Chapter 6. Surficial Sedimentology

6.1 Introduction

The magnitude and variations in near-bed turbidity depend on local and regional hydrodynamics and the availability of sediment suitable for resuspension (Larcombe *et al.*, 1995). The distribution of modern inner-shelf and coastal sediments (and therefore near-bed turbidity) is the result of complex interactions between sediment supply and energy inputs. This chapter details the inner-shelf sedimentary facies surrounding Paluma Shoals and Phillips Reef to aid in the interpretation of the turbidity data, and to identify the local and regional sediment and energy inputs.

The coastal facies assemblage include:

1. Pleistocene gravel deposits;
2. Intertidal sand flats;
3. Intertidal sand bars, beach and beach barrier complex;
4. Mangroves and tidal channels.

The marine inner-shelf facies assemblage include:

1. Sandy muds;
2. Muddy sands;
3. Gravelly muddy sands;
4. Coral reef sediments.

The descriptions of the modern marine inner-shelf and coastal facies are based on field and laboratory observations and high-resolution laser diffraction grain-size analysis of 135 samples. Bradshaw *et al.* (1994) and Woolfe (1995) have demonstrated the use of a quantitative method of grouping high-resolution grain size data. This method has been employed in this project as a comparative tool. The grain-size dataset was statistically grouped using Woolfe & Michbayashi's (1995) Entropy4 program (Chapter 3.0). The resultant entropy groups are interpreted using the methodology of Woolfe (1995). Seven entropy groups have been delineated which correlate well with field observations (Figures 6.25, 6.26 and 6.27).

Figure 6.1. *Aerial photograph and overlay illustrating the sample locations (PS1-PS79) and representative grain size distributions of the coastal facies assemblage. The aerial photograph, taken at a tidal elevation of 0.16 m depicts two of the Paluma Shoals patch reefs, which are established on Pleistocene gravel deposits. The leeward margin of the shoals are bordered by intertidal sands with an intricate system of shore parallel intertidal sand bars established on the low-tide terrace. A small intertidal channel at the mouth of Two Mile Creek migrates across the intertidal sand flat during the tidal ebb, reworking sediment and introducing sand to the coast. An extensive beach, beach barrier and sand spit are developed and protect the network of mangrove fringed meandering and shore parallel tidal channels from periodic high energy events. The mangrove distribution is largely restricted to the tidal channel margins with no extensively developed mangrove forest. High-tidal saltfats, which are only inundated on the highest tides or during storm surges are developed between the tidal channels and mangroves, and support halophytes and samphires.*

N
120 m
.Sand spit
Intertidal sandbars
.Beach barrier complex
.Intertidal channel
Paluma Shoals
Beach
146° 33.90' E

6.2 Coastal Facies

Pleistocene Gravel deposits

The Pleistocene gravel deposits underlie all modern coastal facies and outcrop within the intertidal and subtidal zones of southern Halifax Bay. The deposits consist of poorly sorted, sub-angular to sub-rounded, clast-supported gravels. The gravels are 1 cm to 25 cm in diameter and primarily composed of weathered, water worn granitic and volcanic clasts. The clasts exhibit a seaward directed imbrication and form extensive pediment-like platforms (Figure 6.2).

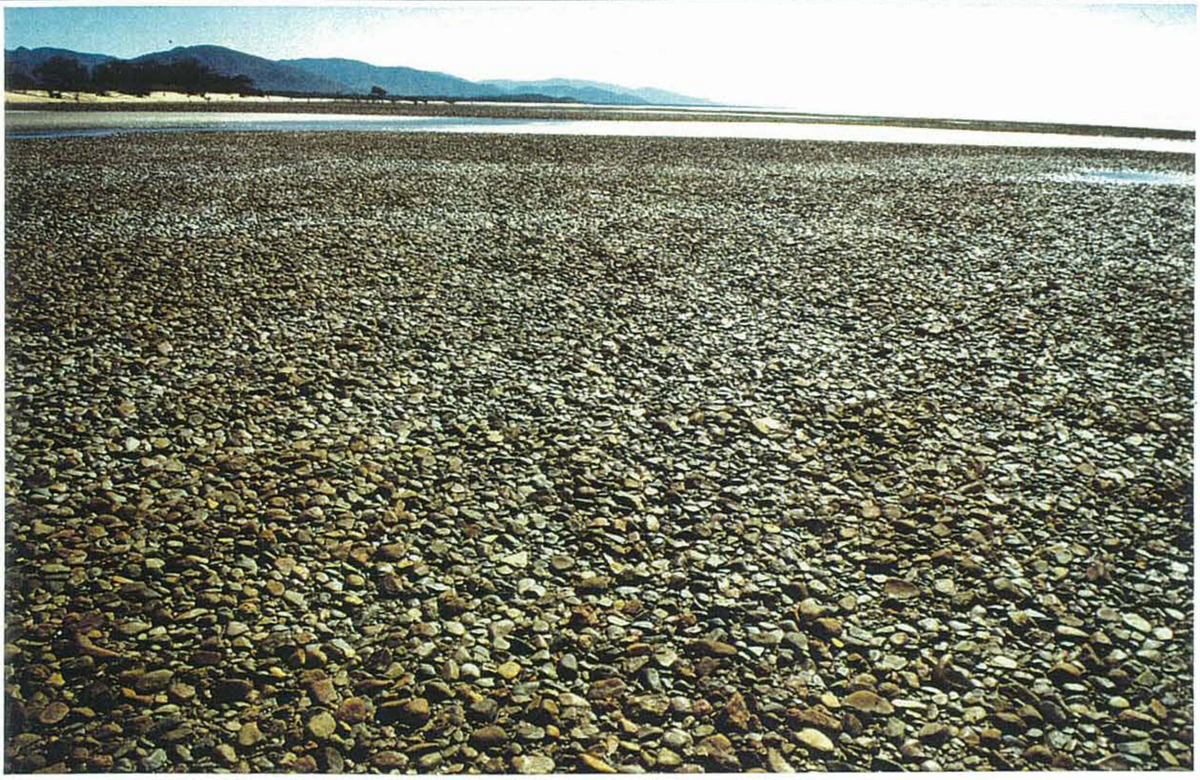


Figure 6.2 *Photograph illustrating the extent of the Pleistocene gravel deposits looking northwest toward Leichhardt Creek. Note the seaward directed imbrication. Shore normal gutters have formed between the gravel deposits and may indicate that the deposits are not laterally continuous or represent topographic lows in the underlying topography (photograph, R.G. Purdon).*

Approximately 2 km north of the study area the gravel deposits are extensively exposed, directly underlying intertidal flat, mangrove and beach sediments (Figure 6.3). The gravel deposits stretch almost continuously from the modern beach to the subtidal zone where hard and soft corals have become established on the gravel surface (Figure 6.4). Seaward orientated gutters (up to 0.6 m deep) have formed between the gravel deposits and are infilled with a veneer of intertidal sands, and may indicate that the deposits are not laterally continuous or represent topographic lows in the underlying topography. Adjacent to Paluma Shoals the gravels outcrop as small (< 50 m in diameter) isolated patches in a well-formed low tide terrace.

Hopley and Murtha (1975) mapped the Quaternary sediment deposits of the Townsville coastal plain and describe similar deposits, defining them as Pleistocene to early-Holocene river channel deposits. The channel deposits which are comprised of coarse sands and water worn gravels are common over much of the coastal plain, occurring as closely spaced, linear rises elevated 1 to 2 m above the surrounding coastal plain. They note the distribution of the river channel deposits are similar to modern drainage systems of the coastal plain.

Figure 6.3. *Photograph illustrating the Pleistocene gravels underlying mangrove deposits (indicated by the mangrove stump and ancient muds which overlie the gravels to the right of the photograph) and modern beach sands (to the left). The gravel clasts are subangular to subrounded, poorly sorted and appear water worn. (Photography K.J Woolfe).*

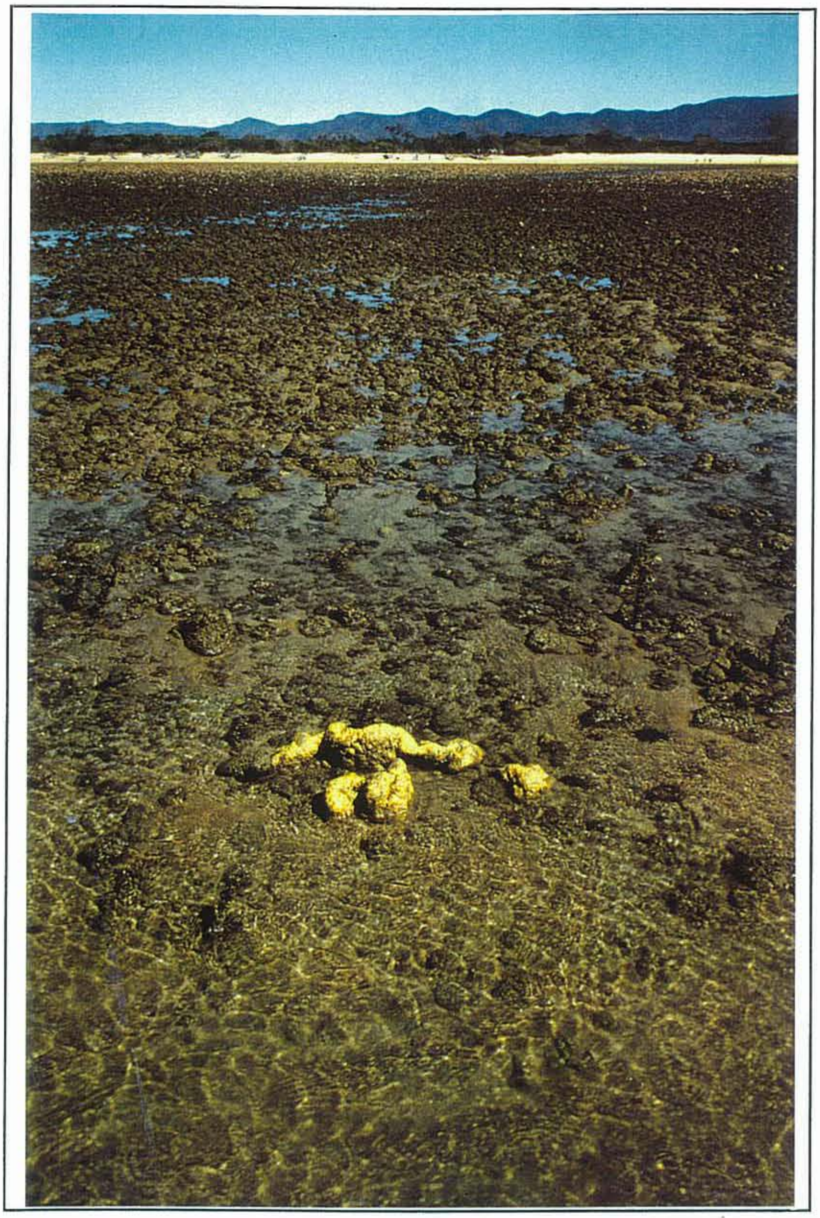


Figure 6.4. *Photograph looking southwest toward the coastal plain south of Leichhardt Creek, illustrating the extent of the relict gravel deposits and the establishment of corals at MLWS (photograph, R.G. Purdon).*

