1989

Preliminary assessment of beaches and offshore sand resources of St. Eustatius, Netherlands Antilles : a report to the Government of St. Eustatius

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PRELIMINARY ASSESSMENT OF BEACHES AND OFFSHORE SAND RESOURCES OF ST. EUSTATIUS NETHERLANDS ANTILLES

June 1989

A Report to

the

Government of St. Eustatius

by

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EXECUTIVE SUMMARY

Objectives: A pilot study was undertaken in July 1988 to:

1. Provide an estimate of the location and size of offshore sand resources suitable for beach nourishment.

2. Perform beach surveys and associated sampling for determining beach equilibrium configurations.

3. Provide a preliminary assessment of sites suitable for beach enhancement.

4. Provide a preliminary assessment of areas having extraordinary environmental sensitivity.

Emphasis was given to Oranje Baai and adjoining regions.

Results:

1. Using shallow seismic surveys, substantial deposits of sediments were located in Oranje Baai. These are expected to be sand deposits but coring will be necessary to substantiate both the thickness and characteristics of the material.

   The sediments have an interfacial covering of seagrass. Sea grasses are important nursery habitat for juvenile spiny lobster and conch; therefore, considerable care must be exercised in exploitation of the potential offshore deposits.

2. The beaches of Oranje Baai, currently in a sand-starved condition, would benefit from the emplacement of sand to protect the historical waterfront. A groyne field or other structures would likely be required to inhibit sand loss.

3. In addition to Oranje Baai, several other locations around the island are identified as candidates for beach enhancement.

4. Areas identified as being extraordinarily sensitive include:

   a. Nearshore coral reefs between Oranjestad and Kay Bay, and Corre-Corre.

   b. The seagrass beds in Oranje Baai and near the White Wall. The seagrass beds are important nursery areas for spiny lobster and conch, and thus highly important to any efforts for stock enhancement.

These habitats are particularly sensitive to water turbidity and sedimentation. Thus extraordinary precautions are warranted to avoid these impacts from port or other construction.

5. Additional studies are recommended. These include:

   a. Verification of the offshore sand deposits.

   b. Wave refraction/diffraction analyses to understand beach behavior and the effects of port construction.

   c. Additional field measurements of waves and currents toward predicting the response of beach fill.

   d. A beach profile monitoring system.

PURPOSE OF THE STUDY

A pilot study of the beach and nearshore processes, offshore sand distribution, and sea floor morphology on the leeward side of St. Eustatius was conducted in July 1988. Emphasis was on Oranje Baai and adjoining regions. The purpose of the study was to:

1. Provide an estimate of the location and size of offshore sand resources suitable for beach nourishment.

2. Perform beach surveys and associated sand sampling aimed at determining beach equilibrium configurations and identifying the type of conditions which might favor beach stability.

3. Provide a preliminary assessment of sites suitable for beach enhancement.

4. Provide a preliminary assessment of areas having an extraordinary environmental sensitivity.

During the course of our study, we have been made aware of the plan for a multipurpose port facility at Oranjestad. Our discussion here includes comment on some environmental concerns related to that plan. The study involved:

1. Side-scan sonar surveys of the sea floor morphology, bottom types, sand distribution patterns, and shipwreck sites;

2. Sub-bottom (shallow seismic) profiling which was conducted along with the side-scan surveying to estimate the vertical thickness of offshore sand resources;

3. Diver traverses of selected profiles in order to "ground-truth" side-scan sonar imagery;

4. Deployment of an internally recording wave and current meter in Oranje Baai to assess the directionality, magnitude, and source of sand transporting forces;

5. Beach surveys and associated sand sampling. In addition to the Oranjestad beaches, observations were also obtained at Concordia Beach on the windward side of the island; and

6. Acquisition of low altitude, oblique aerial photography of the shorefront of the entire island. This photographic mission was performed in October 1988.

It is to be emphasized that this effort was a pilot study. A two-week summer period is not sufficient to assess the hydrodynamic regime responsible for shaping the beaches on the island or to assess the responses of the beaches to those forces. Included in this report are our recommendations for additional study.

