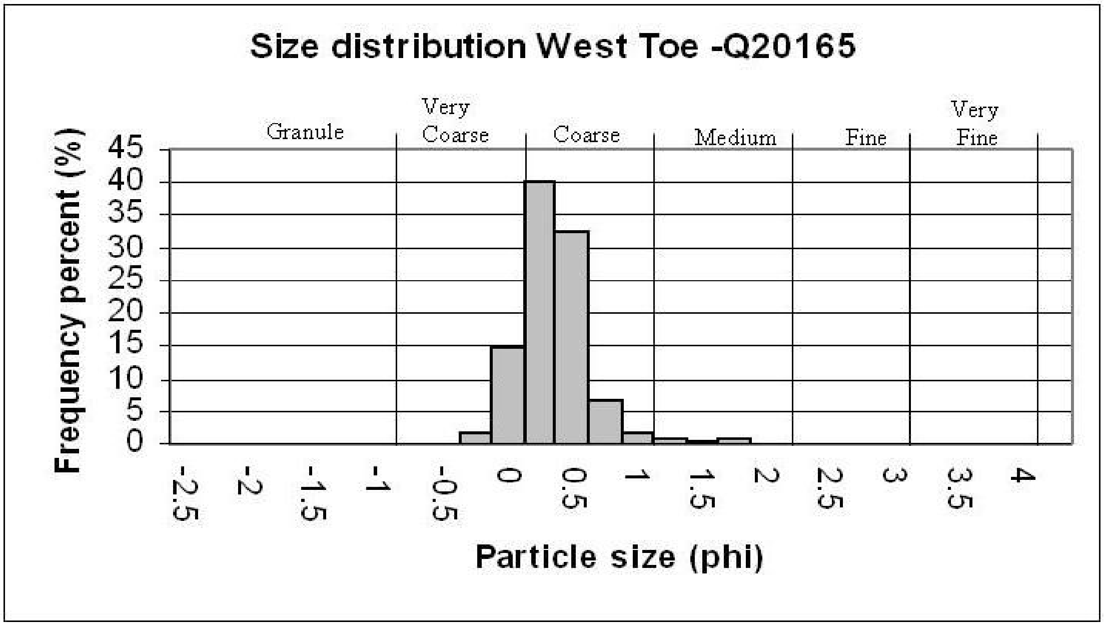


Figure 14. Representative histogram of grain size distribution for the toe zone at Sandbank 7 (sample Q20165). See all grain size histograms for samples collected from the toe of the beach at Sandbank 7 at Appendix 9.

4.3.2 Compositional Analysis

Molluscs dominate the constituent composition of sediments at Sandbank 7, making up nearly 50% of most samples (47.8%). Foraminiferans, coral, coralline algae and *Halimeda* are also relatively abundant, comprising 18.8%, 14.3%, 9.8% and 7.8% of the sediment respectively (Figure 15). Each zone at Sandbank 7 has a similar constituent composition Figure 16.

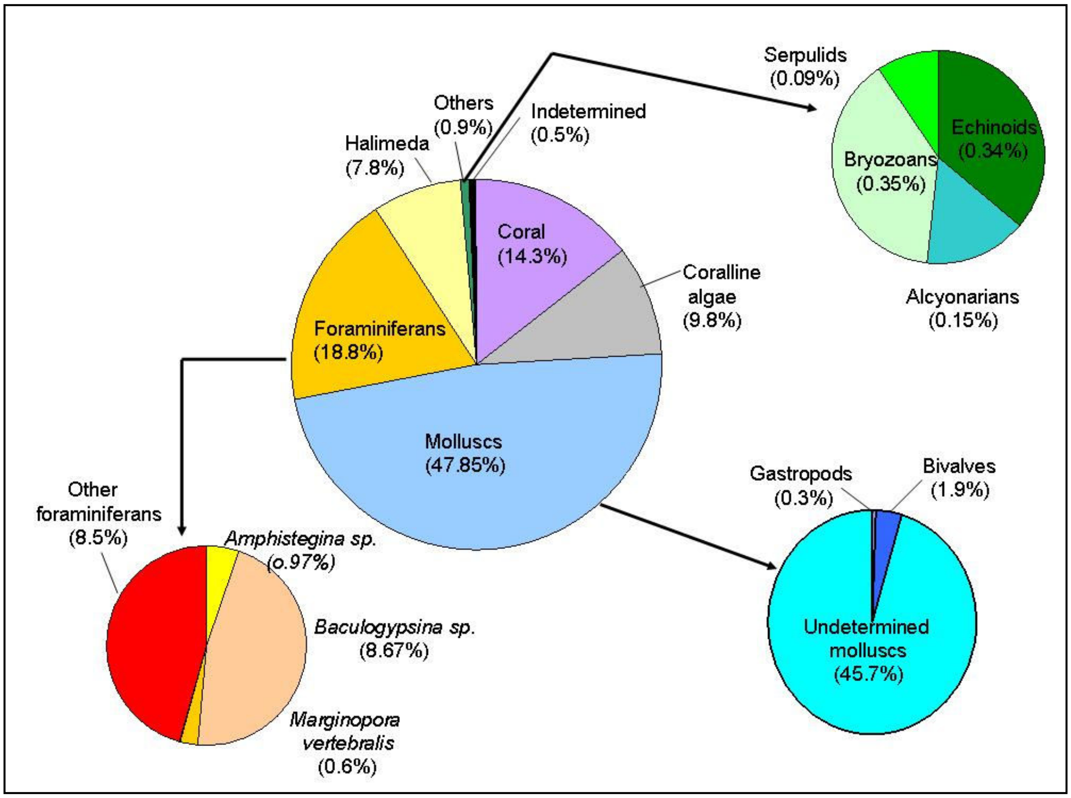


Figure 15. The skeletal constituent composition of surficial biogenic carbonate sediment samples collected at Sandbank 7, December 2006

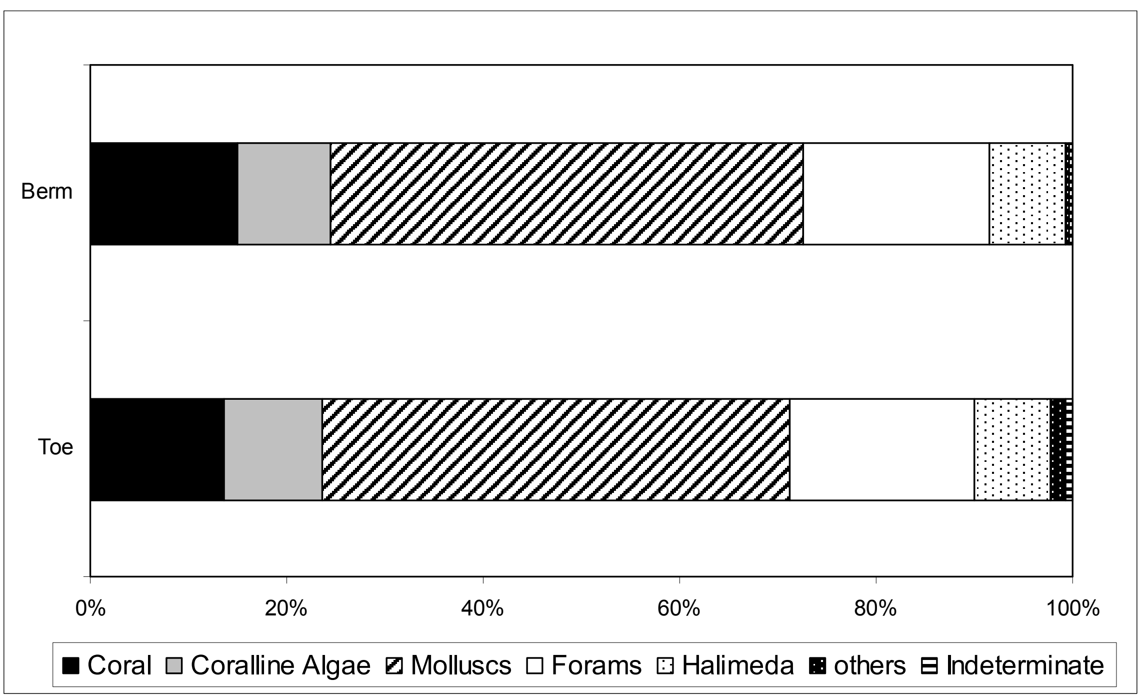


Figure 16. Constituent composition of sediment samples collected from different zones at Sandbank 7, December 2006

Table 5. Constituent composition of samples collected at sandbank 7, December 2006.

Sample #	Zone	Coral	Coralline Algae	*Halimeda*	Molluscs	Forams	Others	Undetermined
Q20161	Toe (E)	21.3	13.4	4.9	37.7	19.9	0.6	2.3
Q20159	Toe (N)	8.1	5.2	6.2	59.9	19.6	1.0	0.1
Q20163	Toe (S)	14.6	13.1	13.7	40.7	16.3	1.6	0.4
Q20165	Toe W)	10.7	8.2	6.2	51.8	19.3	3.2	0.8
Q20162	Berm (E)	14.4	6.5	7.3	49.2	22.2	0.2	0.4
Q20160	Berm (N)	17.4	10.2	9.7	46.4	15.8	0.5	0.2
Q20164	Berm (S)	14.7	13.7	8.3	47.5	15.4	0.4	0.2
Q20166	Berm (W)	13.5	8.0	6.3	49.5	22.0	0.0	0.7

E= east, N= north, S= south and W = west.