The water worn nature of the relict gravels is suggestive of fluvial processes rather than the action of waves and tidal currents. The morphology of the Pleistocene gravels *i.e.* their elevated linear nature and their grain-size characteristics is consistent with those described by Hopley and Murtha (1975) indicating they may be Pleistocene to early Holocene river channel deposits. The distribution of the channel deposits on the coastal plain correlate well with the relict gravels exposed along the intertidal and subtidal zones of the study area (Figure 6.5). The distribution pattern and the establishment of corals at MLWS (Figure 6.4)

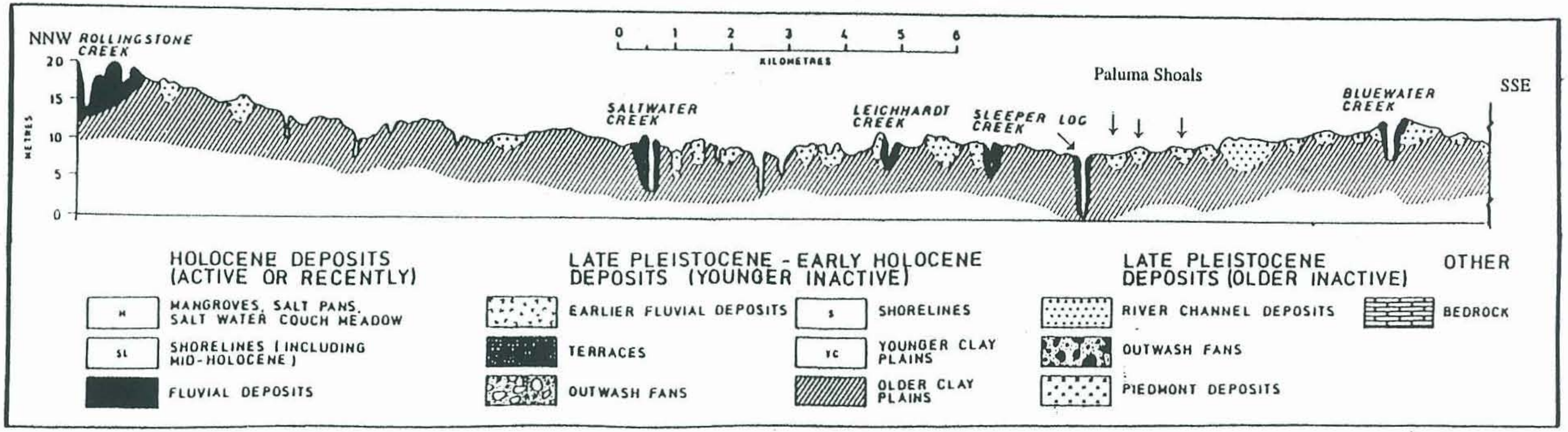


Figure 6.5. *Cross section through Quaternary coastal plain sediments between Rollingstone and Bluewater creeks approximately 3 km inland (Modified from Hopley and Murtha, 19 75). The location and morphology of the late Pleistocene deposits correlate well with the relict gravel deposits exposed in the intertidal and subtidal zones of southern Halifax Bay. This evidence supports the hypothesis that the river channel deposits form the substrate on which the corals at Paluma Shoals initiated.*

indicates that the river channel deposits are the likely substrate on which coral recruitment initiated leading to the development of Paluma Shoals. The exposure of the Pleistocene gravel deposits within the intertidal and subtidal zones indicate that net sediment accumulation is zero or less despite the turbid nature of the water.

Intertidal Sandflat

The intertidal sandflat adjacent to Paluma Shoals forms an extensive low-tide terrace stretching from the beach to the landward margins of the shoals (up to 900 m wide) (Figure 6.1). The sediments are well-sorted, fine-grained, unimodal sands with a mode of 100 μm (Figure 6.6). Sediments are composed of olive-grey (5Y 3/2), sub-angular to sub-rounded, quartzose sand with minor plagioclase feldspar grains (~ 5 %) and mica (~ 2 %). The carbonate content consists of abraded shells and foraminiferal tests and increases seaward from ~ 6 % close to the beach and beach barrier to ~ 12 % adjacent to the shoals (Figure 6.15 & Table 6.1).

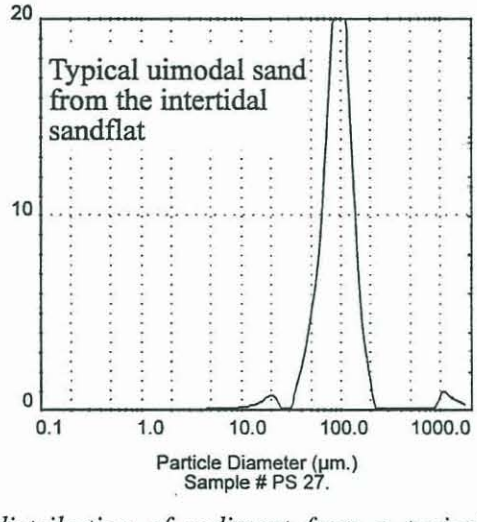


Figure 6.6. *Grain-size distribution of sediment from a typical intertidal sandflat sand adjacent to Paluma Shoals. These sediments are well-sorted, unimodal with a mode at 100 μm.*

The width of the intertidal sand flat is related to wave energy and the availability of sand for distribution across the flat (Belperio, 1978). The widest sandflats occur on the western or leeward side of headlands and spits because the dominant wave spectrum is from the south east (Belperio, 1978). The intertidal sand flat adjacent to Paluma Shoals is on the leeward side of a small headland located at the mouth of Bluewater Creek (Figure 2.2) and is therefore more extensive than sandflats south of the headland. The degree of sorting, *i.e.*

the unimodal nature of the sand and the sandflats location, indicate that these sediments are exposed to periods of high swell and wind wave energy. The sand is most likely debouched from local creeks during intense seasonal rainfall events and moved northward via the wind-driven longshore current during periods of south-easterly winds. The small intertidal channel at the mouth of Two Mile Creek (Figure 6.1) migrates across the sand flat during the tidal ebb, reworking and introducing coarser sediment to the facies. Paluma Shoals is only a limited source of carbonate sand because the carbonate content of the intertidal sands (6-12 %) is significantly lower than those of the reef flat sediments (25-80 %) indicating limited net-landward transport of the reefal calcareous sands (Table 6.1 & Appendix 6.2). Fine-grained sediments which settle during periods of low wave and or tidal slack are winnowed from the sand flats during periods of increased wave (swell wave events) and tidal energy. The resuspended material is transported northward by the wind driven longshore current during periods of south-easterly winds. Recent studies indicate that suspended sediment is also transported landward, during the flow of the tide into some estuaries fringing the GBR (Larcombe & Ridd, 1993; Bryce et al., 1995).

Intertidal Sand Bars

An intricate system of shore-parallel sand bars is established on the intertidal sand flat adjacent to Paluma Shoals (Figure 6.1). The sand bars are up to 120 m wide and 600 m long and elevated up to 30 cm above the low tide terrace. The less than 1 mm fraction (up to 80 percent) of these sediments are moderately sorted bimodal sands, with modes of 1050 μm (the dominant mode) and 200 μm (the subordinate mode) (Figure 6.7). The remaining fraction of the sands are less than 2 mm in diameter (Appendix 6.1). Sediments are moderate yellow/brown (10Y 5/4) sands comprised of subangular to subrounded quartz (~ 85 %) feldspar (~ 5 %) and minor hornblende. The remaining fraction (~ 10 %) consists of shells, shell fragments and minor abraded foraminiferal tests.

Local creeks (including Bluewater, Two Mile and Sleeper Log creeks) are likely sediment sources of the sand. Point bars composed of coarse sand are evident in Two Mile Creek during low tide. Aerial photography demonstrates that where Two Mile Creek has breached the barrier bar, a small intertidal channel has formed, and sand bars have developed (Figure 6.1). Aerial photography taken prior to the breaching of Two Mile Creek (1979) illustrates no development of intertidal sand bars in this location, indicating that local creeks and rivers are sources of sand to the sand bars.

The shore parallel orientation of the sand bars may be influenced by the south-easterly trade winds and the linear nature of the southern Halifax Bay coastline Belperio (1978). The sand bars tend to erode at their southern ends and prograde at their northern ends, subsequently migrating along the coast. However, if these sand bars become "anchored" at their southern end, coastal accretion may result as the sand bar growth would only occur on the northern extremities (Belperio, 1978). Therefore, the morphology, distribution and the subsequent progradation of the sand bars may be a result of the availability of sand and the dominant transport mechanism within the inner-shelf, the southeasterly trade winds.

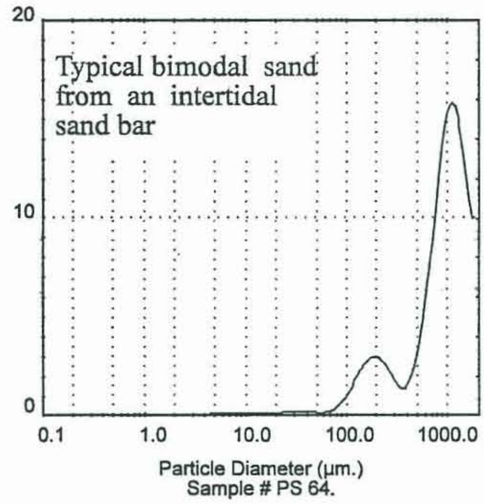


Figure 6.7. *Representative grain size distribution of the intertidal sand bars adjacent to Paluma Shoals. This particular sample has modes at 1050 and 200 microns.*

Beach and Beach Barrier Complex

Adjacent to Paluma Shoals an extensive beach, a well vegetated beach barrier and sand spit are developed along the linear coastline (Figure 6.1). The beach, beach barrier and sand spit are composed of angular to sub-rounded quartzose (~ 90 %) sands with minor feldspar (5 %) shells and wood fragments. The carbonate content is commonly less than 5 % by weight. On average 93 % of the sediment fraction is below 1 mm, 96.5 % less than 2 mm and the remaining fraction 2 mm or greater (gravel) (Appendix 6.1). Grain size analysis indicates that these sediments are well-sorted unimodal sands, with modes from 325 µm to 1385 µm (Figure 6.8).