METHODS

Wave and Current Measurements - A Seadata model 635-9 directional wave gauge was installed 21 July 1988 on the nearshore bottom of Oranje Baai along a shore-normal transect, Profile A, intersecting the shoreline between near Interloper's Point just south of Fort Royal hill (Figure 1). A windmill was located along the landward extension of Profile A and for purposes of reference this area is herein designated as Windmill Beach.

The wave gauge was contained in a waterproof housing which was bolted to a 70 x 90 x 15 cm concrete block placed on the bottom by divers near the 3.5 meter depth contour. Our 635-9 unit was equipped

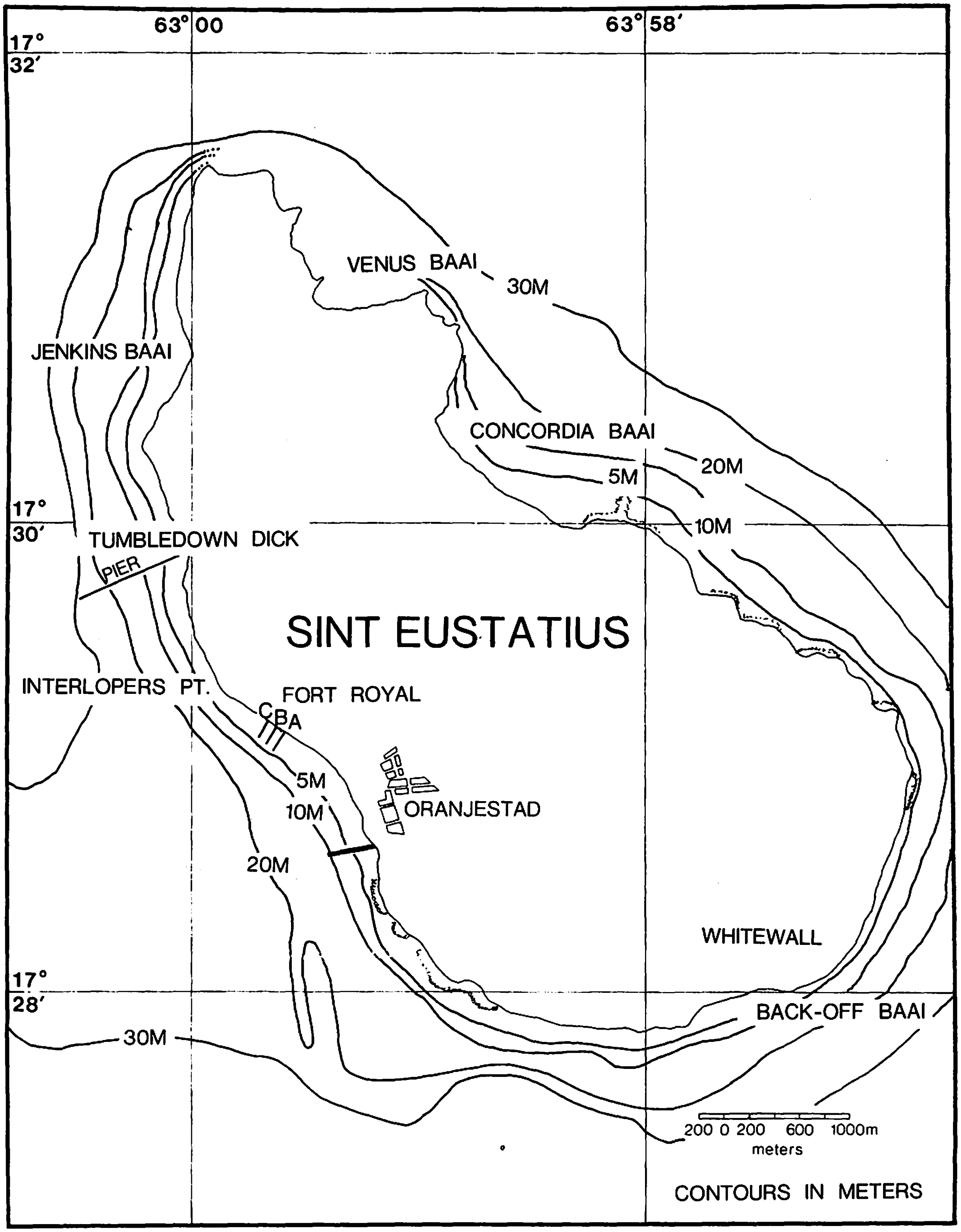

63° 00
63° 58′
17° 32′
17° 30′
17° 28′
VENUS BAAI
30M
JENKINS BAAI
CONCORDIA BAAI
20M
5M
10M
TUMBLEDOWN DICK
PIER
SINT EUSTATIUS
INTERLOPERS PT.
FORT ROYAL
C B A
5M
10M
ORANJESTAD
20M
WHITEWALL
BACK-OFF BAAI
30M
200 0 200 600 1000m
meters
CONTOURS IN METERS

