An examination of the offshore bathymetry and sedimentology of Cocos Bay, Trinidad

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Summary: *Cocos Bay, Trinidad, has a very dynamic system owing to the open bay morphology, and exposure to the Atlantic Ocean. The interplay of coastal processes, sediment characteristics and coastline orientation account for variations in the intensity of the processes operating at each beach. While the nearshore coastal geomorphology has received much attention by researchers, the offshore bathymetry and sedimentology remained fairly unresolved. In order to fully appreciate the nearshore-offshore relations at this bay, a hydrographic survey was undertaken. This paper examines the offshore bathymetry and sediment characteristics at several sections in Cocos Bay. Results indicate that megaripples and sandwaves with superimposed ripples dominate the offshore region, where the megaripples have a relationship with the surface wavelengths of oncoming incident waves.*

Key Words
COASTAL GEOMORPHOLOGY SEDIMENTOLOGY TRINIDAD

Introduction

The severe coastal erosion at Manzanilla beach in Cocos Bay has been of much concern for many years. Means for controlling such erosion and methods for proper beach management have been and continue to be at the forefront of concern. In 1982, the Institute of Marine Affairs [IMA] embarked on coastal conservation studies in Trinidad and Tobago. By 1985, a structured programme of data collection and analysis was established (Institute of Marine Affairs, 1986). The IMA set up 41 beach profile stations around Trinidad and Tobago from which nearshore processes and beach profile data were collected. These data revealed that there is a complex interplay of aspect, coastal geology, and nearshore hydrodynamics that contribute to the form of the coastlines (Bertrand *et al*., 1992).

Georges (1983) undertook a coastal classification for Trinidad using geology, angle (orientation) and nature of contact between shore and coast, vegetation cover and usage of the coast. By 1990, the IMA established 70 beach monitoring stations in Trinidad and 42 in Tobago. Beach profiles and littoral processes data were collected monthly from 1990 to 1995, and quarterly from 1996 to present. These data were used to set up a database for the IMA's Coastal Conservation Project (O'Brien-Delpesh, 1998).

Other researchers such as Singh (1997), Lackhai (1999; 2000), Environmental Management Authority (2001), Darsan (2005) and Mahabir and Nurse (2007) all focused on the nearshore coastal geomorphology of Cocos Bay. The most recent bathymetric survey of Cocos Bay was compiled from previous data in 1985. These surveys however looked at large-scale offshore features up to 80m water depth, using a resolution of 10m. The nearshore zone closer to wave base, shoreward of the 10m water depth, was not surveyed. One of the reasons for the lack of such surveys was due to the high energy environment of the Atlantic which produced very rough seas, making such research very dangerous. The aim of this research is to investigate the offshore environment of Cocos Bay, shoreward of this 10m water depth, at several sections along the bay.

Coastal Environment of Trinidad

Trinidad and Tobago, the most southerly of the Caribbean islands, is located on the continental shelf of South America, immediately adjacent to the outflow of the Orinoco River, and this determines to a great extent the nature and form of its coastal and marine environment. Trinidad's coasts are influenced by the discharge of the Orinoco River, and the Guiana current that flows along the east coast of South America (Andel, 1967). Its location on the continental shelf explains why much of its exclusive economic zone lies in shallow enough depths to permit exploitation of petroleum, natural gas and other seabed resources.

Trinidad and Tobago has a tropical maritime climate with two distinct seasons; a wet and dry season. The prevailing wind system is the north-east trades, and the dominant wind direction is from the north-east in the dry season (December to May), and from the east in the wet season (May to December).

The dominant ocean current influence is the northern branch of the South Equatorial Current, the Guiana Current/Orinoco River discharge. As the Guiana Current approaches Trinidad and Tobago it divides into two streams, with the inner stream passing into the Columbus Channel in a predominantly westerly flow and then into the Gulf of Paria, while the outer passes up along the east coast of Trinidad (Hudson, 1988). The physiographic relationship of the Guiana Current and the Orinoco River and its delta system's proximity to Trinidad and Tobago forms the major influence on recent sedimentation patterns in some of the marine areas of Trinidad and Tobago (Hudson, 1988).

The tidal regime experienced is a function of the tide waves from both the Caribbean Sea and the Atlantic Ocean. The tidal regime is semi-diurnal with periods of approximately 12.5 hours. At high spring tides the maximum range is 1.2m with some slight variation from north to south. At other times, the tidal range is less than one metre, averaging 50 to 60cm between high and low tides (Kenny, 2008).

The winter period with associated swell waves is most often experienced in the Caribbean between the months of October to April, and is usually caused by intense mid-latitude storms in the North Atlantic Ocean (Cambers, 1998). During the winter months, swells attack the coast from directions varying from north-west to north-east. On the east coast, deepwater wave attack is primarily from north-east to south-east, with an easterly approach being the most significant.