The sediment source for the sand and gravel components may be the same as the intertidal sand bars *i.e.* local creeks (Figure 6.1). Sediment is debouched from these local sources during episodic rainfall events (Two Mile and Sleeper Log creeks) and is transported (as bedload) parallel to the coastline, forming intertidal sand bars. Spring tides and wave energy deposit sand sized above MHWS increasing the height of the beach and beach barrier (Belperio, 1978). This process which is dependent on the supply rates of sand leads to the progradation of the modern coastal plain and embayments. Calculated the progradation rates are up to 1 km/1000yrs (Belperio, 1983; Carter *et al.*, 1993).

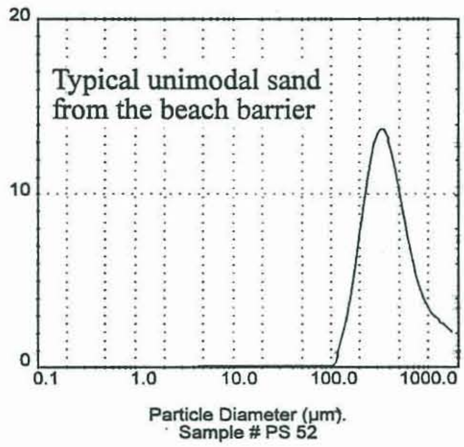


Figure 6.8. *Grain size distribution of a beach sand adjacent to Paluma Shoals with a mode of 325 μm.*

Approximately 2 km north of Sleeper Log Creek, linear coarse grained sands directly overlie ancient mangrove muds (Figure 6.10). The relationship of coarse grained sands directly overlying mud, indicate that these deposits may be cheniers deposited during storm activity.

Mangroves and Tidal Channels

A network of meandering and shore-parallel tidal channels is developed behind the beach and beach barrier (Figure 6.1). The tidal channels of Sleeper Log and Two Mile creeks are mostly 2-35 m wide and their margins are fringed by dense populations of *Rhizophora* spp., (Figure 6.11) and *Bruguira* spp. The mangrove forests are restricted mostly to the borders of the tidal channels and hightidal saltflats are developed between them. The mangrove forest floor is heavily bioturbated by crustaceans and pneumatophores protrude through the black, organic mangrove mud. The saltflats are only inundated on the highest tides, or during storm surges, and support, various halophytes and samphires.

Figure 6.10 *Photograph of coarse grained sands (left and to the back of the photograph) overlying ancient mangrove mud, this stratigraphic relationship may indicate that these sands are cheniers deposited during storm activity (Photography by R.G Purdon.).*

At the mouth of the Sleeper Log and Two Mile creeks, shoals of well-sorted, coarse grained, unimodal (mode of 825 μm) quartzose sand are exposed at low tide. Further upstream (Sleeper Log Creek) quartzose gravelly sands with numerous carbonate nodules form the tidal channel floor.

The sediments from the upper regions of the tidal channels fringed by dense mangroves commonly have a mode at 7 μm with a secondary mode at 25-40 μm (Figure 6.12). The coarse mode at 900-1100 μm consist of quartz, feldspar and mica grains with minor shell and carbonate fragments. The carbonate content of these samples is 2-13 %.

Samples collected from the mangrove forest floor fringing the tidal channels have similar sedimentary characteristics (Figure 6.13). The most common mode of these sediments is 7 μm with a secondary mode at 25-40 μm, the coarse mode at 900-1100 μm is comprised of of quartz and feldspar grains with abundant wood and calcareous fragments.

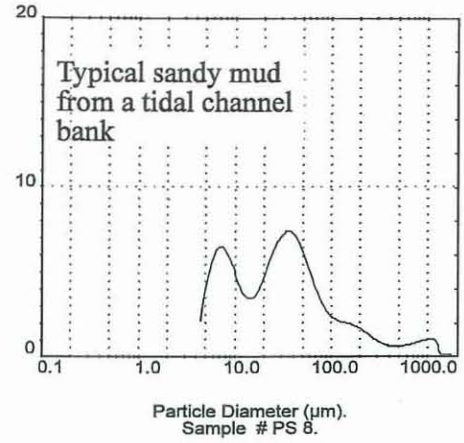


Figure 6.12. *Grain size distribution of sediment from a narrow (< 3 m wide) mangrove-fringed tidal channel, with modes at 7 μm, 25-40 μm and 900-1110 μm.*

The development of coastal mangroves is attributed to the high tidal range low coastal relief, low wave energy and a large supply of fine grained detrital sediment (Belperio, 1978). Sediment transport within mangrove systems may be related to their elevation relative to the local tidal range (Larcombe & Ridd, 1996). The mangroves within the study area experience a tidal range of 3.8 m with inundation of the entire mangrove forest and salt flats only occurring at spring tides or during storm-surges.

Figure 6.11. *Rhizophora spp., mangrove dominated tidal channel (Two Mile Creek) The basal sediment of the channel is dark grey organic rich fine sandy mud (Figure 6.12).*

Data from Gordon Creek, approximately 40 km south of Paluma Shoals indicate that during springs 'overbank tides' inundate the mangrove forest floor so that during the ebb tide the current is accelerated and is significantly stronger than the flood (Larcombe and Ridd, 1996). During neap tides the mangrove floor is not inundated and hence the ebb is not enhanced. Thus the currents in the tidal channels may be ebb-dominated at springs and slightly flood-dominated at neaps (Larcombe & Ridd, 1996).

Recent studies indicate that suspended sediment is transported landward into tidal channels and mangrove forest flats during the flow of the tide at some tidal channels within the GBR lagoon (Larcombe and Ridd, 1996; Bryce, 1995). Suspended sediment fluxes peak on the flood tide, and suspended sediment concentrations reach a minimum at ca. 10 minutes after high tide slack water, indicating rapid sediment settling, which leads to the vertical accumulation of mangrove sediments (Larcombe & Ridd, 1996). Further, overbank tides, which inundate the mangrove forest floor, create ebb currents strong enough to flush bedload seaward at transport rates of up to 0.3 kgs^{-1} per metre of creek width. Thus, there is a net landward transport of fine-grained sediment that is deposited on the mangrove forest floor during the spring tide flood, and a net seaward movement of bedload at the ebb. The transport of bedload may be enhanced during the wet season, because of the influx of freshwater increasing the current velocity and sediment available for transport.

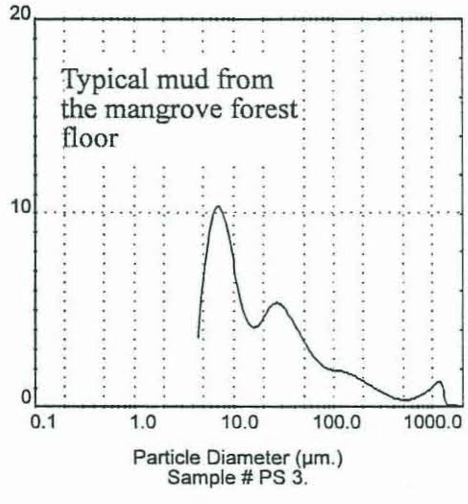


Figure 6.13. *Grain size distribution of an organic mangrove mud. The primaryt mode of these sediments is 7 microns with a secondary mode at 25-40 microns, the coarse mode at 900-1100 microns is composed of quartz and feldspar grains with abundant wood and carbon fragments.*

6.3 Marine Inner-Shelf Facies

Muddy Sands

The distribution of the muddy sands is restricted to the inner-shelf terrestrial sediment wedge, which extends seaward to the 20 m isobath (Figure 6.14). These sediments are moderate olive-brown (5Y 4/4) poorly sorted, slightly gravelly, muddy quartzose sands with an admixture of shell fragments, foraminifera and molluscs. The carbonate content of these sediments increases seawards and ranges between 12 % and 60 % (Figure 6.15). Grain size analysis reveals that these sediments are trimodal, with a representative sample having modes at 7 µm, 125 µm and 1150 µm (Figure 6.16). The 1-2 mm size fraction consists of shell fragments, forams and quartz grains. The gravel content of these sediments is commonly less than 5 % consisting of complete shells, shell fragments and minor lithics of quartz and feldspar.

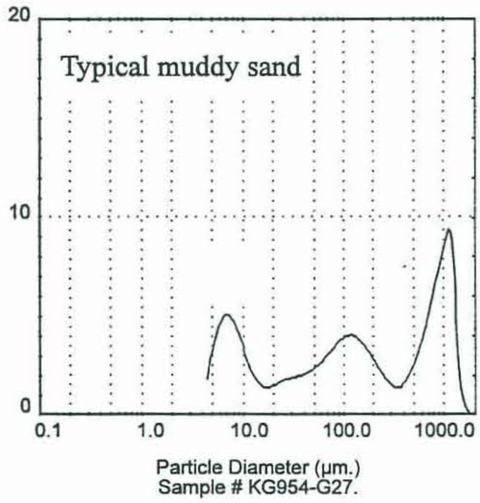


Figure 6.16 *Grain size distribution of a muddy sand from southern Halifax Bay with modes at 7 µm, 125 µm and 1150 µm.*

The muddy sands are contiguous with the bay fill facies described in chapter 5 representing modern marine sedimentation. This facies has a trimodal sediment distribution pattern consistent with the bay fill facies from Cleveland Bay (Carter et al, 1993).