Figure 1

with a high resolution Paroscientific quartz pressure transducer for determining wave heights and periods as well as a 4.0 cm diameter Marsh-McBirney two-axis electromagnetic current sensor for determining wave orbital velocities (instantaneous speed and direction) and bottom currents (time-averaged speed and direction). The sealed electronic controls, battery power and data recording mechanism of the model 635-9 allow the gauge to operate unattended in a "burst" mode of operation for a duration of several days to several weeks, depending upon the sampling intervals selected. In the July 1988 deployment which spanned slightly more than four days (100 hours), settings were used that enabled a burst to be taken once every two hours. Each burst consisted of 2048 measurements of pressure and velocity taken at 1 second intervals.

Beach Profile Measurements - Three beach profile transects (Profiles A,B and C) were established at Oranje Baai at the location described above and a single profile transect (Profile D) was measured at the northwest end of Concordia Baai (Figure 1). The horizontal and vertical reference for elevations measured at interval distances along these profiles was taken as the mean shoreline position. This reference will, of course, change with the rise and fall of the tide and with shoreline retreat or advance (beach cut and fill). The mean tidal range is about 15 cm at St. Eustatius (Kjerfve, 1981) which gives adequate stability to the vertical reference for present purposes. In collecting these particular measurements, we were concerned mainly with beach profile shape rather than shoreline advance or retreat and thus the horizontal reference of the mean shoreline position was chosen. Subaerial elevations landward of the shoreline were measured with an automatic level and metric survey rod while subaqueous elevations (depths) were measured at interval distances along each offshore segment by divers using a precision depth gauge and fibreglass metric tape positioned along the bottom. Sediment samples were also collected at selected positions along each transect for size and mineral composition analysis as described below.

Grain size and Mineral Composition of Beach Sands - Grain size analysis of beach sand samples was conducted using a rapid sand analyzer (RSA) incorporating a 1.4 meter fall tube with 18 cm inside diameter. The size distribution of sediment samples introduced into the top of the tube was computed after converting fall velocity to equivalent grain diameter for sand with a density of quartz (2.65 g/cm^3). Weight percentages in each size class interval were determined from cumulative weight readings sensed by an electronic balance connected to a microcomputer. Standard grain size statistics including mean grain size and sorting index were then determined by means of a computer program utilizing the size-weight information. The mean grain size (grain diameter in mm) was computed using the percentile statistic Mz = (P16+P50+P84)/3 where P16, P50 and P84 are the 16th, 50th and 84th percentiles, respectively, of the cumulative curve of weight percent coarser than size indicated in phi units (phi= $-\log_2$(Dmm)). Mz was converted to mm units following its determination in phi units. The sorting index (SI) was calculated using SI = (P84-P16)/2 which describes a sediment of $SI<0.35$ as very well sorted, $0.35<SI<0.50$ as well sorted, $0.50<SI<1.00$ as moderately sorted and $SI>1.00$ as poorly sorted.

Point counts were made for a selected number of beach sand samples using a petrographic microscope for identification of individual minerals. Density-based mineral separation techniques were used to determine weight percentages of light minerals (quartz, feldspar) versus heavy minerals (ferromagnesians). Calcium carbonate (calcite, aragonite) weight percentages were determined by acid removal. Ferromagnesian minerals include olivine, magnetite, amphiboles and pyroxenes. In contrast to quartz and feldspar with densities of between 2.6 and 2.8 g/cm3, heavy mineral densities commonly vary between 3.0 and 5.5 g/cm3.