4.4 Sandbank 8

4.4.1 Textural Analysis

The surficial sediments collected from Sandbank 8 are predominantly well sorted sand (95.5%), with samples varying from being very well sorted to moderately sorted sand. Sediments are coarse (-0.3 to 0.74 φ), with some pebbles (4.5%) and no mud. See Appendix 10 and 11 for further textural information and sample locations.

4.4.1.1 Berm

The berm is predominately composed of well sorted coarse sand, with no fine sand present (Figure 17).

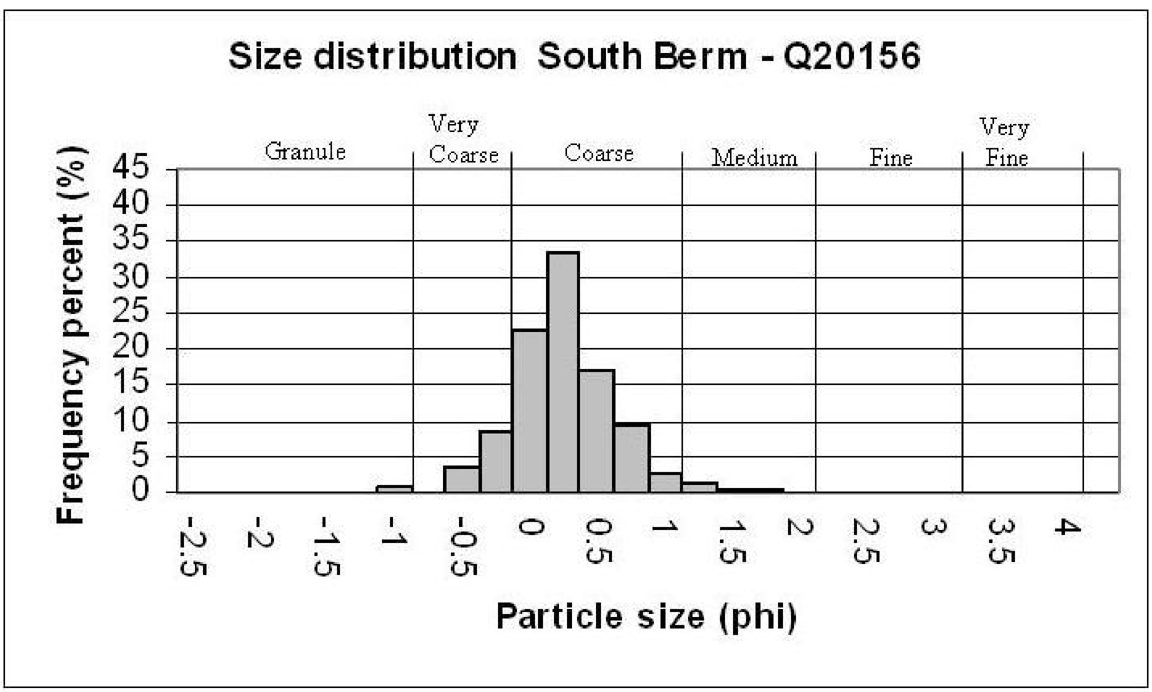


Figure 17. Representative histogram of grain size distribution for the berm zone at Sandbank 8 (sample Q20156). See Appendix 11 for all histograms from the berm.

4.4.1.2 Toe of the beach

The toe of beach is predominately composed of well sorted coarse sand with grain size ranging from -1φ (granule) to 1.5 φ (medium sand). The modal size class is 0 to 1φ (Figure 18).

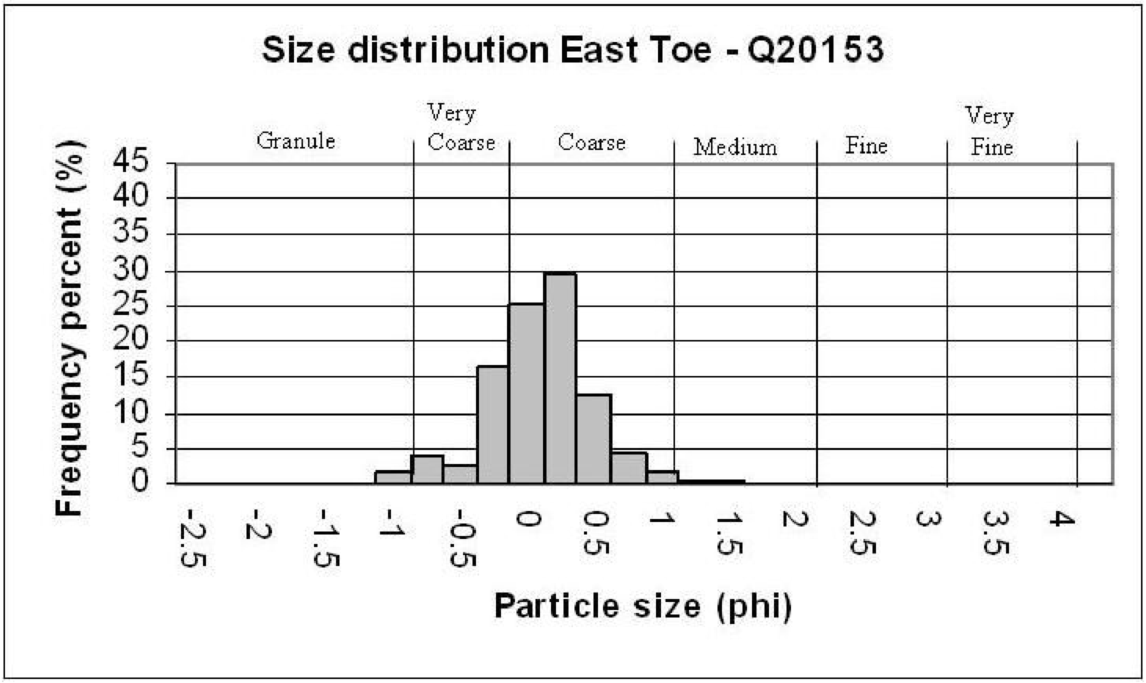


Figure 18. Representative histogram of grain size distribution for the toe zone at Sandbank 8 (Sample Q20153). See Appendix 11 for all histograms from the toe of the beach.

4.4.2 Compositional Analysis

The most dominant skeletal constituents of sediments at Sandbank 8 are molluscs (29.2%), foraminiferans (23%), corals (20.6%), with *Halimeda* (12.4%) and coralline algae (11.2%) contributing smaller but nevertheless significant sediment to most samples (Figure 19). For additional information on the composition of individual samples see Table 6.Compositional similarity is observed across the toe and berm zone across all orientations (Figure 20).

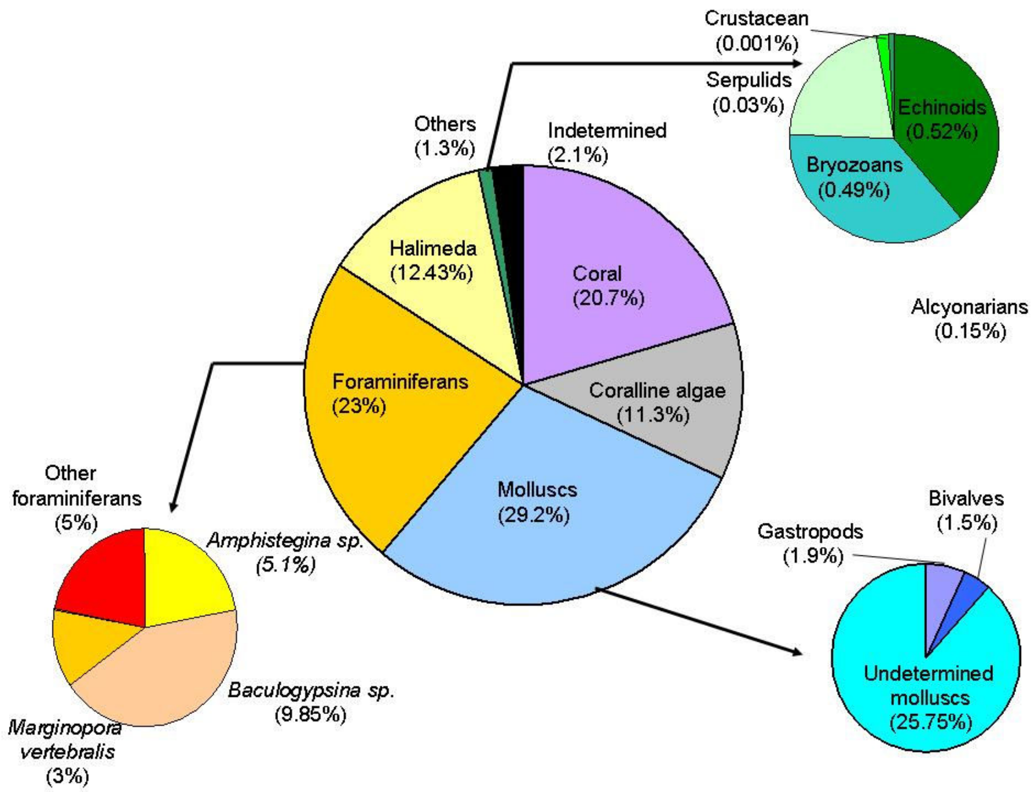


Figure 19. The skeletal constituent composition of surficial biogenic carbonate sediment samples collected at Sandbank 8, December 2006.