Gravelly Muddy Sands

These sediments are moderate olive-brown (5Y 4/4) poorly sorted gravelly muddy sands. The carbonate content increases seawards and ranges between 13 % and 70 % (Figure 6.15). The gravelly muddy sands are distributed as an isolated patch of sediment north of Paluma Shoals and as a large body of sediment north of Rattlesnake and Herald islands

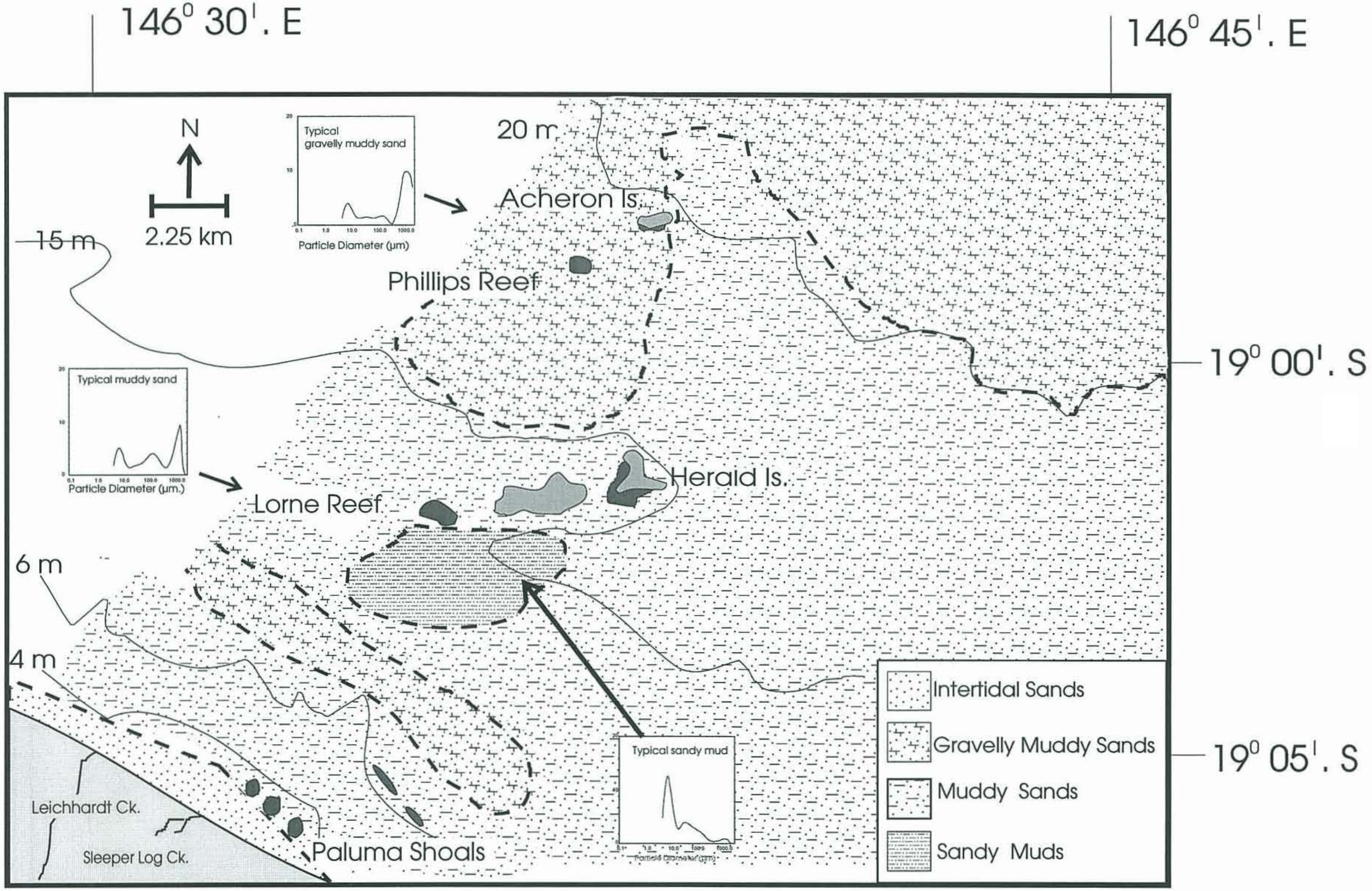


Figure 6.14. *Surficial sediment distibution of the inner-shelf of southern Halifax Bay and grain size distributions for the < 1 mm fraction. Beyond the 20 m isobath, gravelly muddy sands dominate (Belperio, 1978). Note boundaries are tentativ*

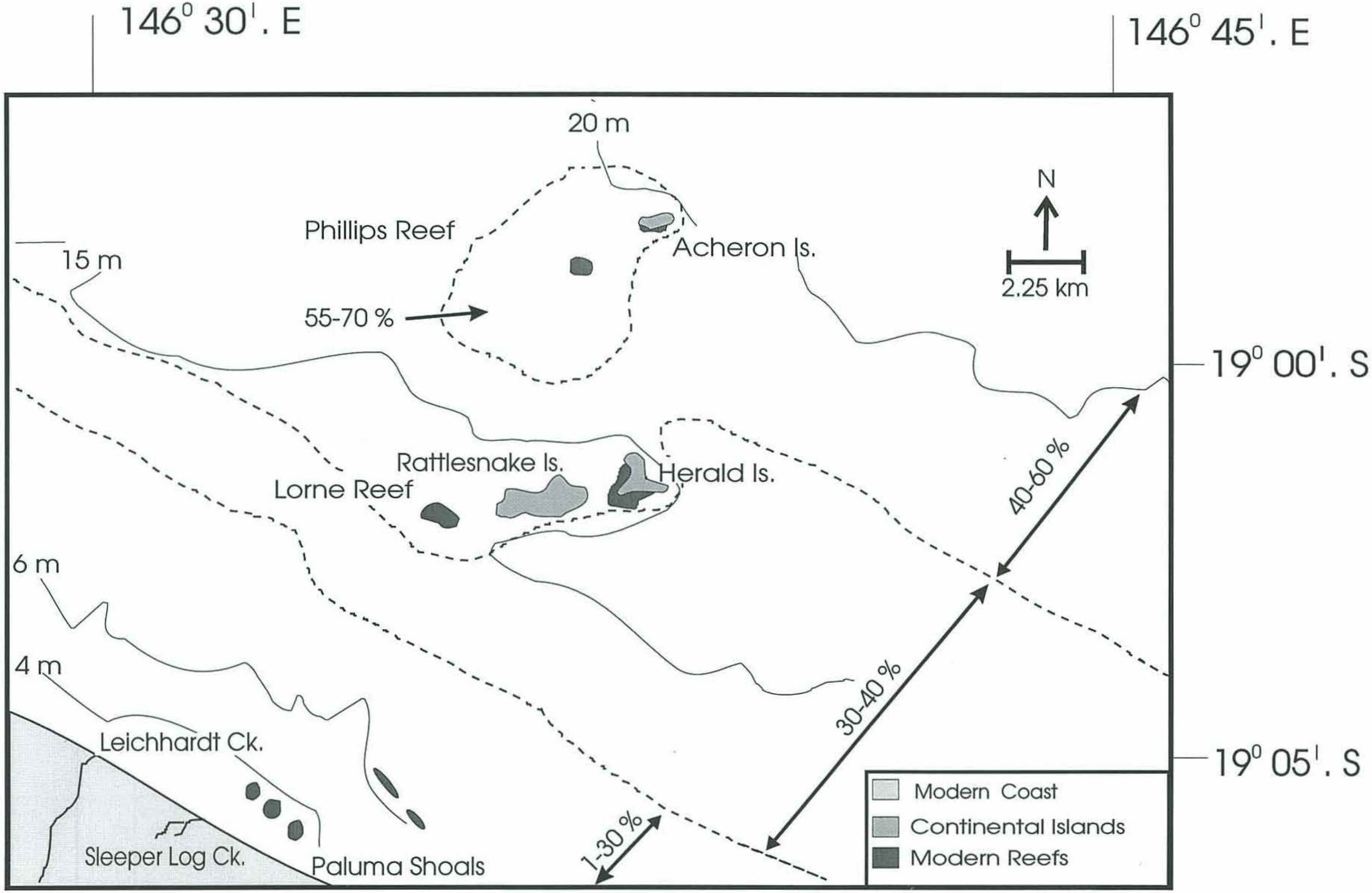


Figure 6.15. *Distribution of carbonate (% wt.) of the inner-shelf terrigenous sediment wedge (20 m isobath) southern Halifax Bay. The carbonate content of the sediments increase seaward but varies from ~15-80 % around Paluma Shoals.*

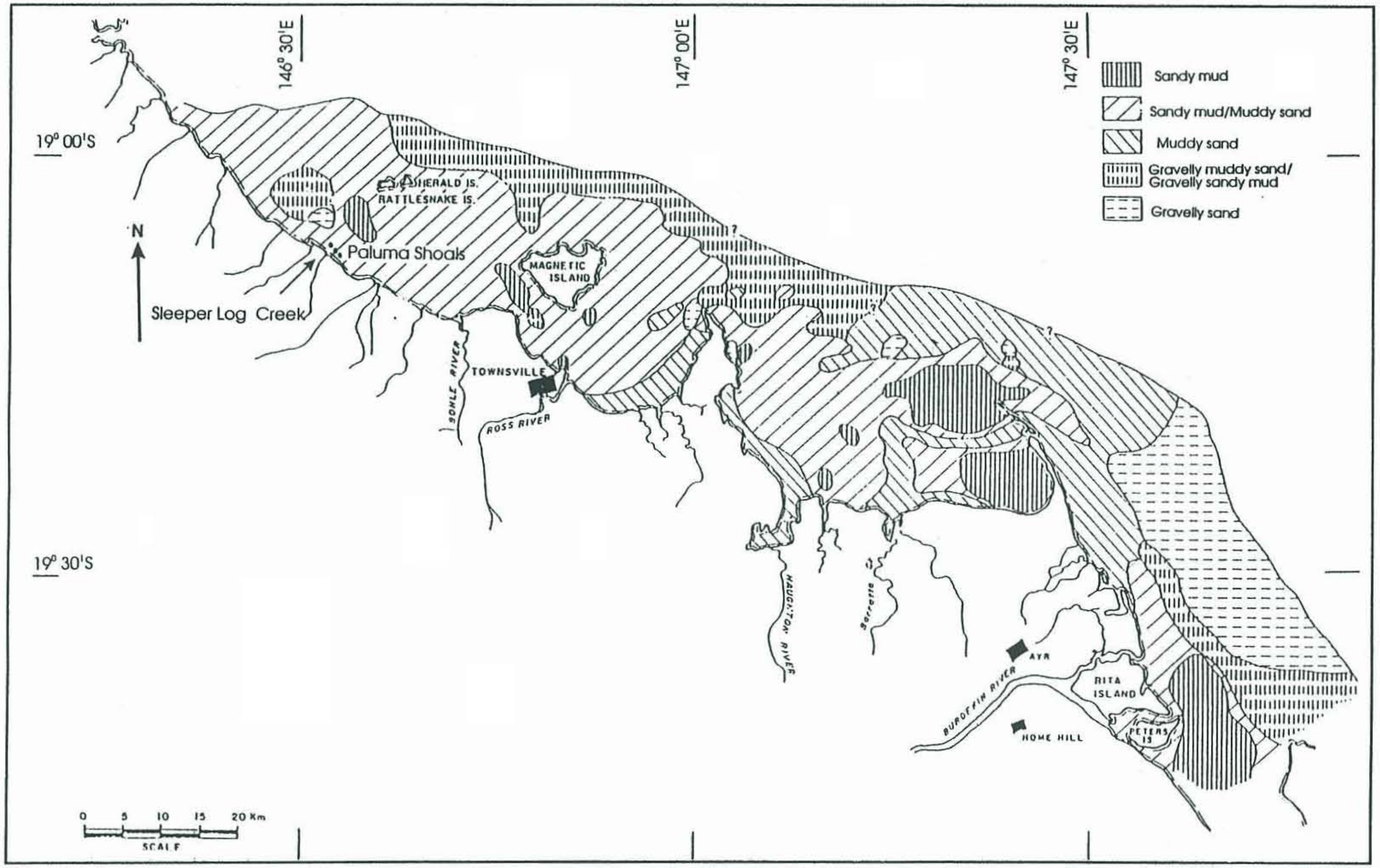


Figure 6.17. *Distribution of surficial sediment facies from the Townsville region (modified from Belperio, 1978). The distribution of the sandy mud and gravelly sand facies detailed in Figure 6.14. correlates with the sandy muds and gravelly sands identified by (Belperio, 1978).*