Side-Scan Sonar and Sub-Bottom Profile Survey - An EG&G model SMS 960 side scan sonar - sea floor mapping system was employed to delineate bottom sediment types using acoustic imagery. This unit is a digital system which utilizes microprocessor technology to ensure a high degree of repeatability and to control (automatically) signal amplitude, conversion of slant range to horizontal distance and scale change due to variations in vessel speed. The selected range for this survey was 100 meters producing a 200 meter wide swath at a fixed scale of 1:1000. Resolution at this range is 0.25 meters. "Ground-truthing" of the imagery was accomplished using divers, underwater photography and video recording media.

In conjunction with the SMS 960 side scan unit, a Datasonics model SBP 5000 low-frequency, shallow water sub-bottom profiling system was used to collect continuous seismic reflection records. This unit offers a frequency range of 3.5 kHz to 12 kHz. Throughout the survey the 3.5 kHz range produced the best results in delineating bottom sediment thickness adjacent to the island. Navigational control was obtained by plotting three-point fixes from simultaneous horizontal sextant angles measured between positively identified shore control objects located on a 1:30,000 field survey map. Numbered sextant fixes were cross-referenced with numbered shot points annotated according to local time on the acoustic records.

RESULTS

Beach Processes at Oranje Baai - Due to the limited amount of time available to VIMS personnel in the field, it was not possible to conduct measurements addressing the long-term change in shoreline position for the limited areas featuring natural beaches on St. Eustatius. We know of no reliable map sequence or other long-term data which would permit evaluation of long-term trends or seasonal and interannual variability. However, photographs taken by a colleague of the main beach along Oranje Baai on April 10, 1971 (**Figure 2a**) show a wide sand backshore with the shoreline advanced roughly 20 to 30 meters seaward of the position found in the summer of 1988 and winter of 1989 (**Figure 2b**). Although a second photograph taken in 1971 (September 8, **Figure 2a**) evidences some seasonal retreat and advance of the shoreline in that year, the net shoreline retreat observed between the years

1971-1989 suggests that a considerable volume of sand has been transported either alongshore, or in the offshore direction, and has not returned.

Shoreline Photography - To compare this apparent loss with observed variations in shoreline position caused by hydrodynamic factors (seasonal change in wave characteristics and wave-induced currents), we requested the island government to conduct photographic monitoring covering a period of one year. This was implemented on 10 October, 1988, using an automatic 35 mm camera with date imprint. A single view of the beachfront as seen from the western wall of Fort Oranje was selected for photographing approximately three to four times each week on a continuing basis for one year. At the time of this writing, photography covering the period 10 October 1988 through 5 February 1989 has been collected and forwarded to us for analysis.

The limited photographic evidence in hand indicates that the beach at Oranje Baai, a well-protected, lee shore site where low-energy wave conditions prevail much of the time and swimming or bathing would normally be optimal, may have undergone a significant net loss of sand during the past two decades. A "sand-starved" condition now exists along the remaining beaches with rock exposures along almost all segments of the shoreline from the town landing of Oranjestad harbor to Windmill Beach and Interloper's Point (Figure 1).

BEACH CHANGES

1971

ORANJESTAD BEACH APRIL 10 ,1971

ORANJESTAD BEACH SEPTEMBER 8 ,1971.

Figure 2a

BEACH CHANGES

1989

ORANJESTAD BEACH FEBRUARY 5 ,1989

ORANJESTAD BEACH MAY 1 , 1989.

Figure 2b

Field examination disclosed no significant sand sources south of the Charles Woodly Pier which would serve as supply to Oranjestad beaches. We infer therefore that fluctuations in beach volume occur as exchange between the beach and nearshore sands located offshore and to the north in response to directional shifts of wave energy. The gross alongshore transport rate cannot be determined from the existing data base; however, over the last year, the most likely direction of the <u>net</u> transport is to the north.

Photographs taken of Oranje Baai Beach over a four-month winter period (10 October 1988 to 5 February 1989) have revealed almost no change in the volume of sand present, even though a variety of incident wave conditions and wave angles of approach have been observed, including large breaking waves from the northwest (**Figure 2b**) which should reverse the presumed northwest drift taking place under normal conditions. In essence, no seasonal change was detected in the winter of 1988 - 1989. Possible explanations for a long-term net loss include:

1. Nearshore grass beds may stabilize the bottom such that sand lost from the beach is inhibited from returning. Storm waves of sufficient intensity may dislodge the seagrass and thereby activate a temporary sand source to resupply the beach. By this hypothesis, the frequency of large storms could play a significant role in exposing a post-storm sand supply. Hine et al., (1987) observed a sustained shoreline depositional response to large-scale seagrass mortality that occurred between 1957 and 1968 in the nearshore zone off Anclote Key in West-Central Florida.