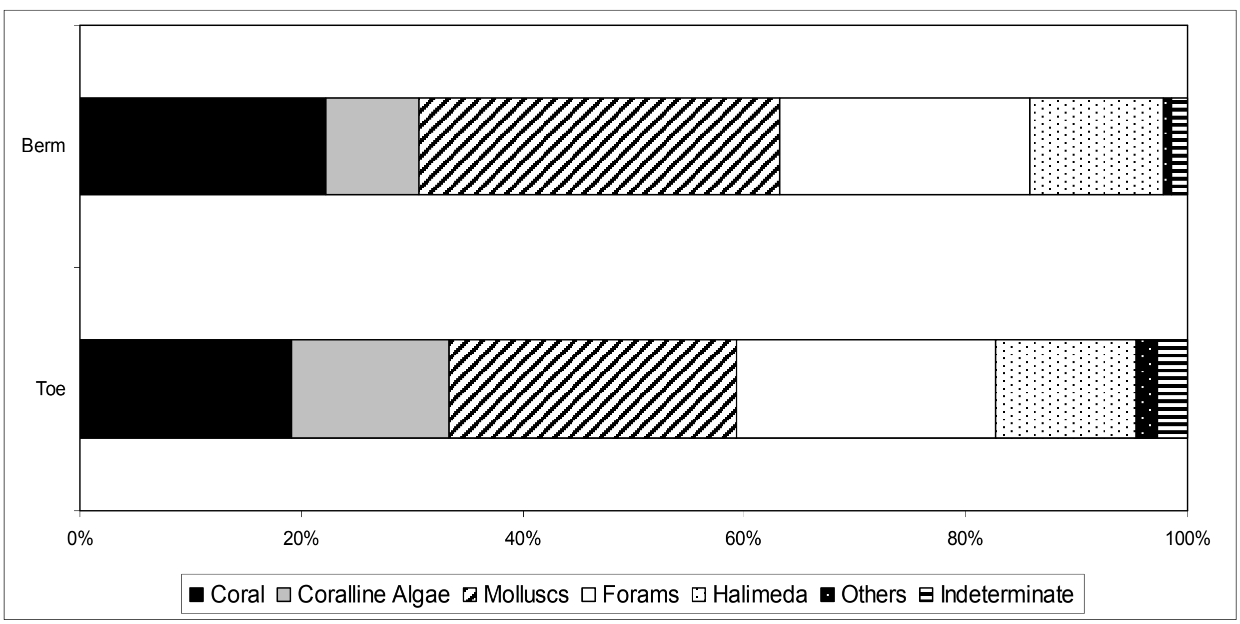


Figure 20. Constituent composition of sediment samples collected from the different zones at Sandbank 8, December 2006

Table 6. Constituent composition of samples collected at Sandbank 8, December 2006.

Sample #	Zone	Coral	Coralline Algae	*Halimeda*	Molluscs	Forams	Others	Undetermined
Q20153	Toe (E)	20.1	12.4	18.0	14.9	28.8	1.4	4.6
Q20151	Toe (N)	22.6	21.6	11.8	37.4	5.0	1.6	0.2
Q20155	Toe (S)	11.5	14.7	14.4	17.7	36.3	1.6	5.3
Q20157	Toe (W)	22.6	8.3	6.9	34.7	23.9	3.2	0.7
Q20154	Berm (E)	15.2	5.4	18.8	15.5	37.5	1.9	6.0
Q20152	Berm (N)	21.2	7.8	10.3	44.4	14.8	1.3	0.6
Q20156	Berm (S)	27.9	11.5	10.2	28.4	21.3	0.2	0.6
Q20158	Berm (W)	23.7	8.5	8.5	42.6	15.5	0.6	1.0

E= east, N= north, S= south and W = west.

5. Discussion

The Green turtle rookeries under investigation are dynamic reef islands. Their structure and morphology reflect the interdependence between physical, biological and geological factors (Gourlay 1988). Their shape, position or elevation may rapidly change as a result of sediment supply, storms and cyclones, wave height and direction, wind patterns, lithification, or vegetative growth (Bayliss-Smith 1988; Gourlay 1988; Gourlay and Hacker 1991; Hopley 1982; Li *et al.* 1997; 1998; Rasmussen and Hopley 1996; Stoddart et al 1981).

The four rookeries are dominated by medium to coarse sands, which are entirely biogenic and originate from plants and animals on the surrounding reef flats. Most rookeries are dominated by coarse well sorted sand, with variations between zones and orientation. Carbonate sediments are largely composed of the skeletal remains of marine organisms (primary carbonate) and/or the mechanical and biological breakdown of rigid reef framework (secondary carbonate). These sediments are characterized by assemblages dominated by foraminifera, molluscs and coral as well as coralline algae and *Halimeda*. Skeletal constituents such as echinoids, bryozoans, and crustaceans typically represent a small proportion of the beach sediment at all four islands.

Distribution and compositional character of sand is dependent largely by the complex interactions between the location of their source and their skeletal property (including resistance to mechanical destruction and growth of frame building) with the various processes that promote degradation, redistribution and stabilization (Dawson 2006; Smithers *et al.* 1994). These processes are mainly governed by a combination of external parameters relating to hydrodynamics, biological, geological and meteorological events (Dawson 2006; Graham 1988; McLean *et al.* 1978; Smithers 1994). Therefore, skeletal property together with the influences of wave intensity and current action determines the degree to which material will separate and be transported from their production source (Maxwell *et al.* 1964).

The sands of Raine Island are dominated by the shallow water benthic foraminifera, *Baculogypsina* and *Calcarina*, which makes up to 35% of the sediment. Molluscan debris (especially gastropods) is also another dominant constituent. Beach sediment grains are polished and typically well rounded; a product of subaerial processes and reworking by waves. Various authors have found similarly high proportions of *Baculogypsina* and *Calcarina* in reef island beach sediments (Yamano *et al*. 2000; Collen and Garton 2004; Dawson 2006). The sediment of Raine Island presented significantly more foraminiferans than all other rookeries, with foraminiferans being the single most important contributor to the sediment mass of the island. On Raine Island, foraminiferal tests are most common in the 0φ-0.5φ size fractions and most of the sands on Raine Island fall into these size fractions. The majority of sediments collected from Raine Island are moderately well sorted to very well sorted, symmetrically to positively skewed, coarse sands. Thus physical rather than biological processes are more likely to govern grain size.

In the same way to Raine Island, the sands of Sandbank 7 and Moulter Cay are biogenic and derive from similar material produced on the reef flat. However, Moulter Cay and Sandbank 7 have significantly more molluscs than Raine Island and Sandbank 8, with molluscs representing almost half of their sediments. Predominance of molluscs, may be explained by their superior skeletal durability to physical attrition in comparison to foraminiferans and *Halimeda* (Chave 1964; Milliman 1974; Smith *et al.* 1992). Sediments form Sandbank 7 is significantly better sorted than the other rookeries, with the majority of sediments from Sandbank 7 being very well sorted coarse sand.

Sandbank 8 is characterized by having foraminiferans, molluscs and *Halimeda* as important constituents, with no single skeletal component standing out as a dominant contributor.

As each rookery is comprised of different compositional structure they are likely to be affected differently to climate change. The potential consequences of these compositional differences in island sediments to climate change are yet to be determined. Impacts will vary according to sediment budget, sensitivity of different organism and sediment behaviour from each rookery.

6. References

Bayliss-Smith TP (1988) The Role of Hurricanes in the Development of Reef Islands, Ontong Java Atoll, Solomon Islands. Geographical Journal 154: 377-391

Chave KE (1964) Skeletal durability and preservation. In: Imbrie J, Newell N (eds) Approaches to Palaeoecology. Wiley, New York, pp 377- 387

Collen JD, Garton GW (2004) Larger foraminifera and sedimentation around Fongafale Island, Funafuti Atoll, Tuvalu. Coral Reefs 23: 445-454

Dawson JL (2006) Surficial carbonate facies across a platform reef, Masig, Torres Strait. Honours. School of Earth and Environmental Sciences, Townsville

Folk RL, Ward GH (1957) Brazos river bar: a study of significance of grain size parameters. Journal of Sedimentary Petrology 27: 3-26

Galehouse JS (1971) Point Counting. In: Carver RE (ed) Procedures in Sedimentary Petrology. John Wiley & Sons, Inc., New York, pp 69-94

Gibbs, RJ, Matthews MD and Link DA (1971) The relationship between sphere size and settling velocity. Journal of Sedimentary Petrology, 41(1): 7-18.

Gourlay MR (1988) Coral cays: products of wave action and geological processes in a biogenic environment. Proceedings of the 6th International Coral Reef Symposium, pp 491-496

Gourlay, MR and Hacker, JLF., (1991). Raine Island: coastal processes and sedimentology. CH40/91, Department of Civil Engineering, University of Queensland, Brisbane.