(Figure 6.14). These sediments form the dominant sediment type surrounding Phillips Reef. Belperio (1978) notes that beyond the 20 m isobath the sediments are dominated by gravelly muddy sands and gravelly sandy muds (Figure 6.17).

The gravel fraction of these sediments north of Paluma Shoals ranges between 5% and 20 %. The gravel fraction is comprised of sub-angular to sub-rounded lithoclasts of granitic and volcanic fragments, quartz grains (some Fe stained) shell fragments and abraded foraminiferal tests (in total ~15 %). The 1 mm to 2 mm fraction of these sediments is composed of angular to sub-rounded granitic lithoclasts (~75 %) shell fragments, abraded foraminiferal tests (~10-12 %) and quartz grains (~10-15 %). Grain size analysis indicates that the < 1 mm fraction is a bimodal muddy sand with modes at 7 μm and 825 μm.

North of Herald and Rattlesnake islands the gravel fraction of these sediments ranges between ~5% and 25% and the carbonate content from 44% to 70 %. The gravel fraction is comprised of shell fragments (~65%) carbonate nodules (~30%) quartz and granitic lithoclasts (< 5%). The 1 mm to 2 mm fraction constitutes up to 11 % of these sediments and contains up to 90 % carbonate material, composed of shell and coral detritus, carbonate nodules, forams and minor (10%) Fe-stained quartz grains and lithoclasts. The < 1 mm fraction is bimodal muddy sand with modes at 7 μm and 980 μm (Figure 6.18).

The muddy-sand fraction of the gravelly muddy sands north of Rattlesnake Island have a similar grain size distribution to the muddy sand facies (Figure 6.16 & Figure 6.18). Johnson (1985) notes that there is probably only minor redistribution of the coarse fraction occurring in the modern regime. Thus, it is probable that the muds have a similar source to the muddy sands but that the gravel component is derived locally. The muddy sand fraction represents modern deposition of terrigenous sediment which is restricted to the inner-shelf terrestrial sediment wedge by regional energy inputs, including the dominant southeasterly trade winds (Belperio, 1978; Ridd *et al.*, 1995). The lower mud content of these sediments is probably due to their distance from regional and local sediment sources.

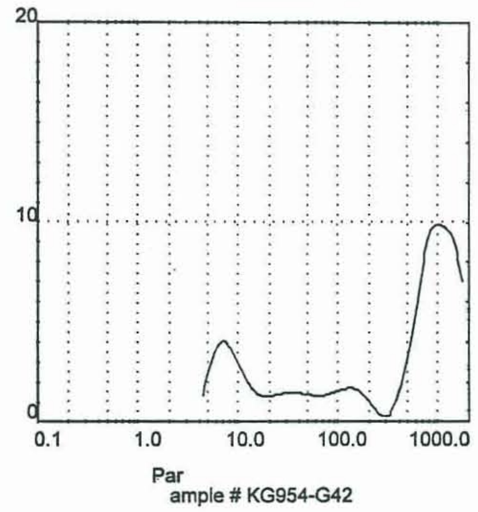


Figure 6.18. *Grain size distribution of the < 1 mm fraction of a representative gravelly muddy sand sample (KG954-G42) from southern Halifax Bay. These sediments have modes at 7 μm and 980 μm.*

Carbonate nodules, biogenic detritus, minor quartz grains and lithics comprise the coarse (1mm to 2mm) and gravel components of these sediments, representing contrasting depositional regimes. The carbonate nodules are relict sediments which may be formed in soil horizons which have undergone sub-aerial diagenesis prior to the Holocene transgression (Davidson, 1981). Johnson and Risk, (1982) describe similar nodules within green and red clays that underlie the fringing reef deposits of Fantome Island. These nodules may have have been reworked from the Pleistocene surface (Reflector A) forming up to 40 % of the gravel fraction. The small % of Fe-stained quartz grains may also be related to the reworking of sub-aerially exposed sediments. The reworking of relict sediments may indicate that the veneer of modern marine sediment is thin and the Pleistocene surface is relatively shallow.

The high biogenic component of these sediments is probably related to an increase in the population of benthic and epifaunal organisms. This presumably is related to the increased availability of suitable substrates for colonization associated with Herald, Rattlesnake and Acheron Islands. The sub-aqueous erosion of these islands may add the minor quartz, feldspar and lithic components to the sediment.

The coarse (1 to 2 mm) and gravel fraction of gravelly muddy sands located seaward of Paluma Shoals is possibly also locally sourced. Johnson (1985) describes similar sediments in northern Halifax Bay and proposes that the lithoclastic gravels represent a late Holocene transgressive veneer developed from an abandoned lobe from the proto-Herbert river. However, seismic profiles (Chapter 5) indicate that the reefs forming Paluma Shoals are more extensive than is detailed on the charts (Figure 5.1 & 5.3). Thus, it is probable that the Pleistocene gravel deposits are also more extensive. Therefore, it is possible that sub-aqueous erosion of the gravel deposits adds the coarse terrigenous component to these sediments. Davidson (1981) describes similar sediments north of Paluma Shoals, noting that the Lady Elliot Reef developed on a "gravel" platform. Davidson (1981) notes that the reworking of these "gravels" may add the coarse component to these sediments. The carbonate content of the gravelly muddy sands may be a function of the increased epifaunal activity associated with the reefal community. Therefore, the gravelly muddy sands are an admixture of the regionally sourced bay fill (muddy sands) and locally derived gravels and coarse sands.

Sandy Muds

The sandy muds are restricted to the leeward margin of Rattlesnake Island and Lorne Reef. These sediments are moderate olive-grey, slightly sandy muds with a mode at 7 µm (Figure 6.19). The carbonate content of these sediments ranges between 30% and 40 %. The sand fraction is composed of shell fragments (95 %) and clean angular quartz grains (5%).

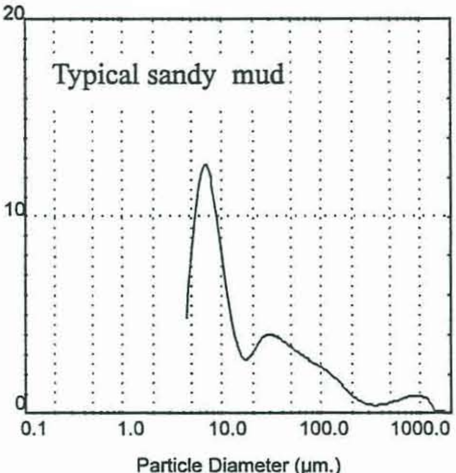


Figure 6.19. *Representative grain size distribution of a sandy mud with a mode at 7µ m.*

Belperio (1978) identified a "submarine lobe"in approximately the same location as the sandy mud facies from southern Halifax Bay (Figure 6.17) noting that a substantial supply of fine grained terrigenous sediment is required for their accumulation. The sand within the mud lobe may be attributed to the intermixing of these sediments with relict coarser grained material (Belperio, 1978) Sandy mud facies have also been identified on the leeward sides of Magnetic Island and Cape Bowling Green (Belperio, 1978; Orpin, 1995). Belperio (1978) notes that the silt concentration within Halifax Bay appears to be closely related to discharge from local rivers and creeks but that the supply of clay is related to the Burdekin Rivers annual sediment discharge. The Burdekin River is believed to deliver 0.4 million tonnes of sediment to Halifax Bay per year, the bulk of these fine sediments are debouched during major flood events (Belperio, 1978)

The restricted distribution of the fine sandy mud facies is probably related to Rattlesnake and Herald islands acting as a barrier from the southeasterly wave trains. The islands would produce a sheltered environment for the accumulation of these fine sediments, with limited swell wave energy available to resuspend and redistribute the sediments across the shelf. Therefore, it is probable that these facies accumulate in locations of lower wave and wind energy.