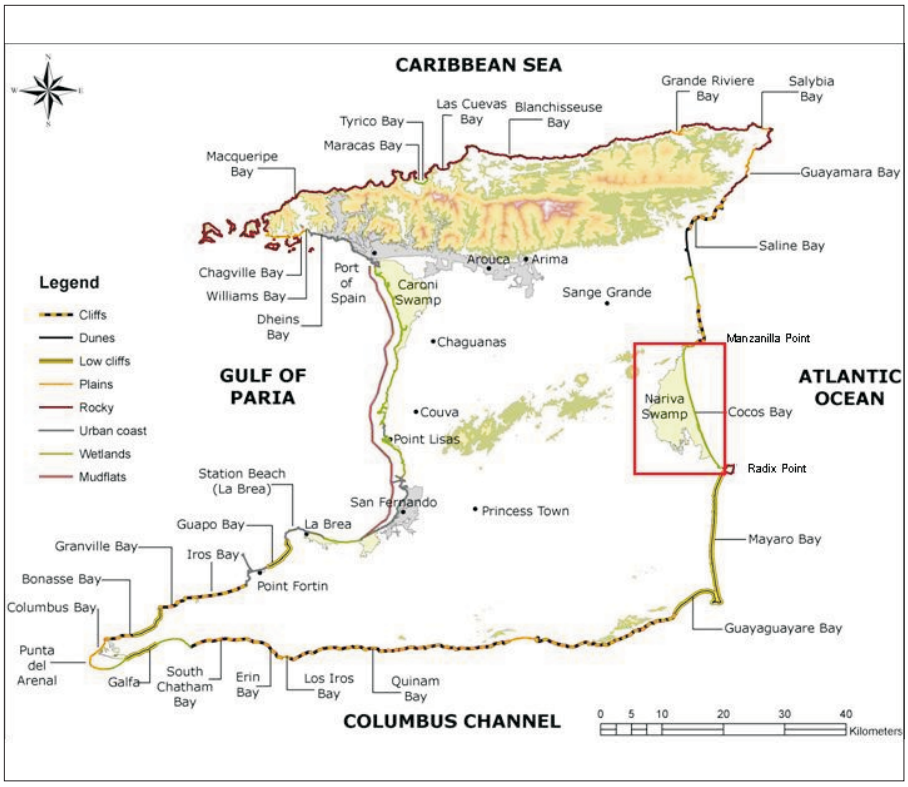

FIGURE 1: Location of the Study Area
SOURCE: Darsan et al. (2012)

Description of the study area

The variations in direction and strength of the wave attack along with the variations in geologic structure have produced a wide range of coastal landforms on the beaches in Trinidad. Cocos Bay has been classified as an open sea beach (Georges, 1983).

The east coast of Trinidad is rugged in its northern section where the rocks of the Northern Range outcrop. On the east coast, the sea bed dips gently downward from the coast towards the edge of the continental shelf approximately 100km away. Further south the coastline becomes gentler, where in the central regions the Nariva wetlands are found (Bertrand *et al.*, 1992; Institute of Marine Affairs, 1988). The east coast of Trinidad is extremely varied with three stretches of low coast separated by prominent headlands. Manzanilla beach is a barrier beach system found in Cocos Bay, embraced by two prominent headlands at Manzanilla Point and Radix Point (Figure 1). The Manzanilla beach is oriented north to south, and is exposed to the Atlantic Ocean.

The Cocal area includes the Manzanilla beach in Cocos Bay and the Nariva Swamp. The Cocal sand bar known locally as Manzanilla beach, has a relationship with the Nariva Swamp whereby the swamp is protected from the marine environment by the

barrier beach. The beach protects the swamp from salt water intrusion, helping to maintain the correct salinity levels that promote life in this wetland ecosystem. Without the Cocal Sand Bar (the Manzanilla beach), the Nariva Swamp would not exist in its present condition. The characteristics (including the geology and hydrogeology) of the sand bar are not well known having not been much researched (Environmental Management Authority, 2001). The Cocal sand bar has a fairly low topography with some sections below sea level (Williams, 2000).

The Manzanilla beach at Cocos Bay located along the Manzanilla/Mayaro Main Road, is about 20km long, and borders the landward edge of the Nariva Swamp. The barrier beach protects the Nariva Swamp and its distinct wetland ecosystem from the marine environment. The back of the barrier beach has not been driven inland with coastal retreat, and as such, sections of the barrier are becoming progressively narrower (Institute of Marine Affairs, 1988).

There is also significant erosion along several parts of the Manzanilla beach (Singh, 1997), particularly near the Nariva River mouth, attributable to fresh water outflow and tidal inflow dynamics. The Nariva River also carries large quantities of particulates and nutrients to Cocos Bay which has implications for marine biota and productivity (Bacon *et al.*, 1979). At several points along Manzanilla beach, the sand bar has been eroded from fresh water outflow and sea water inflow, creating points where salt water is able to directly penetrate and alter salinity in the Nariva Swamp (Environmental Management Authority, 2001).

Methodology

The Offshore Bathymetry was carried out in collaboration with Cane Associates (hydrographic surveyors) in St James, Trinidad. Because of the very high energy environment of Cocos Bay, finding the right day to undertake this survey involved a close monitoring of meteorological data, and site observations of sea conditions. The survey was conducted on the 7th of August, 2007 where the marine weather conditions were satisfactory. In conducting the survey, a dual phase Hydrographic Echo Sounder was mounted on the side of the vessel (7m fishing boat), with its transducer (probe) immersed in the water (Figure 2).

The survey was carried out as an extension of the beach profiles done up to wading depth (1.5m water depth) into the offshore region. For this survey, seven profiles were selected, however only five survey lines were conducted due to weather, time and cost constraints on the day of the survey. When the hydrographic survey was being undertaken, the boat followed a bearing that corresponded with that of the land-based beach profile, so that a continuation of the profile into the offshore region was obtained. The boat was guided using GPS positioning, and specialty surveying software. The offshore profiles generated have Universal Transverse Mercator (UTM) positions and are relative to the Naparima 1955 Datum.

The predicted tides used for the survey are shown in Figure 3. Predicted tides were used in the hydrographic survey since no tide gauge existed at Cocos Bay. Data from a tide gauge at Guayaguayare Bay were input into the Admiralty Tide Programme to predict the tides at Nariva River mouth. These tides produced for Nariva were then input