Graham J (1988) Collection and analysis of field data. In: Tucker ME (ed) Techniques in Sedimentology. Blackwell Scientific Publications, Oxford, pp 5-62

Hopley D (1982) Geomorphology of the Great Barrier Reef: Quaternary Development of Coral Reefs. John Wiley-Interscience, New York

IPCC (2007). Climate Change 2007: The physical Science Basis, Summary for policy makers.

Kench PS (1997) Currents of removal analysis of carbonate sediments Proceedings of the 8th International Coral Reef Symposium Panama, pp 503-508

Kench PS, McLean RF (1997) A comparison of settling and sieve techniques for the analysis of bioclastic sediments. Sedimentary Geology 109: 111-119

Kennedy DM, Woodroffe CD (2004) Carbonate sediments of Elizabeth and Middleton Reefs close to the southern limits of reef growth in the southwest Pacific. Australian Journal of Earth Sciences 51: 847-857

Kennedy DM, Woodroffe CD, Jones BG, Dickson ME, Phipps CVG (2002) Carbonate sedimentation on subtropical shelves around Lord Howe Island and Balls Pyramid, Southwest Pacific. Marine Geology 188: 333-349

Krumbein WC (1934) Size frequency distributions of sediments. Journal of Sedimentary Petrology 4: 65-77

Li C, Jones B, Blanchon P (1997) Lagoon-shelf sediment exchange by storms - evidence from foraminiferal assemblages, east exchange coast of Grand Cayman, British West Indies. Journal of Sedimentary Research 67: 17-25

Li C, Jones B, Kalbfleisch WBC (1998) Carbonate sediment transport pathways based on foraminifera: case study from Frank Sound, Grand Cayman, British West Indies. Sedimentology 45: 109-120

Limpus C, Miller J, Parmenter J and Limpus D (2003) The green turtle, *Chelonia mydas*, population of Raine Island and the northern great barrier reef 1843-2001, Memoirs of the Queensland museum 49, 349- 440.

Maxwell WGH, Jell JS, McKellar RG (1964) Differentiation of carbonate sediments on the Heron Island Reef. Journal of Sedimentary Petrology 34: 294-308

McLean RF, Stoddart DR, Hopley D, Polach H (1978) Sea level change in the Holocene on the northern Great Barrier Reef. Philosophical Transactions of the Royal Society of London Series A 291: 167-186

Milliman JD (1974) Recent Sedimentary Carbonates. Springer-Verlag, Berlin

Rasmussen CE, Hopley D (1996) Warraber Island Beach Erosion Review. Unpubl. Consultancy Report Commissioned by Edmiston and Taylor: 45

Smith AM, Nelson CS, Danaher PJ (1992) Dissolution behaviour of bryozoan sediments: taphonomic implications for nontropical shelf carbonates. Palaeogeography, Palaeoclimatology, Palaeoecology 93: 213-226

Smithers SG (1994) Sediment facies of the Cocos (Keeling) Islands lagoon. Atoll Research Bulletin 407: 1-34

Smithers SG, Woodroffe CD, McLean RF, Wallensky EA (1994) Lagoonal sedimentation in the Cocos (Keeling) Islands, Indian Ocean Proceedings of the 7th International Coral Reef Symposium, Guam, pp 273-288

Stoddart, DR., Gibbs, PE. and Hopley, D. (1981) Natural history of Raine Island, Great Barrier Reef. Atoll Research Bulletin, 254: 1-70

Yamano H, Miyajima T, Koike I (2000) Importance of foraminifera for the formation and maintenance of a coral sand cay: Green Island, Australia. Coral Reefs 19: 51-58

Appendix 1 - Spatial location of collected samples.

Sample #	UTM (WGS 84)	UTM (WGS 84)	Sample #	UTM (WGS 84)	UTM (WGS 84)
Raine Island			Moulter Cay		
Q20125	176660	8717280	Q20150	174760	8737342
Q20124			Q20149	174765	8737329
Q20123	176625	8717235	Q20148	174774	8737285
Q20122			Q20147	174881	8737235
Q20121	176900	8717114	Q20146	174873	8737230
Q20120			Q20145	174856	8737219
Q20119	176863	8717078	Q20144	175000	8736863
Q20118			Q20143	174997	8736865
Q20117	177027	8716800	Q20142	174971	8736891
Q20116			Q20141	174787	8736962
Q20115	176988	8716845	Q20140	174791	8736968
Q20114			Q20139	174812	8736990
Q20113	176717	8716840	Sandbank 7	Lat	Lon
Q20112			Q20161	13° 26' 17.9"	143° 58' 24.7"
Q20111	176747	8716912	Q20159	13° 26' 14.7"	143° 58' 19.7"
Q20110			Q20163	13° 26' 16.7"	143° 58' 17.2"
Q20109	176579	8716870	Q20165	13° 26' 14.1"	143° 58' 12.6"
Q20108			Q20162	13° 26' 18.0"	143° 58' 24.5"
Q20107	176605	8716940	Q20160	13° 26' 15.1"	143° 58' 19.7"
Q20106			Q20164	13° 26' 16.4"	143° 58' 17.3"
Q20105	176389	8716920	Q20166	13° 26' 13.8"	143° 58' 12.9"
Q20104			Sandbank 8	Lat	Long
Q20103	176433	8716992	Q20154	13°26'18.0"	143°58'24.5"
Q20102			Q20152	13°26'15.1"	143°58'19.7"
Q20101	176262	8717122	Q20156	13°26'16.4"	143°58'17.3"
Q20100			Q20158	13°26'13.8"	143°58'12.9"
Q20099	176356	8717122	Q20153	13°26'17.9"	143°58'24.7"
Q20098			Q20151	13°26'14.7"	143°58'19.7"
Q20094	176461	8717320	Q20155	13°26'16.7"	143°58'17.2"
Q20096			Q20157	13°26'14.1"	143°58'12.6"

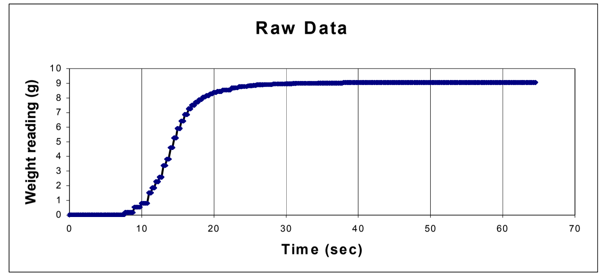
Appendix 2 - RSA Report Sheet output from SedRep

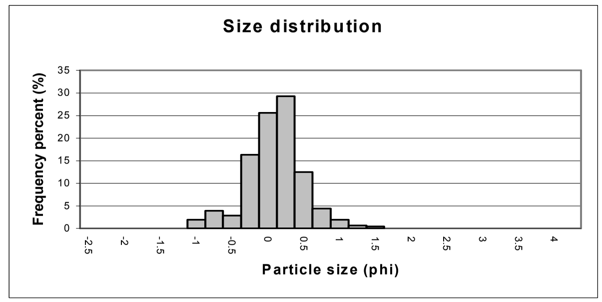
Rapid Sediment Analyser (RSA) Data Sheet

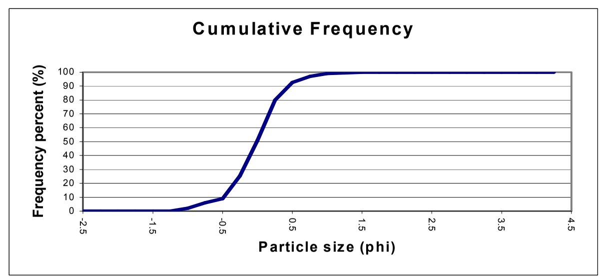
phi	micron	Weight	Weight Percent	Cum. Percent	Distribution	
-2.5	5657	0	0.00	0.00		
-2.25	4757	0	0.00	0.00		
-2	4000	0	0.00	0.00	0.0%	fine pebbles
-1.75	3364	0	0.00	0.00		
-1.5	2828	0	0.00	0.00		
-1.25	2378	0	0.00	0.00		
-1	2000	0.18	1.99	1.99	2.0%	very fine pebbles
-0.75	1682	0.36	3.97	5.96		
-0.5	1414	0.26	2.87	8.83		
-0.25	1189	1.48	16.34	25.17		
0	1000	2.32	25.61	50.77	48.8%	very coarse sand
0.25	841	2.65	29.25	80.02		
0.5	707	1.13	12.47	92.49		
0.75	595	0.4	4.42	96.91		
1	500	0.18	1.99	98.90	48.1%	coarse sand
1.25	420	0.06	0.66	99.56		
1.5	354	0.04	0.44	100.00		
1.75	297	0	0.00	100.00		
2	250	0	0.00	100.00	1.1%	medium sand
2.25	210	0	0.00	100.00		
2.5	177	0	0.00	100.00		
2.75	149	0	0.00	100.00		
3	125	0	0.00	100.00	0.0%	fine sand
3.25	105	0	0.00	100.00		
3.5	88	0	0.00	100.00		
3.75	74	0	0.00	100.00		
4	63	0	0.00	100.00	0.0%	very fine sand
< 4	< 63	0	0.00	100.00	0.0%	sub-sand fraction

Grain Size Statistics
Logarithmic Method of Moments

Mean Grain Size	phi	0.22	
	microns	856.48	
Standard Deviation		0.41	well sorted
Skewness		-0.09	
Kurtosis		4.03	







Sample name
S8_ET_1122_Q20153

Date
28/07/04

Fall distance
1.65 metres

Water Temperature
26 °C

Grain Density
1.85 gm/cm^3

The RSA is a settling tube with an internal balance which measures mass of sediment settled over time. This is converted into a size distribution using Gibbs equation (from Gibbs, et al, 1971).