6.4. Coral Reef Sediments - Paluma Shoals

Introduction

Variations in the surficial sediment distribution at Paluma Shoals is the result of the local and regional sediment sources and energy inputs. Paluma Shoals is bounded on its seaward margin by the inner-shelf terrestrial sediment wedge, which is composed primarily of muddy sands and sandy muds (Figure 6.14 & 6.20). Coral growth at Paluma Shoals has initiated on Pleistocene gravels, and is flanked on its landward margin by a well formed low-tide terrace, composed of unimodal quarztose sands. Approximately 1 km from the shoals, sandy beaches and a beach barrier protect the mangrove-fringed tidal channel complex from the prevailing southeasterly trade winds and periodic high wave energy events. Thus, the surficial sediment distribution pattern at Paluma Shoals can be expected to be a result of the complex interactions between regional (inner-shelf) and local terrigenous sediment sources (mangrove tidal channels) and fluctuating energy inputs. The coral reef sediment facies include:

1. Sandy muds (accumulated on coral colonies);
2. Gravelly muddy sands;
3. Gravelly sandy muds;
4. Gravelly sands.

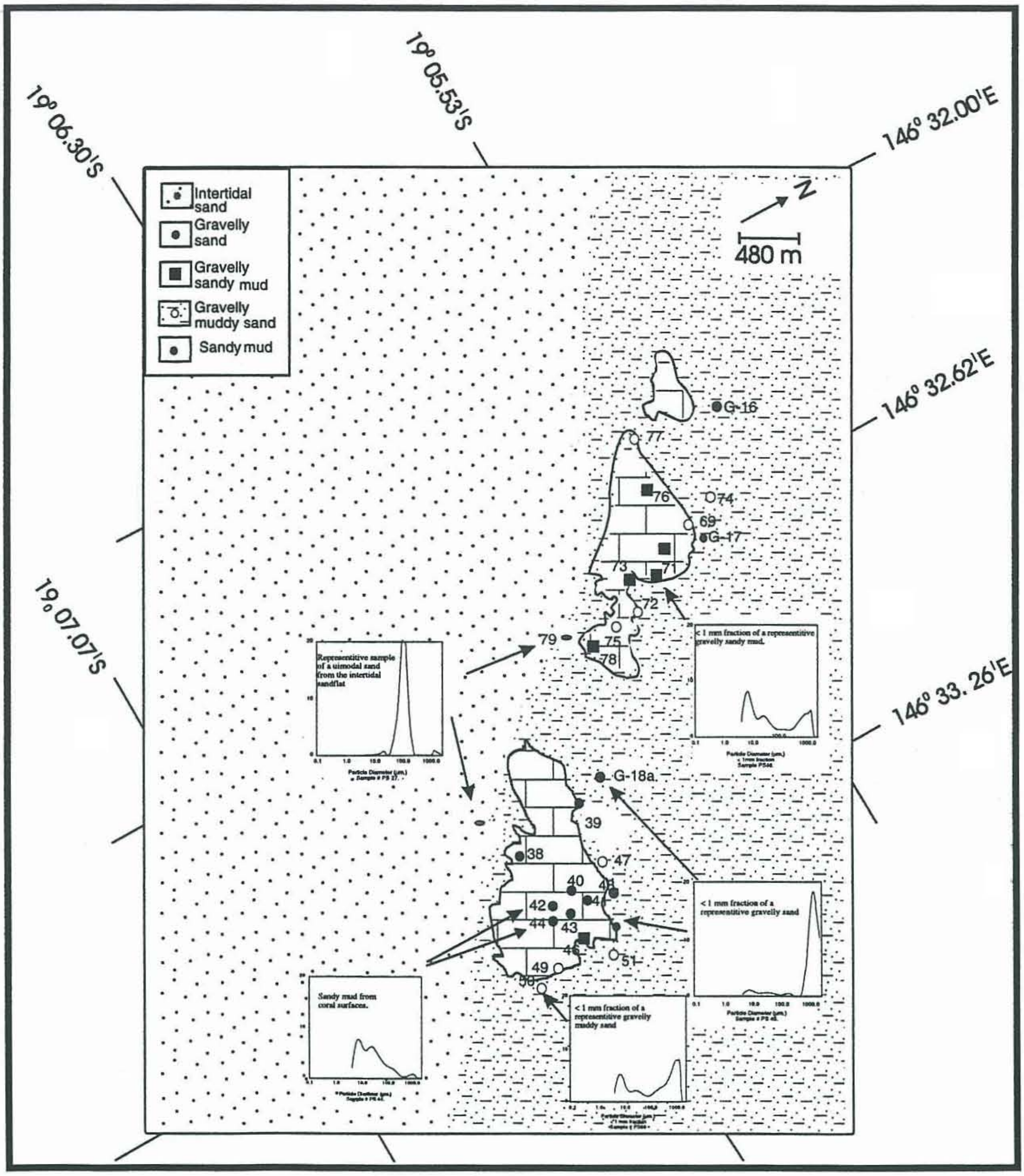


Figure 6.20. *Sample locations and sediment types from 2 of the Paluma Shoals reefs. On the leeward side of the reefs are intertidal sands. The reef flat sediments are primarily composed of gravelly sandy muds and gravelly muddy sands. The windward reef slope is covered with gravelly sands. Minor amounts of sandy muds are deposited on the coral colonies.*

Sample #	Position	Sediment description	% Carbonate
PS37	Tidal flat	Fine grained sand	8.2
PS38	Top of coral	Sandy mud	17.4
PS39	Reef floor	Sandy mud	25.9
PS40	Top of coral	Sandy mud	12.6
PS41	Top of coral	Sandy mud	13.7
PS42	Top of coral	Sandy mud	18.9
PS43	Top of coral	Sandy mud	16.3
PS44	Top of coral	Sandy mud	34.5
PS45	Reef flat	Gravelly sand	43.5
PS46	Reef flat	Gravellysandy mud	59.4
PS47	Reef flat	Gravelly muddy sand	48.4
PS48	Reef flat	Gravelly sand	34.6
PS49	Reef flat	Gravelly muddy sand	67.8
PS50	Reef flat	Gravelly muddy sand	35.1
PS51	Reef flat	Gravelly muddy sand	75.7
PS68	Top of coral	Sandy mud	17.9
PS69	Reef flat	Gravelly muddy sand	76.7
PS70	Reef flat	Gravelly sandy mud	78.7
PS71	Reef flat	Gravelly sandy mud	68.6
PS72	Reef flat	Gravelly sandy mud	54.6
PS73	Reef flat	Gravelly sandy mud	34.4
PS74	Reef flat	Gravelly muddy sand	58.9
PS76	Reef flat	Gravelly sandy mud	41.4
PS77	Reef flat	Gravelly muddy sand	78.2
PS78	Reef flat	Gravelly sandy mud	29.4
PS79	Tidal flat	Fine grained sand	12.3

Table 6.1. *Carbonate content and sediment type from samples collected from Paluma Shoals. Note that the sediments from the upper coral surfaces have lower carbonate contents than the reef floor samples.*

Sandy Muds

Numerous coral heads and romose forms of corals (e.g *Dendrophyllidae turbinaria)* from Paluma Shoals have small amounts of sediment acummulated on their upper surfaces. These sediments are moderate olive brown (5Y 4/4) slightly sandy muds (mode at ~ 7 μm) with 75 % to 90 % of the sediment below 63 μm (Figure 6.21). The carbonate contents varies between 12.5 % to 35 % and is composed of shell debris (Table 6.1). Fine grained, clean, sub-rounded to rounded quartz grains compose the remaining coarse fraction. XRD analysis indicates that the clay fraction is characterised by XRD-peak ratios (kaolinite:illite:smectite-K:I:S) of 42:117:41 for sample PS38 and 27:42:31 for sample PS39 (Table 6.3 & Appendix 6.3).

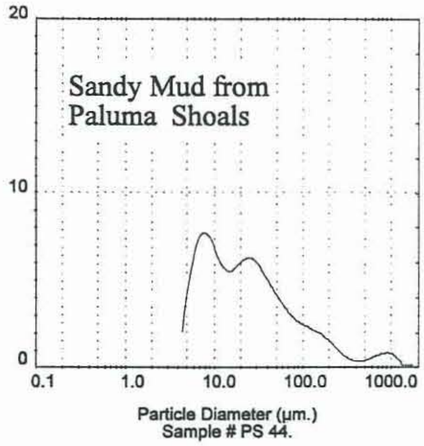


Figure 6.21. *Representative grain size distribution of a sandy mud (with a mode at 7 µm) collected from the upper surface of a coral colony from Paluma Shoals (sample collected during the dry season.*

The low carbonate content of the sandy muds (12.5 % to 35 %) compared to the sediments of the reef flat (up to 78 %) indicate a terrigenous source. Deposition of fine grained material occurrs at high water slack and is probably a random process, with sediment deposited on and off coral surfaces. The sediment that is deposited on the reef platform (i.e. between corals) is reworked by biological activity (*Callianasa sp.*) or resupended. Corals remove sediment by various techniques, thus the sediment accumulated on the coral surfaces may have a short residence time between deposition and removal by the coral or by physical resuspension. Therefore, the sediment accumulated on the coral surfaces (at the time of sampling) reflects the mode of sediment that is being resuspended and subsequently deposited on Paluma Shoals. An attempt to trace the origin of these sediments is detailed in section 6.5.

Gravelly Muddy Sands/Gravelly sandy muds

The reef flat sediments are primarily composed of an admixture of poorly sorted dark yellowish-brown (10 YR 4/2) gravelly muddy sands and olive-grey (5Y 3/2) gravelly sandy muds. The carbonate content of these sediments varies between 29 % and 78 % (Table 6.1 & Appendix 6.2). Grain size analysis of the < 1mm fraction of the gravelly sandy muds indicate that these sediments are bimodal (with modes at 7 µm and ~ 1100 µm) with 53 % to 70 % of the sediments < 63 µm (Figure 6.22). The XRD-peak area ratios of K:I:S in the gravelly sandy muds are 13:22:65 (sample PS76) and 11:22:66 (sample PS78) (Table 6.3). The 1 mm to 2 mm content of these sediments varies between 0.5 % and 6 % and is composed of shell detritus and coral fragments, with minor sub-rounded quartz grains and granitic lithoclasts, feldspars are rare. The gravel content varies between 1 % and 6.5% and is composed of shell and coral fragments with minor subrounded quartz grains.

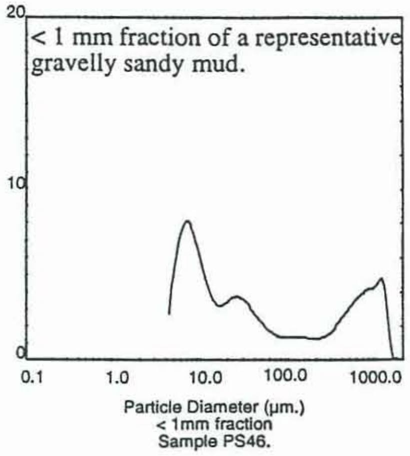


Figure 6.22. *Reresentative grain size distribution for the < 1 mm fraction of a gravelly sandy mud.*

Grain size analysis indicate that 23 % to 34 % of the gravelly muddy sands are < 63 µm. The < 1 mm fraction of these sediments are bimodal with modes at 7 µm and between 770 µm and 870 µm (Figure 6.23). The coarse mode is composed of clean well-sorted quatzose sands with abundant shell and coral fragments. The XRD-peak area ratios of K:I:S in the gravelly muddy sands are charcterised by abundant smectitie with subordinate ratios of illite and kaolinite (Table 6.3). The 1 mm to 2 mm fraction of these sediments varies between 1-12 % and is composed (in varying abundances) of quartz grains, granitic lithocasts coral fragments, and foramineral tests. The gravel component (2-12 %) consists of sub-angular to sub-rounded quartz and granitic lithoclasts and abundant calcareous detritus, feldspar grains are rare.