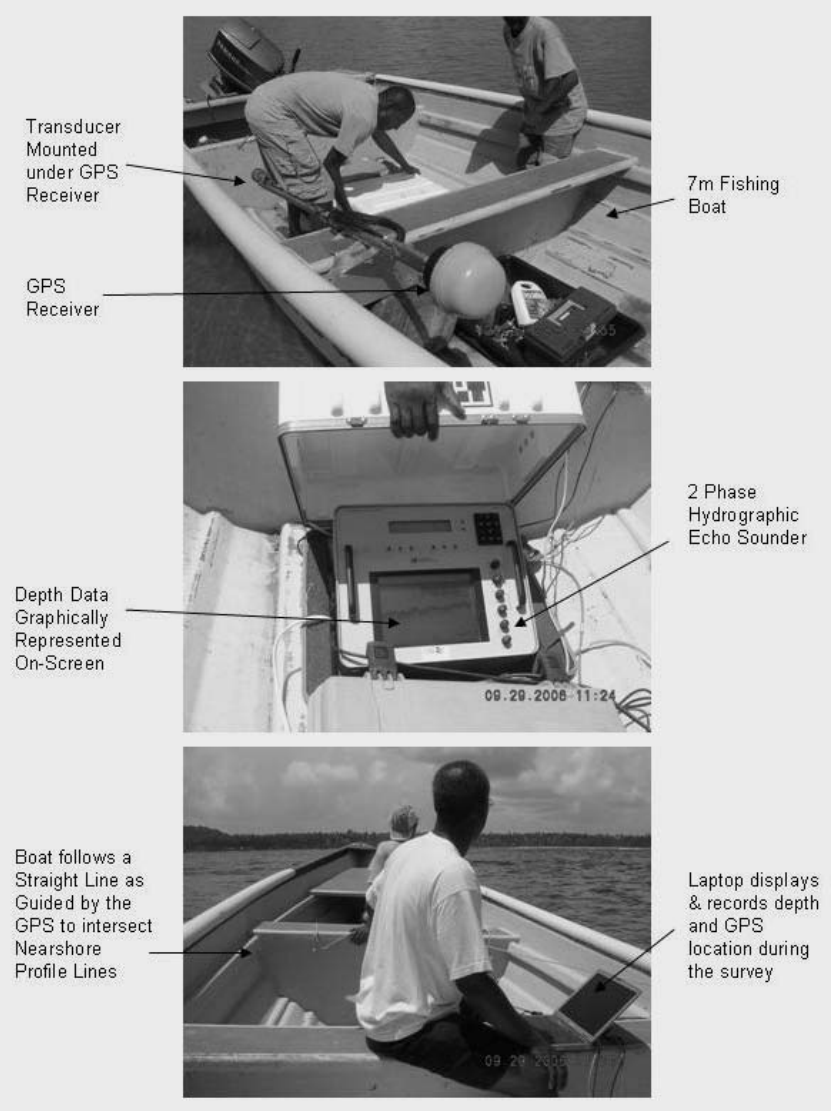

FIGURE 2: The equipment used in conducting the Hydrographic Survey

into the surveying software to calculate the mean sea level while conducting the hydrographic survey.

During the hydrographic survey, offshore sediment was collected from 10m water depth using a sediment grabber at the five sites investigated. At site 9B, sediment was sampled at 10m, 5m and 3m to get an appreciation of how the sediment characteristics change from the offshore region towards the surf zone. Ideally, it would have been better to be able to sample at 5m and 3m at each site but due to time and cost constraints this was not possible.

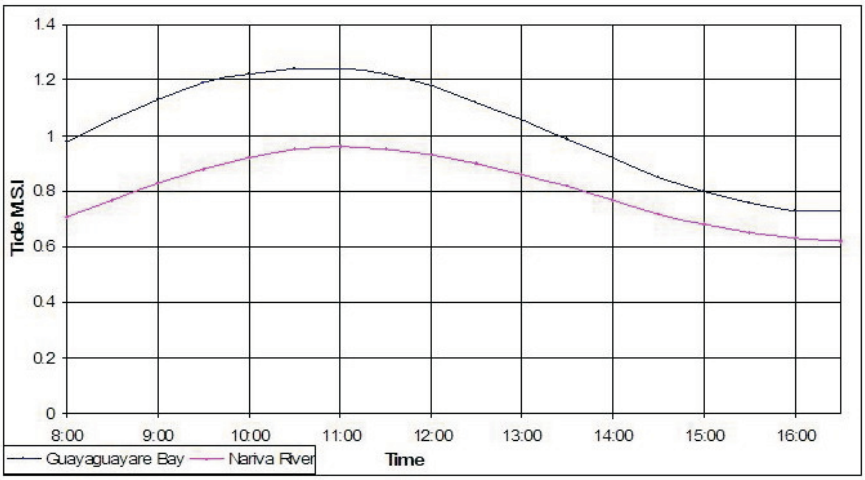

FIGURE 3: Predicted Tides for Guayaguayare Bay and Nariva River
SOURCE: Admiralty Tide Programme

The Offshore Environment of the East Coast

The hydrographic survey lines were done from the 10m water depth mark landwards to intersect the land-based profile lines at sites 3, 5, 6, 8B and 9B. The bathymetric contour map (Figure 4) shows the offshore seabed topography of the east coast of Trinidad. Due to the lack of recent bathymetric surveys on the entire east coast, the data presented are the most recent. Additionally, offshore bathymetry has not been conducted at Cocos Bay at depths shallower than 10m. Figure 4 shows the shoreward limit of the available data which is demarcated by the 10m water depth line that runs almost parallel to the shoreline at Cocos Bay.

Offshore Profiles

A universal characteristic of flows in the sea is that a sandy bed has the tendency to develop into a variety of bedforms such as current ripples, wave ripples, sandwaves and dunes, or breaker bars (Soulsby, 1997). The type of bedform that results depends on the strength and nature of the flow (Figure 5). In the sea, the tidal currents with their oscillatory nature continuously modify the ripple pattern and may cause a more symmetrical form of dune or sandwave to develop (Soulsby, 1997).

Studies of the intertidal zone have shown that four distinct size classes of bedforms exist; ripples, megaripples, dunes and sandwaves. While ripples are small-scale bedforms (a few centimeters), dunes and sandwaves are much larger bedforms ranging from tens of metres up to hundreds of metres in wavelength, and some metres in height. Their heights and wavelengths are governed by the water depth as well as the bed shear-stress (Soulsby, 1997). Soulsby (1997) estimates that the wavelengths of sandwaves are roughly 6 times the water depth. Sandwaves often have intermediate bedforms superimposed on them, and these are referred to as dunes.