The apparatus and SedRep software were developed by;

School of Geography & Environmental Science

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

Appendix 3 – D50 values from Raine Island.

D50 values for sediment samples from Raine Island.

Sample #	D50 (mm)
RI_E_TB_Q20116	1.4
RI_E_RF_Q20117	1.3
RI_E_MB_Q20115	0.9
RI_E_CLO_Q20114	0.8
RI_N_RF_Q20125	2.0
RI_N_MB_Q20123	0.8
RI_N_CLO_Q20122	0.7
RI_N_TB_Q20124	0.9
RI_S_Reef_Q20109	1.1
RI_S_MB_Q20107	2.9
RI_S_TB_Q20108	1.2
RI_S_Cliff_Q20106	1.0
RI_W_Reef_Q20101	1.0
RI_W_MB_Q20099	0.9
RI_W_Cliff_Q20098	1.0
RI_W_TB_Q20100	0.9
RI_NE_RF_Q20121	1.2
RI_NE_MB_Q20119	0.9
RI_NE_CLO_Q20118	0.8
RI_NE_TB_Q20120	1.0
RI_NW_RF_Q20094	1.2
RI_NW_MB_Q20097	0.8
RI_NW_CLO_Q20095	0.8
RI_NW_TB_Q20096	0.7
RI_SE_Reef_Q20113	1.3
RI_SE_MB_Q20111	0.9
RI_SE_Cliff_Q20110	0.8
RI_SE_TB_Q20112	1.1
RI_SW_RF_Q20105	1.3
RI_SW_MB_Q20103	0.8
RI_SW_CLO_Q20102	0.8
RI_SW_TB_Q20104	1.1

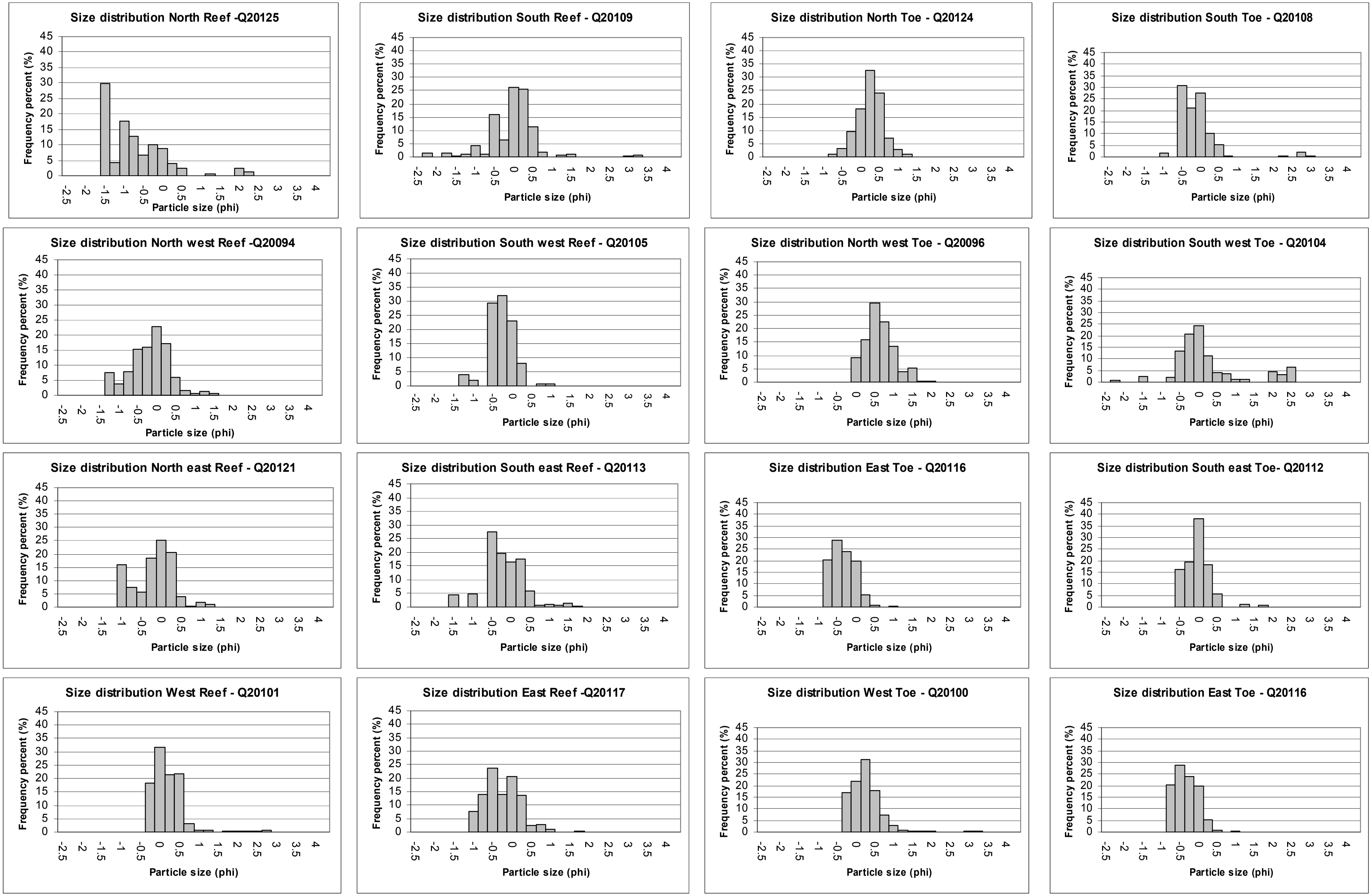
Appendix 4 – Textural characteristic of samples collected at Raine Island, December 2006.

Sample #	Environment	phi x	SD	skewness	kurtosis	fine pebbles	very fine pebbles	very coarse sand	coarse sand	medium sand	fine sand	very fine sand
Q20117	Reef (E)	-0.12	0.46	0.6	3.72	0	7.62	72.01	19.75	0.62	0	0
Q20125	Reef (N)	-0.59	0.82	1.54	5.93	0	51.47	37.94	6.18	3.24	1.18	0
Q20121	Reef (NE)	-0.06	0.5	-0.06	2.79	0	15.88	56.68	26.41	1.04	0	0
Q20094	Reef (NW)	-0.07	0.53	-0.06	3.26	0	11.36	61.99	25.08	1.58	0	0
Q20109	Reef (S)	0.1	0.67	0.52	9.66	1.42	7.22	49.72	38.81	1.56	0.57	0.71
Q20113	Reef (SE)	-0.05	0.53	0.14	4.63	0	9.31	63.37	24.96	2.36	0	0
Q20105	Reef(SW)	-0.14	0.36	-0.19	5.37	0	6.17	84.29	9.4	0.15	0	0
Q20101	Reef (W)	0.33	0.43	2.61	14.36	0	0	50.14	47.14	1.43	1.29	0
Q20116	Toe (E)	-0.2	0.33	0.95	5.26	0	0	92.8	6.87	0.34	0	0
Q20124	Toe (N)	0.38	0.36	-0.03	3.57	0	0	31.78	66.87	1.36	0	0
Q20120	Toe (NE)	0.31	0.56	-0.56	6.79	1.27	1.08	48.28	38.52	10.85	0	0
Q20096	Toe (NW)	0.76	0.39	0.56	3.18	0	0	9.01	81.01	9.98	0	0
Q20108	Toe (S)	0.03	0.57	3.23	16.9	0	1.74	79.54	15.97	0.15	2.61	0
Q20112	Toe (SE)	0.1	0.35	1.46	8.3	0	0	73.73	24.27	2	0	0
Q20104	Toe (SW)	0.36	0.97	1.01	3.88	0.98	2.61	60.59	20.2	5.86	9.77	0
Q20100	Toe (W)	0.38	0.44	2.61	16.64	0	0	39.08	58.57	1.57	0.45	0.34
Q20115	Berm (E)	0.39	0.39	-1.62	18.29	0.62	0	31.37	66.3	1.72	0	0
Q20123	Berm (N)	0.66	0.37	0.23	3.44	0	0	13.62	80.96	5.42	0	0
Q20119	Berm (NE)	0.39	0.39	1.76	10.31	0	0	34.46	62.29	2.54	0.71	0
Q20097	Berm (NW)	0.5	0.43	-0.32	3.83	0	0	25.4	71	3.61	0	0
Q20107	Berm (S)	0.5	0.44	2.83	18.12	0	0	21.88	76.39	0.41	1.32	0
Q20111	Berm (SE)	0.46	0.38	-1.81	19.66	0.66	0	23.52	73.96	1.86	0	0
Q20103	Berm (SW)	0.64	0.57	1.34	8.97	0	0	15.95	75.6	6.7	0.96	0.8
Q20099	Berm (W)	0.4	0.5	2.07	12.32	0	0.9	35.41	59.28	2.49	1.92	0
Q20114	Cliff (E)	0.55	0.27	0.89	5.63	0	0	6.34	92.74	0.93	0	0
Q20122	Cliff (N)	0.89	0.7	1.03	4.34	0	0	12.73	66.02	14.43	6.82	0
Q20118	Cliff (NE)	0.65	0.58	1.27	8.73	0	0	15.95	75.6	6.7	0.96	0.8
Q20095	Cliff (NW)	0.43	0.6	-0.34	3.72	0	4.26	27.66	61.54	6.22	0.33	0
Q20106	Cliff (S)	0.32	0.77	1.26	5.12	0	1.65	49.85	40.24	2.85	5.41	0
Q20110	Cliff (SE)	0.59	0.42	0.62	4.61	0	0.23	18.01	74.83	6.81	0.12	0
Q20102	Cliff (SW)	0.55	0.47	-0.4	12.63	0.68	0.68	16.94	77.73	3.28	0.68	0
Q20098	Cliff (W)	0.5	0.58	0.75	7.54	0	2.53	23.77	67.51	4.78	1.13	0.28