2. Biogenic sources of carbonate sand may have been reduced in the nearshore zone in combination with a partial interruption of volcanic sand sources on land. Given the apparent mobility of these sands on or near the beach face, equilibrium may depend on positive source input rates.

3. The open pile pier, constructed in 1974, may have induced a seaward flowing return circulation which, in turn, provided an offshore sand transport pathway. Circulation of this type has been documented elsewhere in higher energy environments.

<u>Nearshore Waves and Currents</u> - Using burst-averaged values of current speed and direction obtained for the 100 hours of our directional wave gauge observations, we have plotted a "progressive vector" diagram showing the bottom current trajectory (Figure 3).

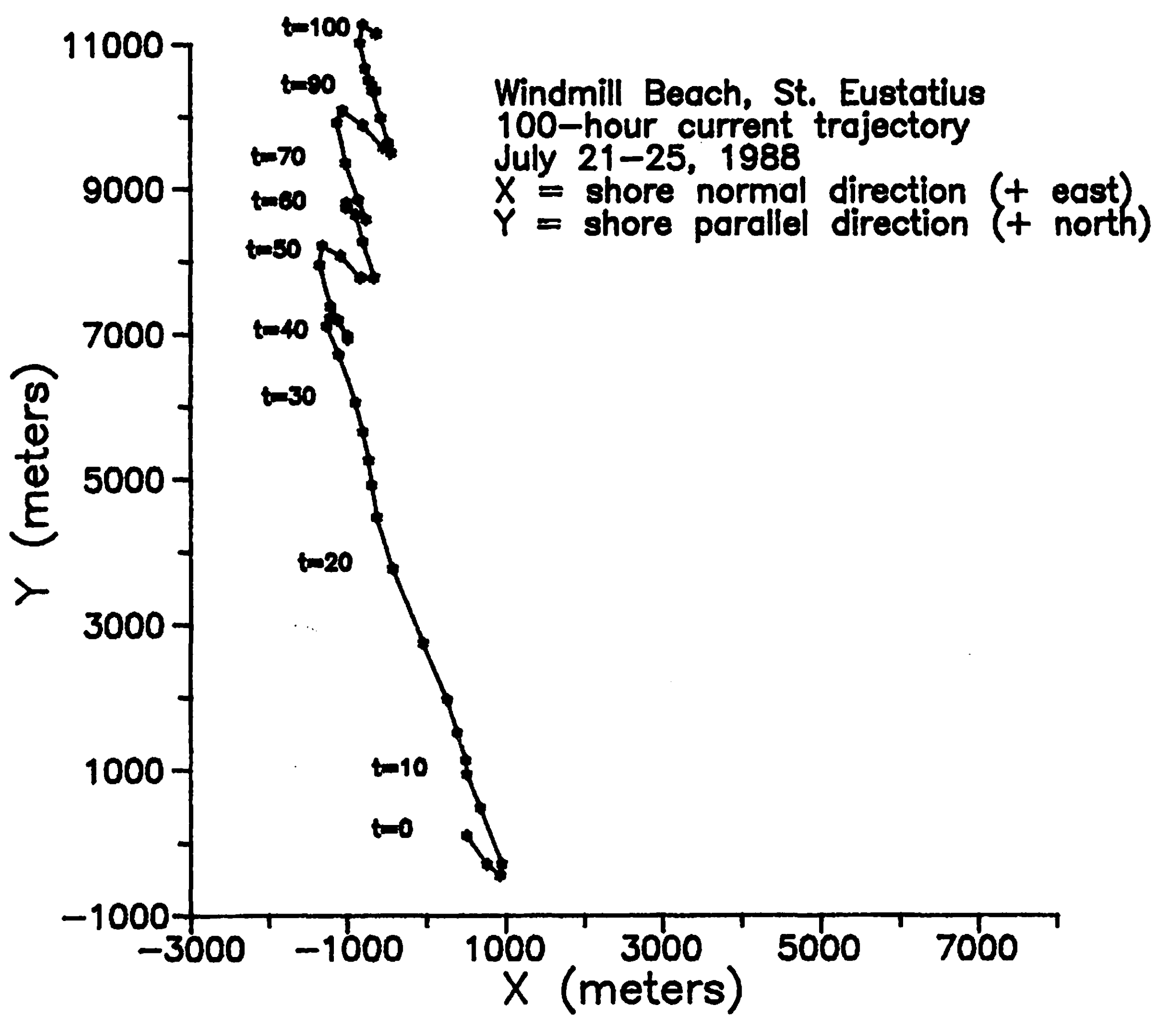


Figure 3.

In a uniform flow field, these measures depict the path taken by an object floating neutrally buoyant near the bottom. In the present instance, the observed motion was consistently toward the northwest with small reversals at tidal periods occurring near the end of the measurement period. The net northwestward displacement was approximately 12 kilometers in 100 hours, suggesting an average drift rate of between 3 and 4 cm/s. During this time, the angle of wave approach was between 30 and 45 degrees opening to the southeast. Waves of low significant height (20 to 30 cm) and short period (5 to 6 seconds) were recorded which produced little, if any, observed sediment motion on the bottom except near the toe of the beach face. This pattern of observations may prevail much of the time but will almost certainly be interrupted by occasional high waves of long period coming from the northwest as noted on 16 December, 1988 and again on January 6, 1989 (**Figure 2b**).

<u>Nearshore Bottom Types</u> - Side-scan imagery along the tracklines shown in **Figure 4** and diver reconnaissance along bottom transects running across the nearshore zone of Oranje Baai reveal a mixture of rocks, coral rubble, seagrass and bare sand flats with bedforms of varying height (**Figure 5**). The bottom sands observed at depths of more than 5 meters appear to consist mainly of coral fragments with a minor component of volcanic minerals. Side-scan imagery (**Figures 6 - 7**) and underwater photographs (**Figures 8 - 11**) illustrate the nature of the various bottom types encountered at selected locations (A through F, **Figure 5**).