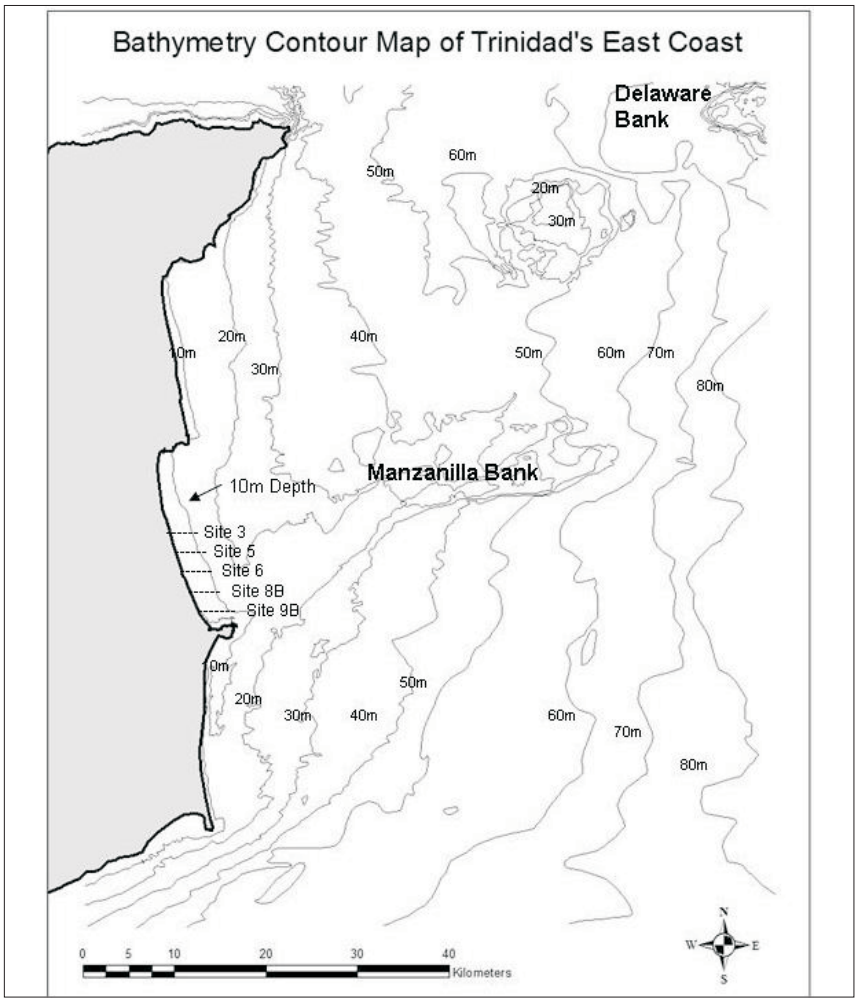

FIGURE 4: Bathymetry Contour Map of Trinidad's East Coast
SOURCE: Author - digitized from Bathymetric Maps of Trinidad's East Coast from Lands & Surveys Hydrographic Unit, 1985

Megaripples are smaller than sandwaves and are usually found superimposed on sandwaves. Van Straaten (1953) identified 20 different kinds of megaripple. McCave and Geiser (1979) described megaripples 0.3-0.6m high and 10-15m long, formed by strong currents during flood tides on intertidal sandflats. Details of current ripples are discussed by Allen (1968), and a classification has been presented by Tanner (1982).

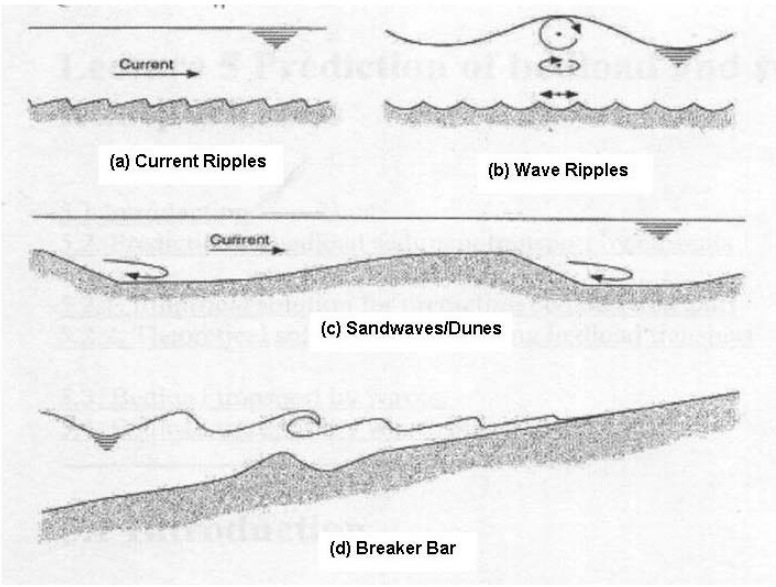

FIGURE 5: Types of Bedforms (a) Current Ripples (b) Wave Ripples (c) Sandwaves/Dunes (d) Breaker Bar
SOURCE: Soulsby (1997)

Offshore Bedforms at Cocos Bay

The offshore profiles reveal that megaripples and sandwaves with superimposed ripples dominate the offshore region. Megaripples are found closer to the surf zone at a depth of 4-5m while the sandwaves are located further offshore (Figures 6-7).

While this study seeks only to identify the offshore morphology that exists at Cocos Bay, a limited explanation of the existence of megaripples can be offered. Soulsby (1997) proposed that megaripples are purely wave generated, while sandwaves and dunes are current generated. As with a study by Traykovski (2007), the bedforms at Cocos Bay suggest that the wavelengths of the megaripples are equivalent to the maximum wavelengths of the oncoming incident waves in deep water (Figure 8). Traykovski (2007) showed that under moderate energy conditions the ripple wavelength typically scaled with wave orbital diameter. In more energetic conditions the ripples reached a maximum wavelength of 0.8 to 1. 2m and did not continue to increase in wavelength or decrease in height, as energy increased.

Traykovski (2007) also showed that relict ripples left after storms typically have wavelengths close to the maximum wavelength of oncoming waves. The observations at Manzanilla show a similar pattern where the megaripples had wavelengths close to the swell wavelengths in deep water. This study does not investigate the formation of these bedforms but notes a relationship between the megaripples and the surface wavelengths of the oncoming incident waves.