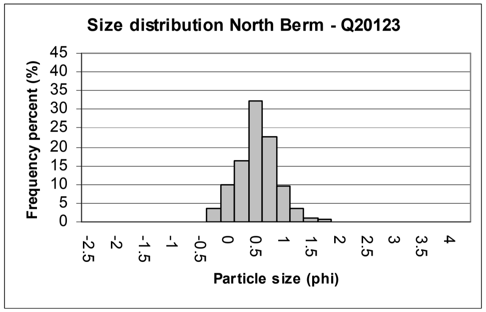
E = east, N = north, NE = north east, NW = north west, S = south, SE = south east, SW= south west and W = west.

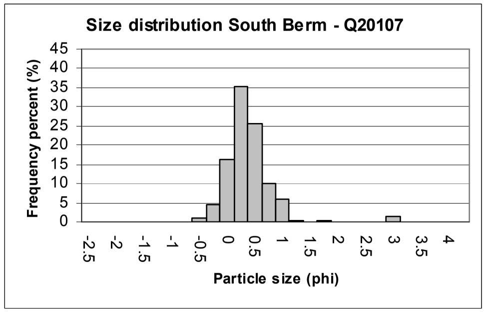
Appendix 5 – Grain Size distribution for samples from Raine Island

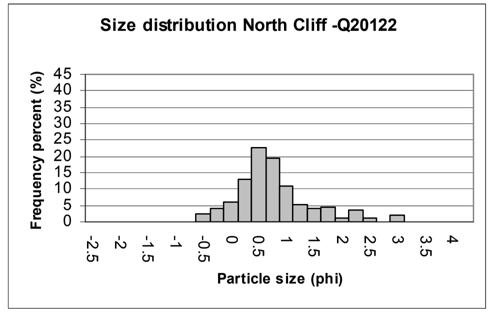
Reef | Reef | Toe | Toe

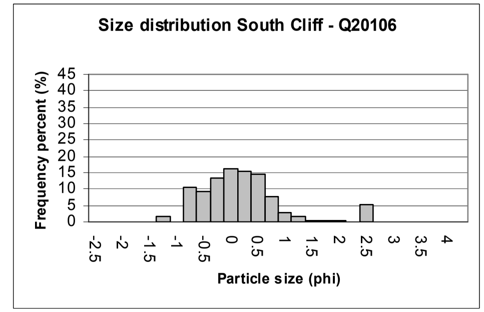


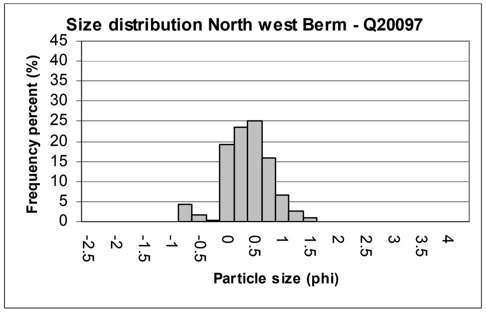
Berm | Berm | Cliff | Cliff

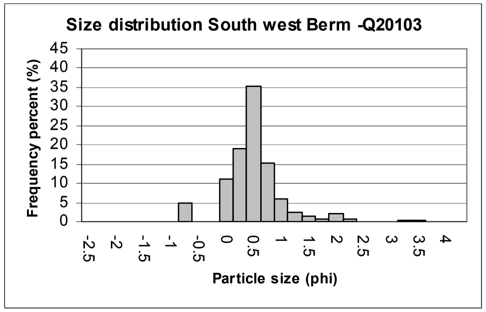


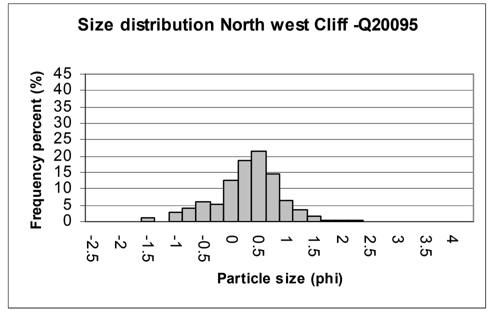


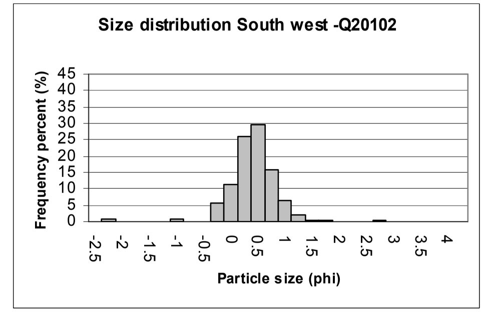


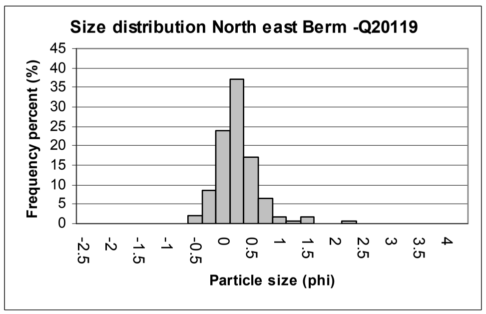


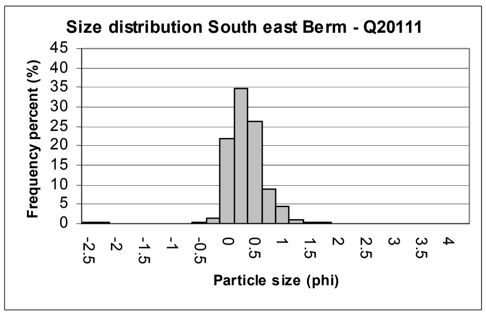


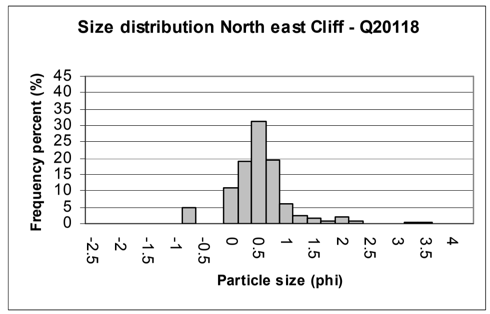


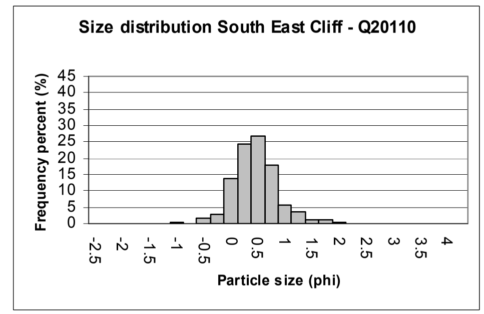


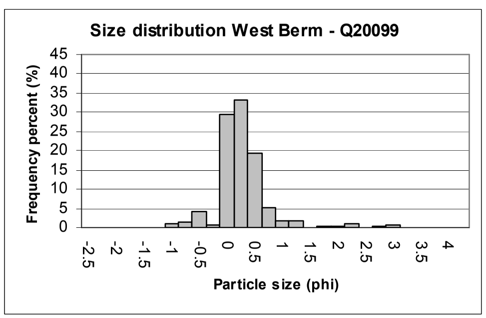


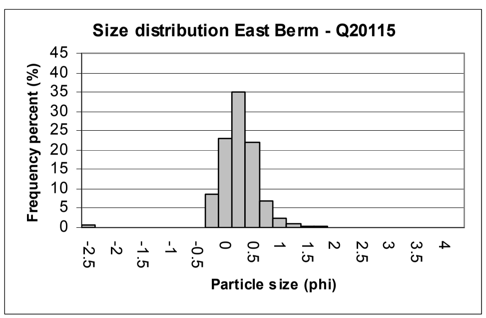


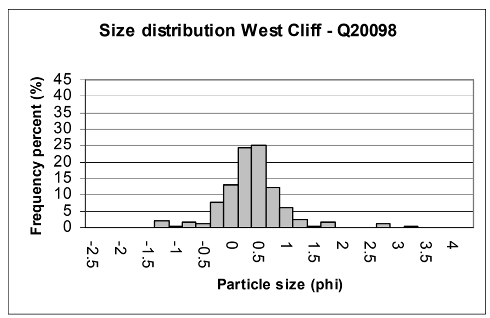


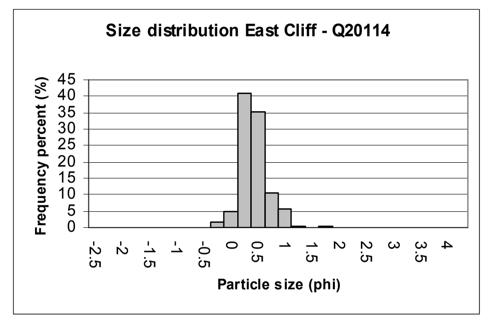












Appendix 6 – Textural characteristic of samples collected at Moulter Cay, December 2006.