The gravelly muddy sands and gravelly sandy muds are an admixture of the terrigenous sediment deposited on the reef and the insitu production of carbonate. The majority of the carbonate component is the result of biological and physical weathering of the benthic and epifaunal organisims from the shoals. The terrginous sands and gravels are possibly derived from the insitu weathering of the relict gravel deposits and/or the transport of sands and gravels during high energy events (high swell wave or cyclonic events).

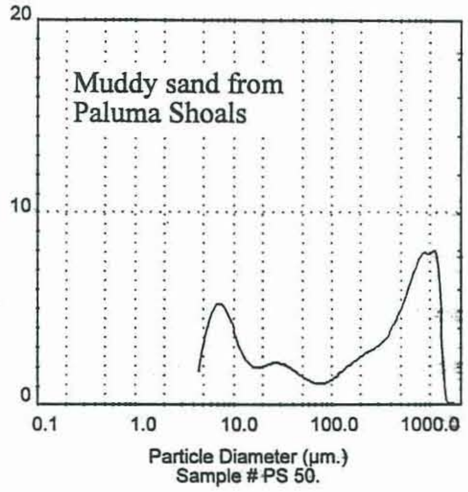


Figure 6.23. *Representitve grain size distribution of the < 1 mm fraction (with modes at 7 µm and between 770 µm and 870 µm) of the gravelly muddy sands from the reef floor at Paluma Shoals*

Gravelly Sands

Gravelly sands are restricted to the reef flat and the reef talus slope of Paluma Shoals (Figure 6.20). These sediments are moderately sorted, gravelly sands with the carbonate content ranging between 30 % and 80 %. The gravel fraction is composed of sub-rounded, granitic and volcanic lithoclasts, quartz grains, coral fragments (up to 3 cm in diameter) shell fragments and foraminiferal tests. The 1-2 mm fraction is composed of sub-angular to sub-rounded quartz (some Fe stained) and feldspar grains, granitic lithioclasts, coral and shell debris, with minor foraminiferal tests. The < 1 mm fraction is a unimodal quartzose sand with a mode at 900 µm.

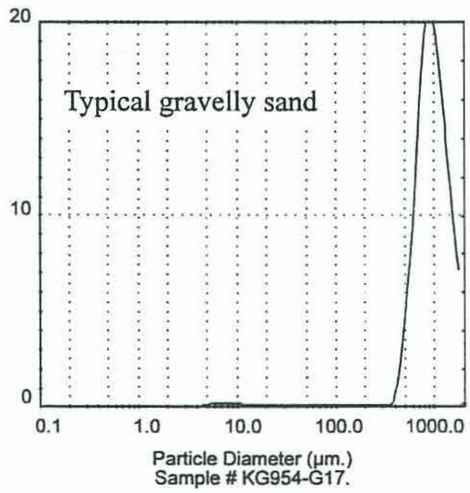


Figure 6.24. *Representative grain size distribution of a gravelly sand with a mode at 900 µm.*

The carbonate component of these sediments is derived from the biological and physical weathering of corals and associated biota at Paluma Shoals. The sub-aqeuous erosion of the Pleistocene gravel deposits (the reef substrate) may produce the gravel and some of the terrigenous sand fraction of these sediments Local creeks. (e.g. Sleeper Log, Two Mile and Bluewater) may form the point source for the unmodal sands. SCUBA diving revealed that the gravelly sands on the reef slope represent the accumulation of reef talus.

6.5. Coral Reef Clay Mineralogy

Introduction

Sediment samples from Paluma Shoals (Table 6.3) were selected for XRD analysis to determine the XRD-peak ratios of kaolinite:illite:smectite (K:I:S) to establish the dominant clay mineralogy of the sediments and infer a possible source of the clays. The composition of sedimentary facies is related to the relative % of carbonate, organic, clay and terrigenous material, which reflects the influence of sediment sources and transport mechanisms. The K:I:S ratios and the species of smectite from the coral surfaces at Paluma Shoals varies from that of the reef flat (*i.e.* directly below the coral from which the first sample was taken). Thus, there is either a variation in the sediment source, transport mechanisms or both.

Sample number	Sediment description	Sediment location	XRD-peak area ratios of kaolinite:illite:smectite	XRD-peak area ratios of kaolinite:illite:smectite
PS38	Sandy mud	Coral head	2:1:2	42:17:41
PS39	Sandy mud	Coral head	1:1:1	37:42:31:
PS50	Gravelly muddy sand	Reef flat	1:1:4	14:10:42
PS71	Gravelly muddy sand	Reef flat	1:1:18	5:5:90
PS72	Gravelly muddy sand	Reef flat	1:9:23	3:27:70
PS76	Gravelly sandy mud	Reef flat	1:2:6	13:22:65
PS77	Gravelly muddy sand	Reef flat	1:2:5	12:22:66
PS78	Gravelly sandy mud	Reef flat	1:2:5	11:22:67

Table 6.3. *XRD-peak area ratios for sediments collected from Paluma Shoals. Note the variation between the Kaolonite ratios of the sediments collected from off the coral colonies and those from the reef flat.*

Kaolinite:Illite:Smectite Peak-Area Ratios

The K:I:S peak area ratios of sediments accumulated on the coral surfaces are (sandy muds) 42:17:41 and 37:17:31. The clays on the coral surfaces typically contain higher proportions of kaolinite to illite and smectite, compared to clays from the reef flat (Table

6.3). The smectite species from the coral surfaces is a Na-rich smectite (*pers comm*, Cuff). However, the K:I:S ratios of sediments from the reef floor (gravelly muddy sands & gravelly sandy muds) are mostly smectite, with lower ratios of illite and kaolinite (Table 6.3). Ward (1990) notes the same general trend of K:I:S ratios on and off coral surfaces from Cleveland Bay (Magnetic Island). The smectite accumulated on the reef platform is a mixed layer smectite and is same species from a sample collected from a mangrove tidal channel (Appendix 6.4) (Cuff, *pers comm*).

Clay Sources

Tye (1992) notes that mangrove sediments are dominated by illite and smectite. The periodic flooding of mangrove dominated intertidal zones by seawater enriches the interstitial water with Na and K cations, subsequent evaporation leads to an increase in the the cation activity. This affect is enhanced by the paucity of rainfall, associated with the extended dry season of the region (Tye, 1992)

The concentration of Al and the upstream removal of bases through weathering leads to the preferential formation of kaolinite (Ward, 1994). These sediments are debouched from coastal rivers and creeks (e.g. Bluewater & Sleeper Log creeks) and are not exposed to increases in cation exchange processes.

Belperio (1978) notes that smectite deboched from the Burdekin River floculates on contact with saline water and drops out of suspension close to the coast, while kaolinite is transported away from the sediment source. The preferential flocculation of seaward transported smectite along with the high concentartion of organic matter and cations enhances the nearshore enrichment of smectite (Ward, 1994). Therefore the enrichment of smectite in the K:I:S ratios from the reef flat sediments suggest that a majority of smectite is derived from sediments debouched by local creeks and mangroves. Ward (1994) compiled a contour map of Cleveland Bay, indicating that kaolinite is concentrated offshore, whereas smectite is concentrated neashore. Tye (1992) notes that modern marine sediments are dominated by kaolinite/illite rich clays.

Ward (1990) notes that the different ratios on and off the corals because kaolinite is difficult to remove from the coral head or that more kaolinite is being deposited. However, the different species of smectite on (Na rich) and off the corals suggests separate clay sources. This may be related to the net landward directed flux of sediment within the GBR and the flashy nature of the local rivers and creeks. Kaolinite clays do not form flocs and thus are transporeted further off the coast (Belperio, 1978; Ward, 1994) and reworked into the bay fill facies (Section 6.3). The resuspension of these sediments during swell wave events and the net landward movement of sediment suggests that kaolinite rich clays would be in suspension more readily and thus deposited on the coral surfaces. This may account for the different smectite species on the coral surfaces and the increased kaolinite ratio of the clays.

Smectite rich clays derived from mangrove muds would only be flushed seaward in substantial quantities during episodic rainfall events because of the net landward transport of sediment. Due to its ability to form flocs, smectite would settle on the corals and reef flat. Thus, it is possible that these smectite rich clays (non-Na) may form the dominate clays after such an event upon the coral colonies (samples collected during dry season). However, with the onset of the dry season and the southeasterly trade winds, resuspension and or the removal of the smectite clays by the corals may result. Therefore the distribution and variation of clays and possibly the coarser fraction of sediments on and off the corals is related to both sediment source and transport mechanisims. However, the limited number of samples collected places contraints on these data and the results presented.

6.6. Entropy groups

Introduction

Entropy analysis of grain size distributions from 135 inner-shelf and coastal sediment samples results in clusters which are visually descrete, and can be compared to the sedimentary facies detailed above (Figure 6.25). The technique of entropy analysis has been applied to a variety of geologic applications (Woolfe, 1995; Woolfe & Michbayashi, 1995) including the mapping of modern surficial sediment distribution patterns within the GBR lagoon (Orpin, 1995, Woolfe *et al.*, 1996). In this study, entropy analysis is used as a comparitive tool, producing high resolution grain size maps which are compared to the inner-shelf and coastal surficial sediment facies detailed above. Using the data from the 135 sediment samples, seven groups are defined.

Group 1

Group 1 sediments are clean, coarse-grained garvelly sands. The samples have a principle coarse sand mode between 885 μm and 1030 μm (Figure 6.25). Within the study area this group correlates with the gravelly sands located on the reef flat and the reef slope (talus) of Paluma Shoals, and with the coarse grained shoals located at the mouth of sleeper Log and Two Mile Creeks (Figure 6.21).

Group 2

Group 2 sediments are poorly-sorted slightly gravelly sandy muds with a principle mode at 7 μm (Figure 6.25). This group correlates with the sediments forming the fine grained fill of the mangrove fringed tidal channels of Sleepr Log and Two Mile creeks (Figure 6.1 & 6.27). The sandy muds recovered from numerous coral heads and the slightly gravelly sandy muds from the reef flat are also group 2 sediments (Figure 6.20).