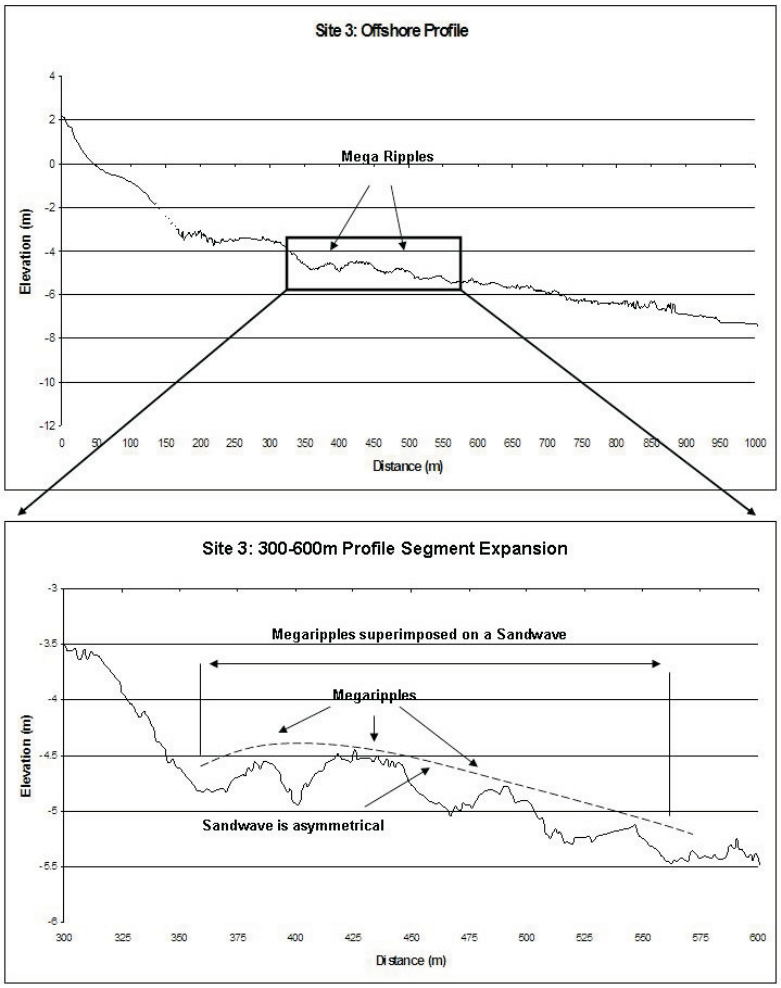

FIGURE 6: Offshore Profiles at Site 3
SOURCE: Author's Fieldwork

At site 3 (Figure 8), the wavelength of the megaripples ranged between 50-60m and so did the surface wavelengths, at a depth of 4-5m offshore. At site 5 the megaripples had a wavelength between 35-45m while the surface wavelengths were between 50-60m. At site 6, a noted reduction in surface wavelengths of 35-50m was also reflected in reduced megaripple wavelengths of 25-35m. As the surface wavelengths continued to decrease down the bay at sites 8B (30-40m) and 9B (25-40m), instead of megaripples, ripples on sandwaves were seen in the offshore region (Figure 9).

These data show that at Cocos Bay, megaripples are found in the middle section of the bay where surface wavelengths range between 40-60m. Megaripples cease to exist where the surface wavelengths fall below 40m, and this condition occurs in the southern end of the bay at sites 8B and 9B. It may also be true that the megaripple formation in the

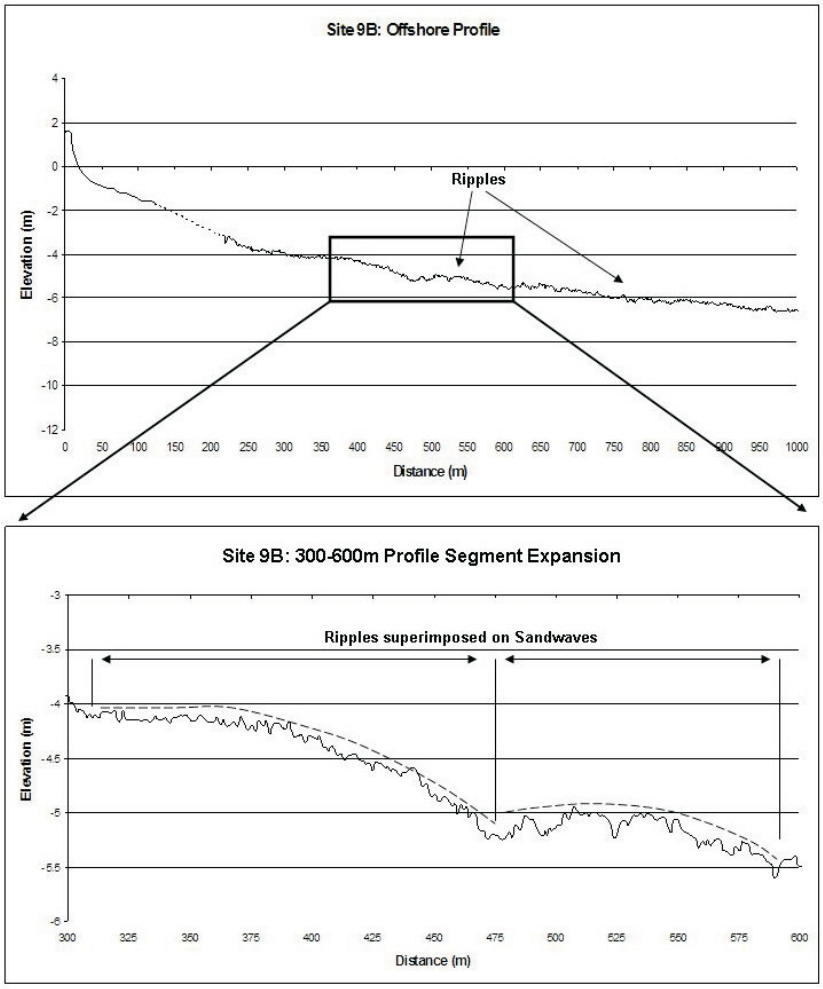

FIGURE 7: Offshore Profiles at Site 9B
SOURCE: Author's Fieldwork

centre of the bay may be related to the more stable profiles that are in equilibrium with oncoming wave trends.

Offshore Sediment Description (Folk & Ward Parameters)

The Folk and Ward Parameters (1957) for the offshore sediments showed that the sediments are all very fine sands, with the exception of Site 9B 5m depth sediment, which is a coarse silt. Sorting ranged from moderately to poorly sorted in the 10m and 5m depth sediments, while at the 3m depth sediment was well-sorted, probably because of its higher energy contact with the wave base that was able to influence its sorting. The sediments were generally very fine-skewed and very leptokurtic (Table 1).