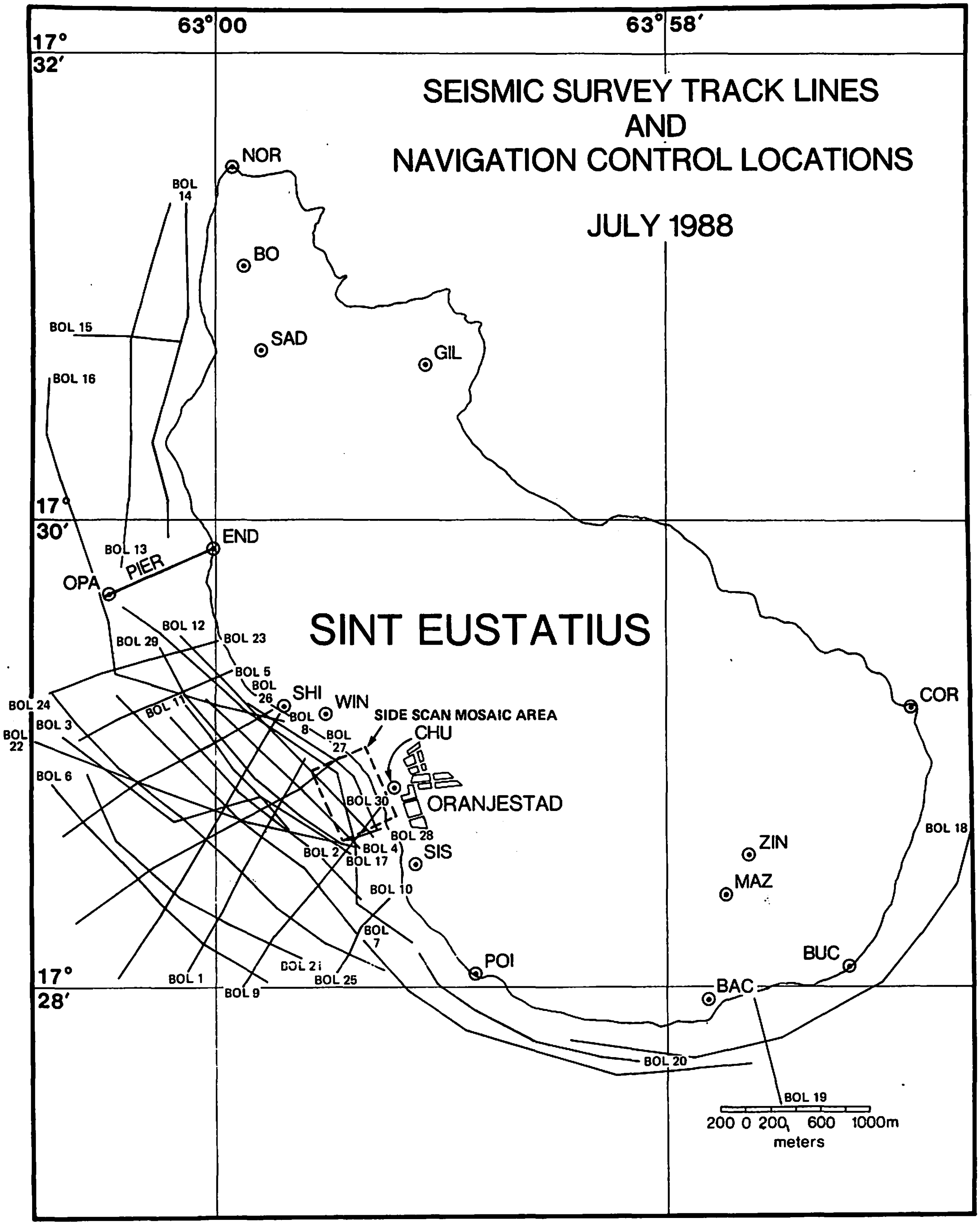

SEISMIC SURVEY TRACK LINES
AND
NAVIGATION CONTROL LOCATIONS
JULY 1988
SINT EUSTATIUS
63° 00
63° 58′
17° 32′
17° 30′
17° 28′
NOR
BO
SAD
GIL
END
OPA
PIER
SHI
WIN
CHU
SIDE SCAN MOSAIC AREA
ORANJESTAD
SIS
ZIN
MAZ
POI
BAC
BUC
COR
BOL 14
BOL 15
BOL 16
BOL 13
BOL 12
BOL 29
BOL 23
BOL 5
BOL 26
BOL 24
BOL 3
BOL 22
BOL 11
BOL 8
BOL 27
BOL 6
BOL 30
BOL 28
BOL 2
BOL 4
BOL 17
BOL 10
BOL 7
BOL 1
BOL 9
BOL 21
BOL 25
BOL 20
BOL 19
BOL 18
200 0 200 600 1000m
meters