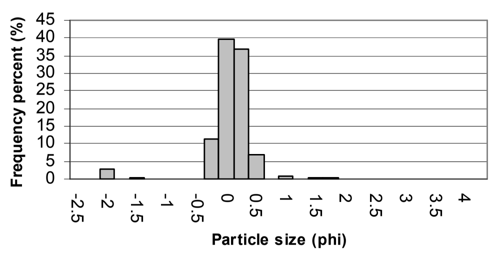
Sample #	Environment	phi x	SD	skewness	kurtosis	Fine pebbles	Very fine pebbles	Very coarse sand	Coarse sand	Medium sand	Fine sand
Q20147	Toe (E)	0.19	0.43	-2.53	15.85	3.00	0.00	51.00	45.00	1.00	0.00
Q20150	Toe (N)	0.06	0.39	-0.04	6.07	0.00	4.00	69.00	25.00	1.00	0.00
Q20144	Toe (S)	0.32	0.65	-1.68	5.78	0.00	11.00	7.00	80.00	2.00	0.00
Q20141	Toe (W)	0.45	0.26	0.91	6.30	0.00	0.00	18.00	81.00	1.00	0.00
Q20146	Berm (E)	0.58	0.52	2.94	13.18	0.00	16.00	78.00	2.00	3.00	0.00
Q20149	Berm (N)	0.48	0.33	0.92	3.59	0.00	0.00	24.00	73.00	3.00	0.00
Q20143	Berm (S)	0.63	0.34	-1.92	14.52	0.00	1.00	2.00	94.00	2.00	0.00
Q20140	Berm (W)	0.48	0.42	-0.92	7.03	0.00	5.00	11.00	82.00	2.00	0.00
Q20145	Cliff (E)	0.48	0.29	0.63	4.92	0.00	0.00	19.00	81.00	1.00	0.00
Q20148	Cliff (N)	0.39	0.42	0.49	3.56	0.00	0.00	39.00	58.00	3.00	0.00
Q20142	Cliff (S)	0.48	0.32	0.38	3.36	0.00	0.00	22.00	76.00	2.00	0.00
Q20159	Cliff (W)	0.44	0.49	-1.48	8.66	0.00	5.00	19.00	73.00	3.00	0.00

E = east, N = north, S = south and W = west

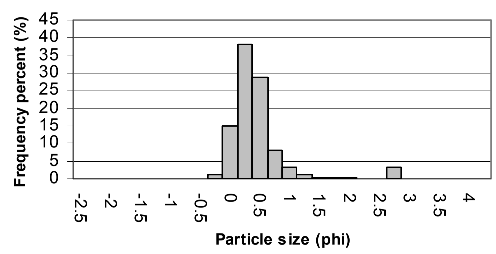
Appendix 7 – Grain Size distribution for samples from Moulter Cay

Toe | Berm | Cliff

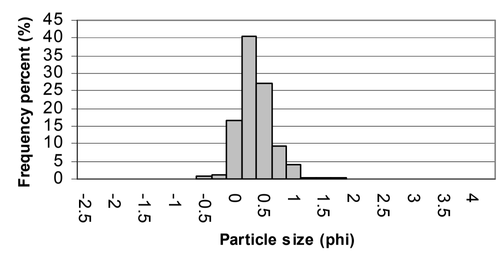
Size distribution East Toe - Q20147



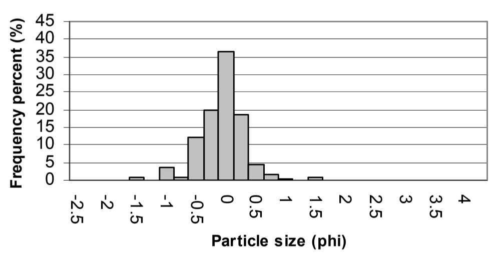
Size distribution East Berm - Q20146



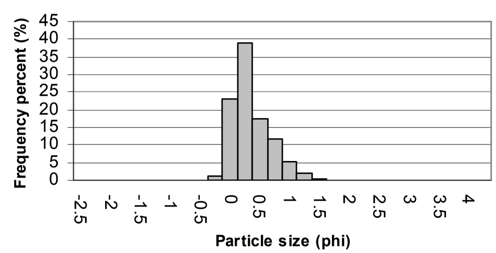
Size distribution East Cliff - Q20145



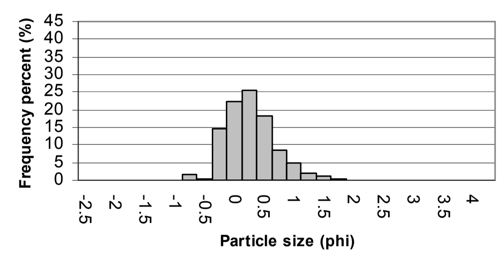
Size distribution North Toe - Q20150



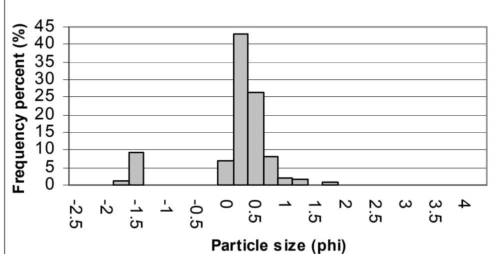
Size distribution North Berm - Q20149



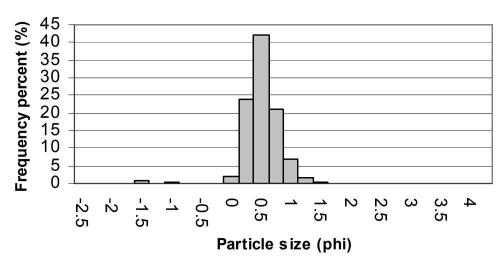
Size distribution North Cliff - Q 20148



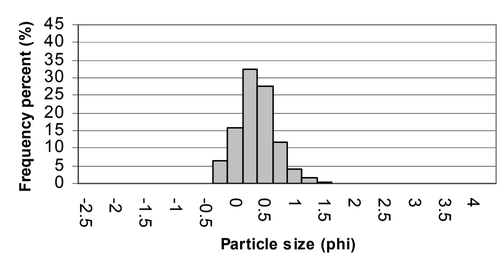
Size distribution South Toe - Q20144



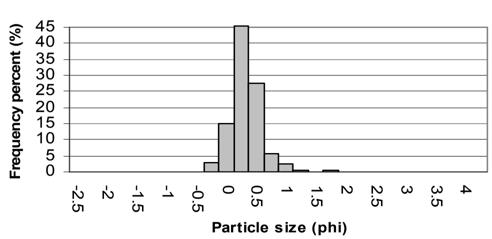
Size distribution South Berm - Q20143



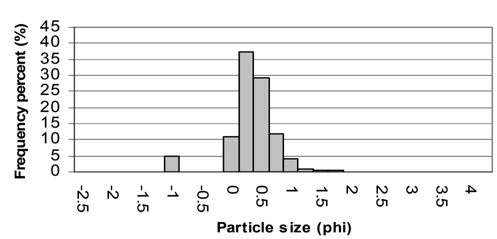
Size distribution South Cliff - Q20142



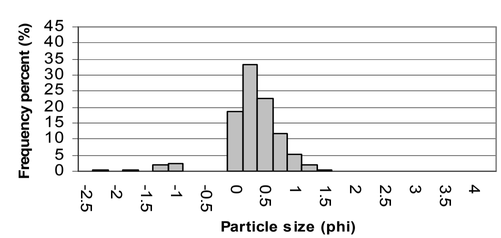
Size distribution West Toe - Q20141



Size distribution West Berm - Q20140



Size distribution West Cliff - Q20159



Appendix 8 – Textural characteristic of samples collected at Sandbank 7, December 2006.