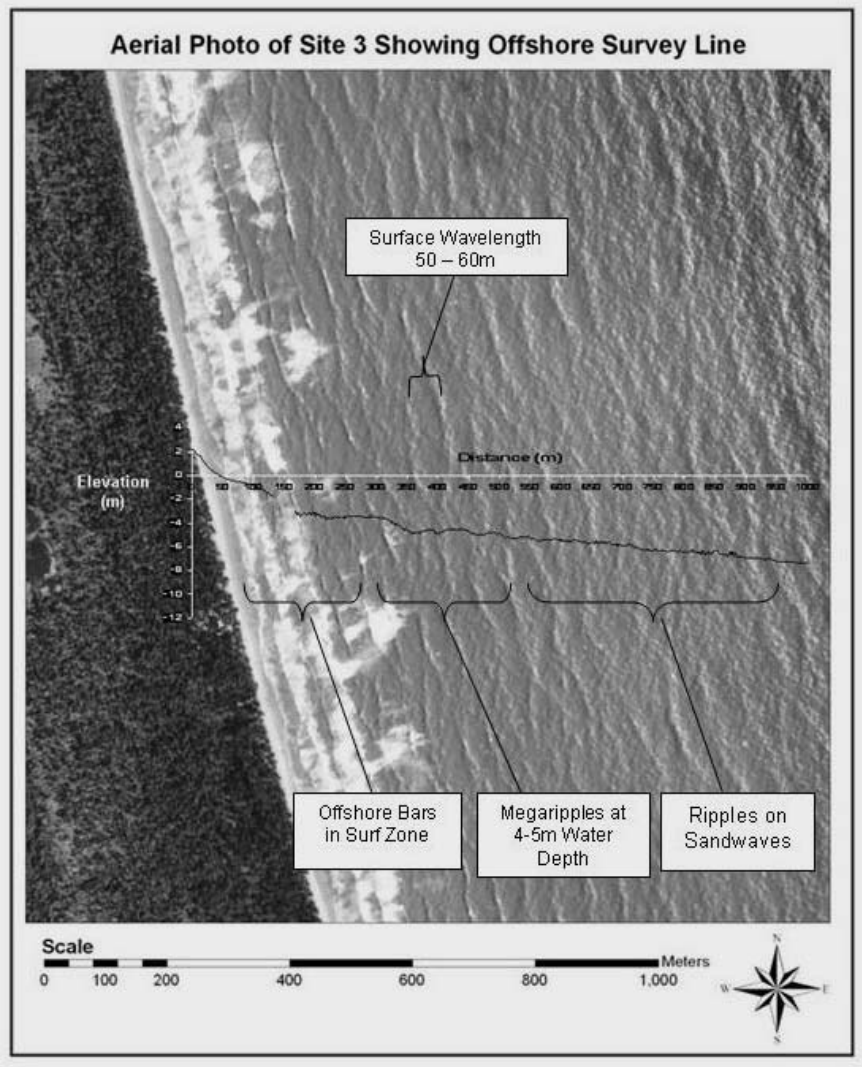

FIGURE 8: Aerial photo of Site 3 showing offshore environment SOURCE:Author's work adapted from 1994 aerial photos from Lands & Surveys Division, Port-of-Spain

The silt/clay ratio diagram shows that the offshore sediments (5m and 10m) are classified as a silty sand with the exception of the sample at 3m, which was placed into a sand category (Figure 10).

The 10m water depth samples showed little variation in grain sizes across the bay (Figure 11). The histogram of the offshore sediment shows a normal distribution around 4-4.5ø (fine to very-fine sand).

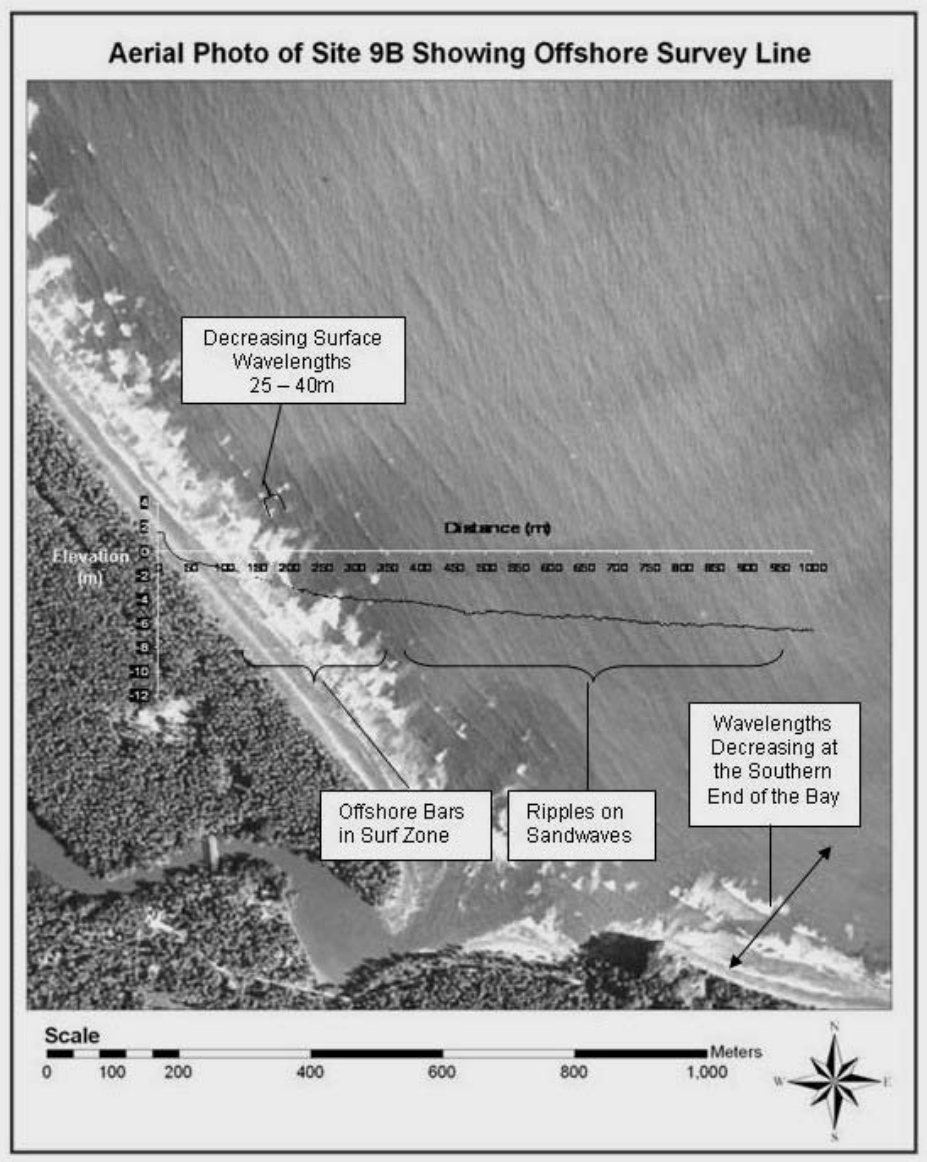

FIGURE 9: Aerial Photo of Site 9B Showing the Offshore Environment
SOURCE: Autho's work adapted from 1994 aerial photos from Lands & Surveys Division, Port-of-Spain