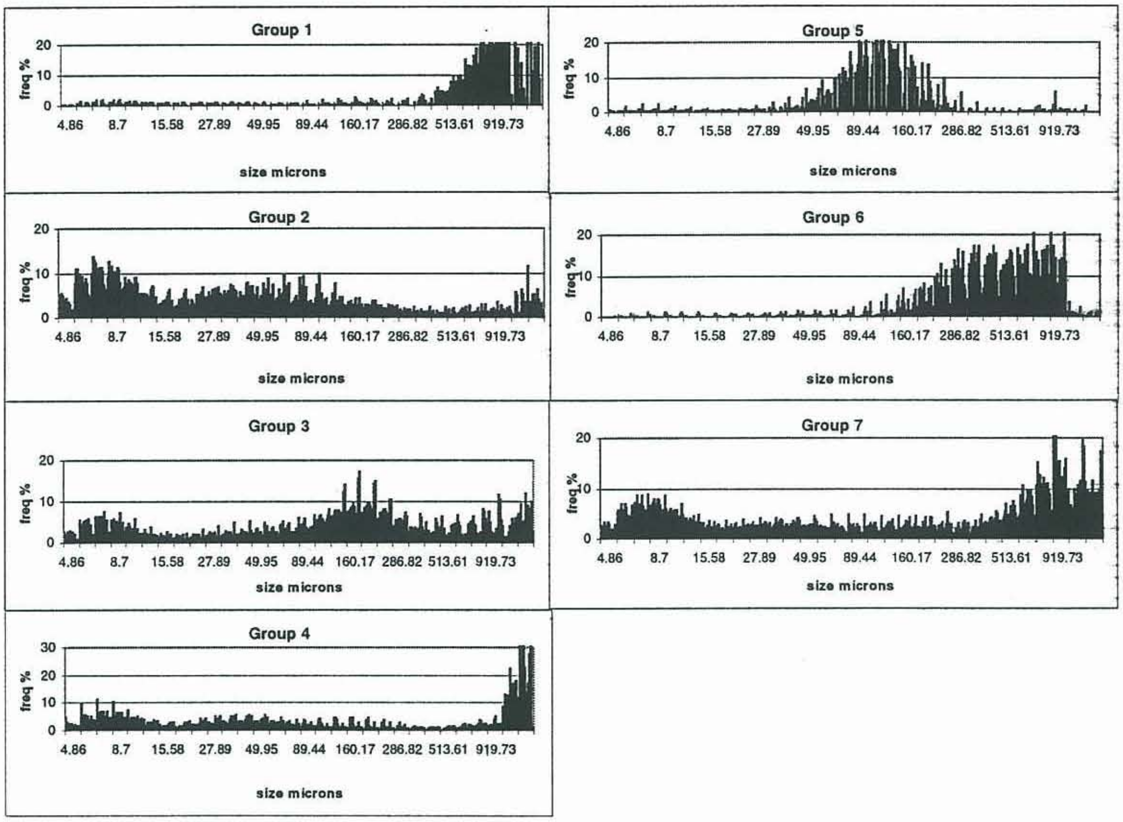
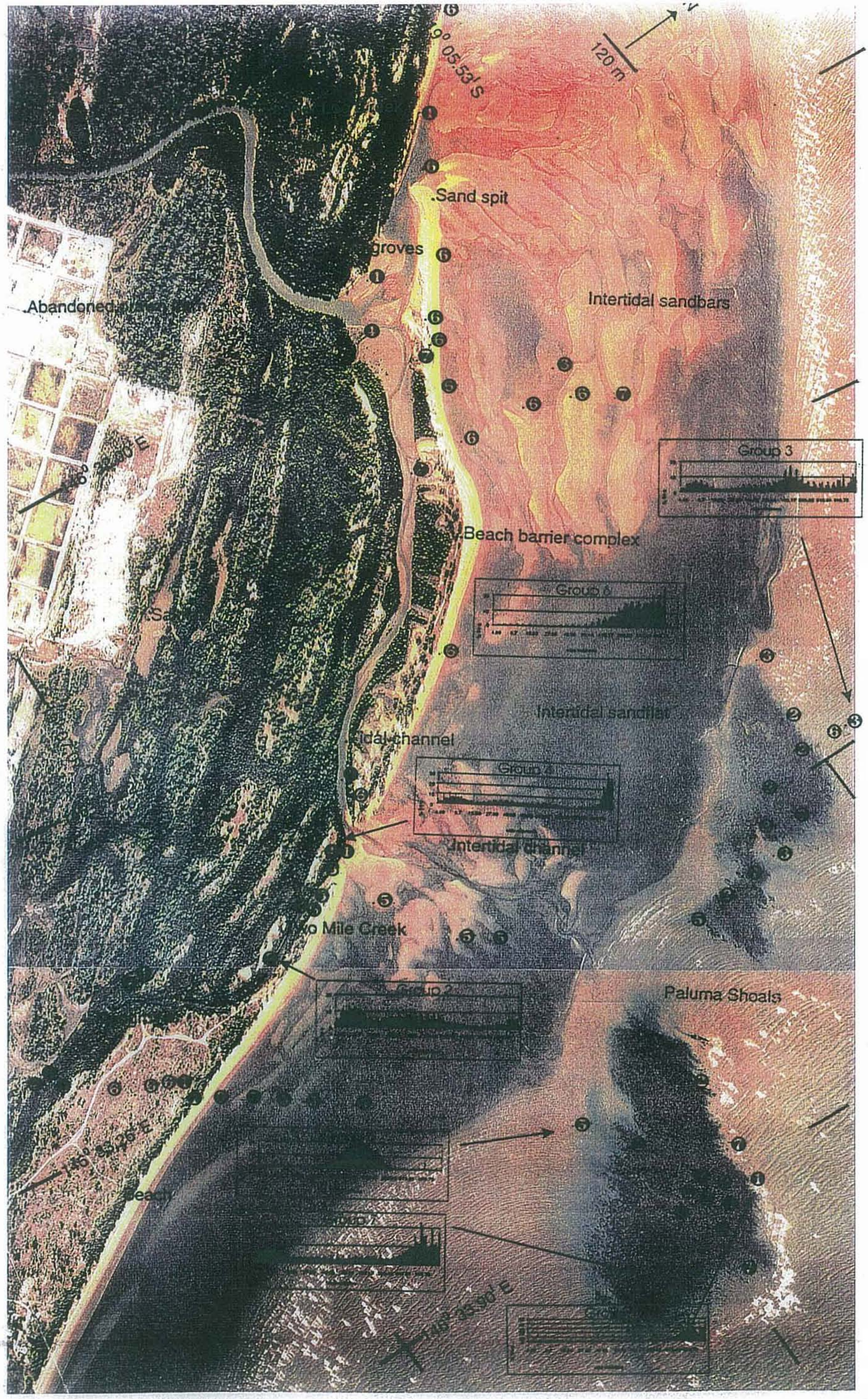


Figure 6.25. *Data groupings of 135 inner-shelf and coastal samples from southern Halifax Bay. Each group represents samples with similar grain size distribution.*

Group 3

These sediments are poorly-sorted trimodal, slightly gravelly muddy sands with modes at 7 μm, 110 μm and ~1000 μm (6.25). Group 3 correlates with the modern bay fill (muddy

Figure 6.27. *Aerial photograph and cover slip illustrating the entropy group distributions of the coastal facies assemblage. Each of the numbered dots indicates the entropy grouping of the sample.*



19° 05.53' S
120 m
Sand spit
Intertidal sandbars
Group 3
Beach barrier complex
Group 6
Intertidal sandflat
Tidal channel
Group 4
Intertidal channel
Two Mile Creek
Group 2
Paluma Shoals
146° 35.26' E
Beach
Group 1
146° 35.90' E

sands) from the inner-shelf terrestrial sediment wedge and some of the samples forming the gravelly muddy sands on the reef flat of Paluma Shoals (6.26).

Group 4

Group 4 sediments are poorly-sorted, gravelly sandy muds with modes at 7 μm, 800 μm and a ~2000 μm (Figure 6.25). Group 4 sediments correlate with samples collected from the mangrove forest floor and the tidal channel bed from the upper reaches of Sleeper Log Creek (PS12 & PS13) (6.1 & 6.26). The coarse fraction of these sediments is composed of quatrz grains, lithoclasts carbonate nodules and minor wood fragments. One sample interpreted as a gravelly sandy mud (PS46 & PS44) from the reef flat at Paluma Shoals is also a group 4 sediment.

Group 5

Group 5 sediments are well-sorted fine grained sands, with a mode of varying between 90 μm and 100 μm (Figure 6.25). These sediments are restricted to the well formed low tide terrace adjacent to Paluma Shoals (Figure 6.1 & 6.27). The well-sorted nature of these sediments is a product of sorting by waves.

Group 6

Group 6 sediments are well-sorted unimodal sands, with the mode varying between 325 μm and 1385 μm (Figure 6.25). This group of sediments correlate to the spit, beach and beach barrier quarztose sands. The intertidal sand bars are also group 6 sediments (Figure 6.1 & 6.27).

Group 7

Group 7 sediments are poorly-sorted, gravelly muddy sands with modes at 7 μm and ~900 μm (Figure 6.25). This group of sediments correlates with the gravelly muddy sands located north of Paluma Shoals and seward of Rattlesnake Island (Figure 6.26). Five samples collected from the reef platform of Paluma Shoals and an anomalous sample from an intertidal sand dune are also group 7 sediments.

Summary (entropy groups)

Grain size distributions are sedimentary responses to sediment transport, resuspension, deposition, chemical processes and bioturbation (Orpin, 1995). Entropy analysis has been employed because of its ability to disriminate sediment groups which are visulally discrete, and thus may represent different sedimentary facies (Woolfe, 1995). High resolution grain size mapping of the inner-shelf (Figure 6.26) is succesful in producing a map that mirrors the distribution of surfical sediment facies (Figure 6.14). This may be attributed to the moderate number of samples (58) and the strong contrasting characteristics between the facies, enabling visual descrimination of the grain size distributions. However, with larger data sets the use of entropy as a facies descrimination and grouping tool would prove invaluable.

The sedimentary facies identified from the modern coast also indicate the usefullness of the technique. However, the number of groups which are appropriate to the study need to be carefully selected (Woolfe, 1995). For this data set, the statistical optimum number of groups was determined by measuring the point at which the Rs statistic no longer increases significantly with the addition of an extra group (Woolfe & Michbayashi, 1995). Seven entropy groups were chosen as the optimum number for this data set (Figures 6.25 & Appendix 6.4). However, a visual comparison and the distribution of groups 2 and 4 reveals a similar grain size and distribution pattern. These sediments were interpreted as the same facies prior to entropy analysis. Therefore, careful mineralogical observations and geochemical analysis are required for the succesful grouping of sedimentary facies.