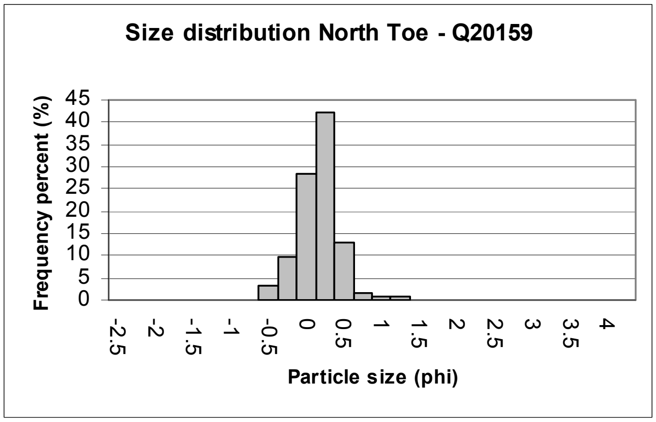
Sample #	Environment	phi x	SD	skewness	kurtosis	Fine pebbles	Very fine pebbles	Very coarse sand	Coarse sand	Medium sand	Fine sand
Q20161	Toe (E)	0.05	0.33	0.86	4.62	0.00	0	76.91	22.58	0.51	0
Q20159	Toe (N)	0.29	0.28	0.48	5.71	0.00	0	41.59	57.62	0.79	0
Q20163	Toe (S)	-0.11	0.25	1.26	6.67	0.00	0	94.10	5.90	0.00	0
Q20165	Toe (W)	0.49	0.29	1.45	8.06	0.00	0	16.57	81.18	2.25	0
Q20162	Berm (E)	0.40	0.37	0.48	4.69	0.00	0	31.69	65.84	2.47	0
Q20160	Berm (N)	0.56	0.40	0.00	4.80	0.00	0	16.80	79.75	3.44	0
Q20164	Berm (S)	0.32	0.43	-1.64	12.28	1.61	0	36.07	61.00	1.32	0
Q20166	Berm (W)	0.68	0.27	0.28	3.90	0.00	0	3.59	94.02	2.39	0

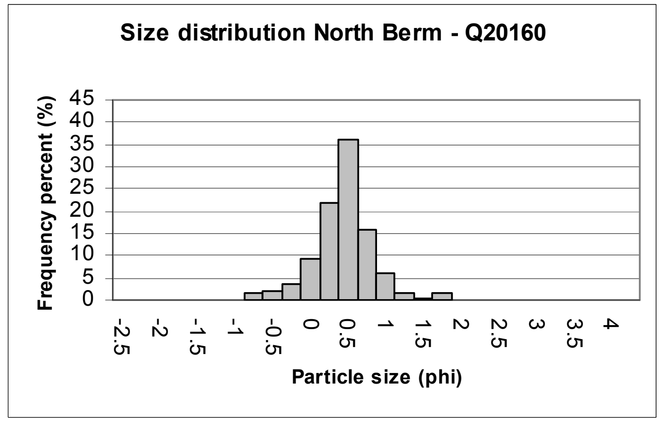
E = east, N = north, S = south and W = west

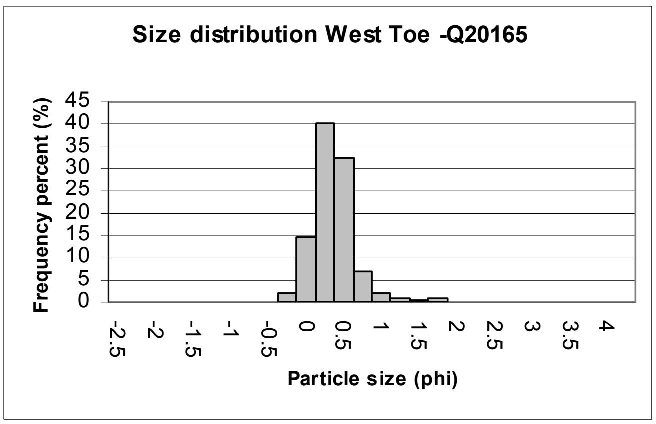
Appendix 9 – Grain Size distribution for samples from Sandbank 7

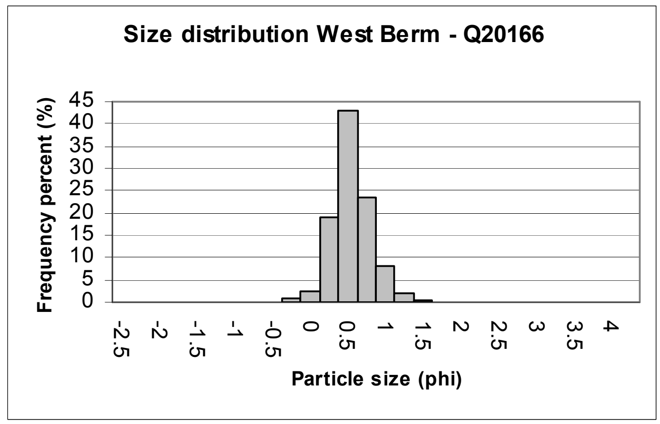
Toe

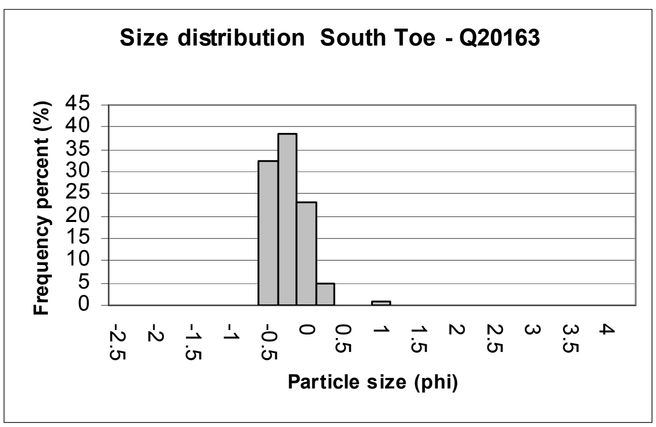
Berm

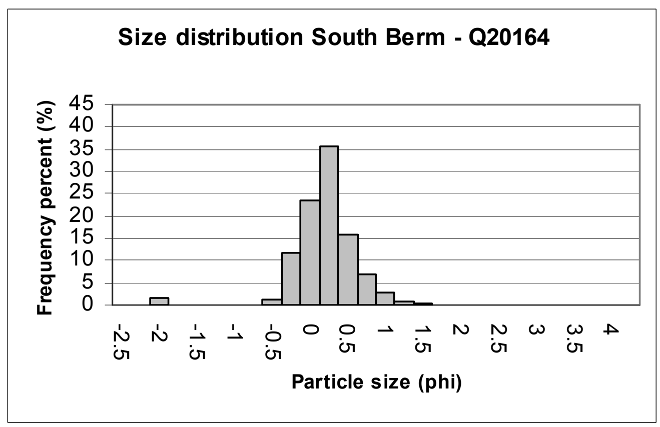


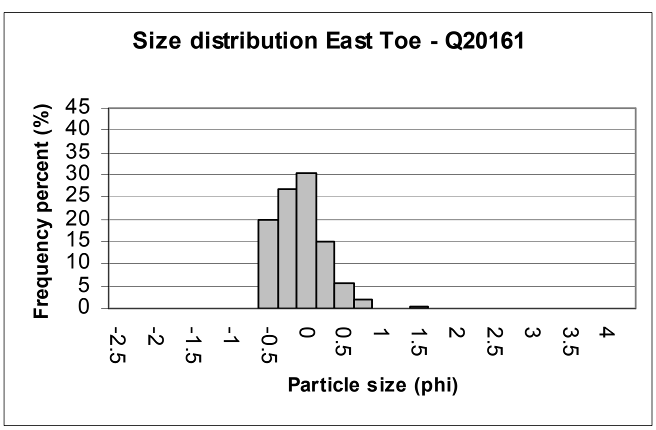


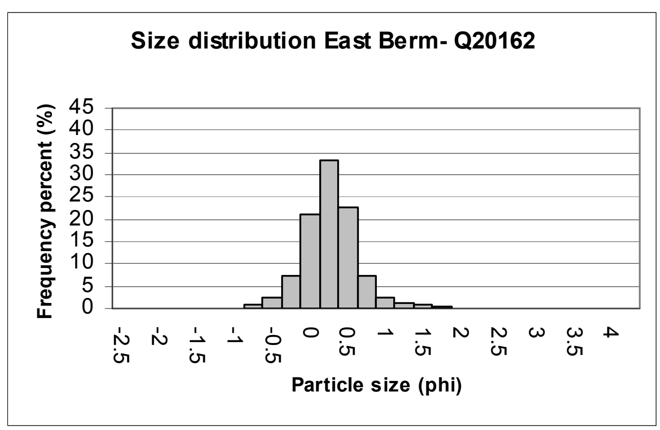












Appendix 10 – Textural characteristic of samples collected at Sandbank 8, December 2006.

Sample #	Environment	phi x	SD	skewness	kurtosis	Fine pebbles	Very fine pebbles	Very coarse sand	Coarse sand	Medium sand	Fine sand
Q20154	MB (E)	0.17	0.47	-1.25	12.14	0.83	2.26	60.17	35.20	1.55	0.00
Q20152	MB (N)	0.69	0.57	1.35	4.92	0.00	0.00	18.86	69.88	6.78	4.48
Q20156	MB (S)	0.38	0.39	0.52	5.14	0.00	0.69	34.60	62.17	2.42	0.12
Q20158	MB (W)	0.74	0.45	-0.23	5.23	0.00	0.00	6.02	83.61	10.12	0.26
Q20153	TB (E)	0.22	0.41	-0.09	4.03	0.00	1.99	48.79	48.12	1.10	0.00
Q20151	TB (N)	-0.31	0.82	1.87	6.86	0.00	29.72	57.08	6.25	4.01	2.95
Q20155	TB (S)	0.19	0.36	1.11	6.28	0.00	0.00	63.14	35.01	1.84	0.00
Q20157	TB (W)	0.53	0.29	1.30	6.09	0.00	0.00	11.68	85.89	2.43	0.00

E = east, N = north, S = south and W = west

Appendix 11 – Grain Size distribution for samples from Sandbank 8

Toe

Berm