At site 9B the three offshore samples (10m, 5m and 3m water depths), were compared against a sample taken in the surf zone at 1m, and the data show a general fining of sediments from nearshore to the offshore region. This result is expected as fines brought down by the Ortoire River would get transported further offshore by coastal currents where they would be deposited. The sample at 5m was slightly finer than that at

TABLE 1: Folk and Ward Parameters for Offshore Sediment

	Site 3 – 10m	Site 5 – 10m	Site 6 – 10m	Site 8B – 10m
MEAN:	Very Fine Sand 3.969	Very Fine Sand 3.685	Very Fine Sand 3.597	Very Fine Sand 3.786
SORTING:	Poorly Sorted 1.033	Moderately Sorted 0.902	Moderately Sorted 0.768	Moderately Sorted 0.906
SKEWNESS:	Very Fine Skewed 0.577	Very Fine Skewed 0.352	Fine Skewed 0.254	Very Fine Skewed 0.452
KURTOSIS:	Extremely Leptokurtic 3.097	Very Leptokurtic 2.775	Very Leptokurtic 2.684	Extremely Leptokurtic 3.028

	Site 9B – 10m	Site 9B – 5m	Site 9B – 3m
MEAN:	Very Fine Sand 3.932	Very Coarse Silt 4.252	Very Fine Sand 3.417
SORTING:	Poorly Sorted 1.109	Poorly Sorted 1.403	Well Sorted 0.493
SKEWNESS:	Very Fine Skewed 0.522	Very Fine Skewed 0.503	Very Fine Skewed 0.427
KURTOSIS:	Very Leptokurtic 2.754	Very Leptokurtic 1.880	Very Leptokurtic 1.678

SOURCE: Author's Fieldwork

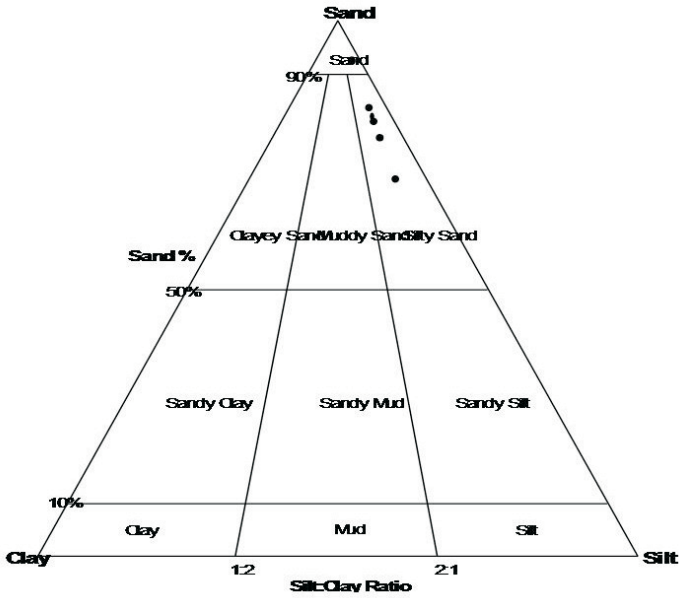

FIGURE 10: The Silt/Clay Ratio of the Offshore Sediments
SOURCE: Author

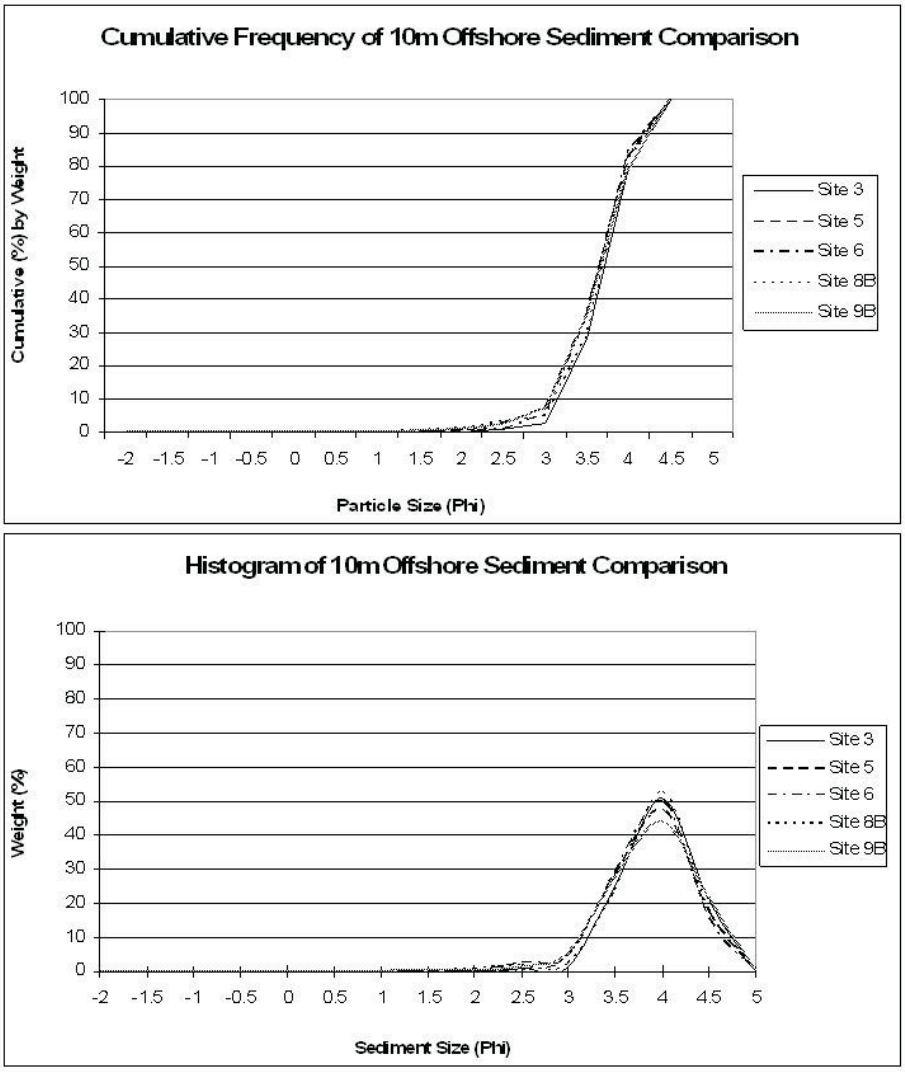

FIGURE 11: Offshore Sediment Comparison from 10m Water Depth at 5 Sites
SOURCE: Author's Fieldwork

10m, and composed of a finer sand and more silt-sized sediments. This finer sediment at 5m could be as a result of the transport and deposition of silt and clay-sized particles from the Ortoire River to that location offshore (Figure 12).

Summary

The offshore seabed topography at Cocos Bay consists of large-scale and smaller-scale bedforms. Sandwaves with superimposed ripples dominate the offshore region at depths

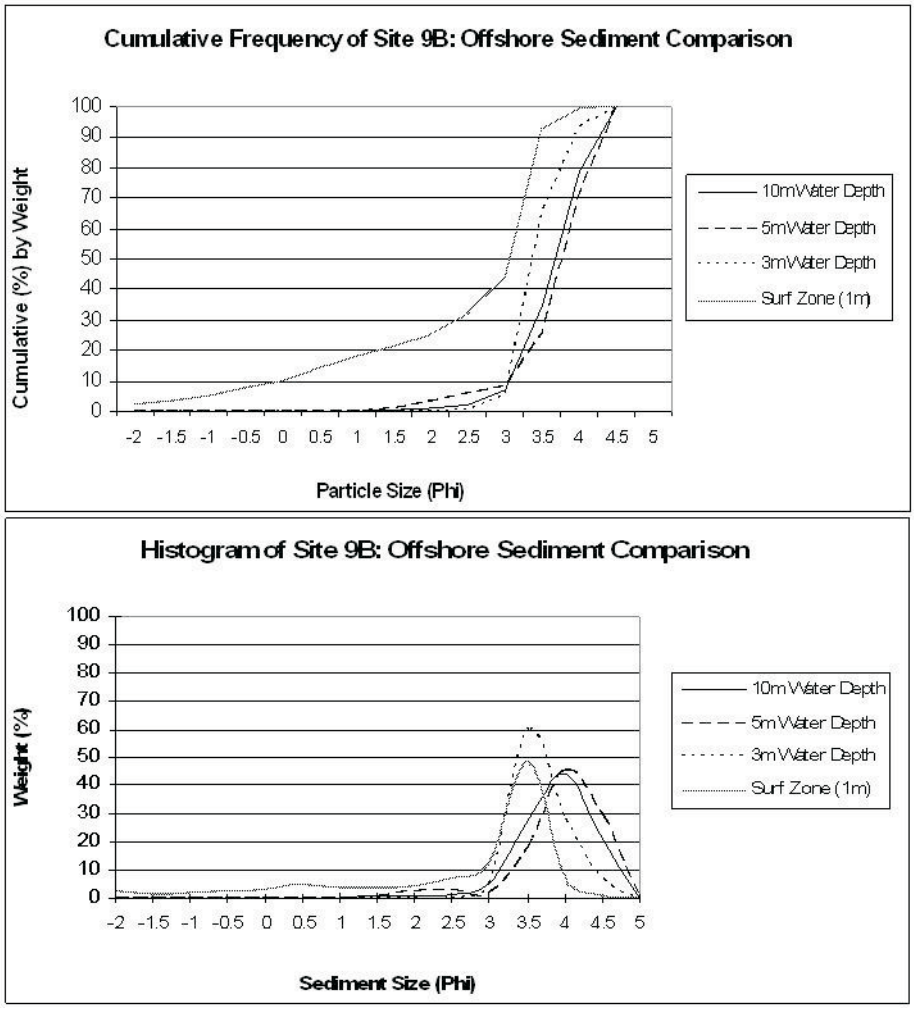

FIGURE 12: Offshore Sediment Comparison for Various Water Depths
SOURCE: Author's Fieldwork

greater than 6m. Megaripples are found at depths of 4-5m and are more pronounced in the middle of the bay where the beach profiles appear to be in a state of dynamic equilibrium with the oncoming wave conditions.

The offshore sediment comprises fine-silt to very fine-sand. At sites 3 and 9B, the sediment was poorly sorted, whereas at the other sites, 5, 6, and 8B, the offshore sediment was moderately-sorted. All the sediments were generally very fine skewed and very leptokurtic. At site 9B, finer grained sediment occurs at the 5m water depth compared to

the sediment at 10m water depth. This finer sediment probably represented the seaward extent of fine sediment output from the Ortoire River being deposited by sea currents.

In terms of the relationship between grain-sizes and morphology, at the 10m water depth, the silty very fine sand was arranged as ripples superimposed on sandwaves. At site 9B, the 5m and 10m depth sediments were associated with ripple-scale bedforms. At the 3m water depth, sediments were associated with offshore bars in the surf zone.

This study has revealed the bedforms exist in the offshore environment off the east coast of Trinidad. Results show the existence of large-scale bedforms in the offshore morphology of Cocos Bay. Such bedforms play an integral role in the sediment budgets of the coastal environment, since they function as sediment storage areas. Owing to the water depth (4-5m) at which megaripples and sandwaves (>6m) are found, they may not normally migrate under fair weather conditions. However, because of the high energy environment of the east coast, with storms/hurricanes that form in the Atlantic, megaripples will undoubtedly migrate under these storm conditions due to the deeper wave base of storm waves.

Landward migration of these bedforms may play a significant role in the supply of sediment to the beach during accretionary cycles during the summer months (wet season). Conversely, seaward migration may be reflected in erosion of the beach, as sediment is removed, and/or cross-shore sediment supply restricted. More studies on these large-scale bedforms need to be undertaken to ascertain the extent of their influence on the sediment budget of Cocos Bay.

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