Figure 4

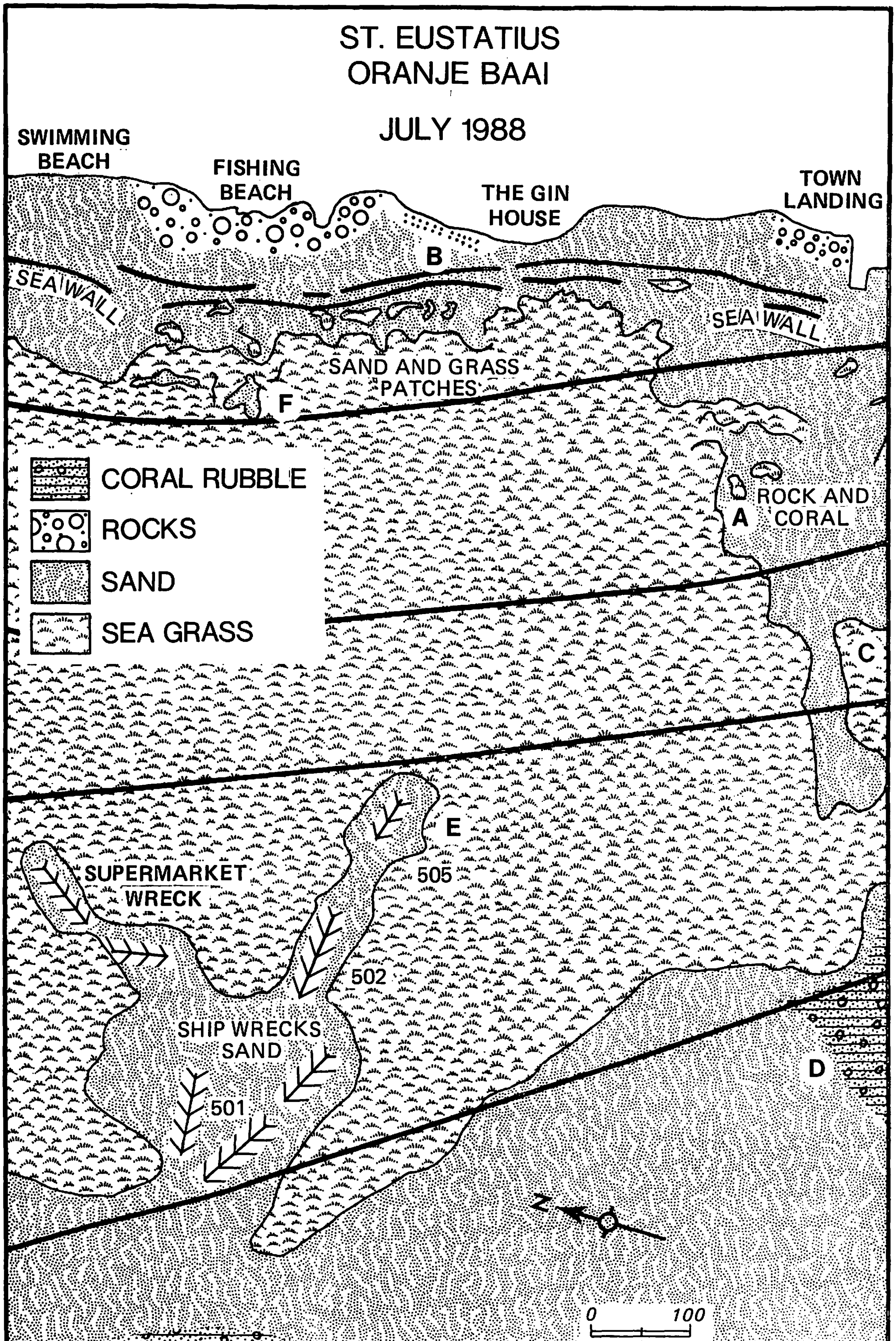
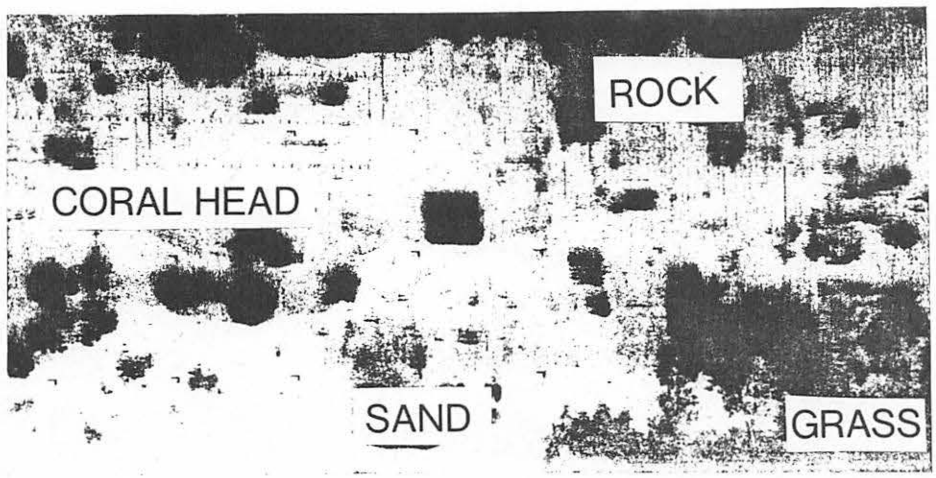

ST. EUSTATIUS
ORANJE BAAI
JULY 1988
SWIMMING BEACH
FISHING BEACH
THE GIN HOUSE
TOWN LANDING
B
SEA WALL
SEA WALL
5 M
SAND AND GRASS PATCHES
F
CORAL RUBBLE
ROCKS
SAND
SEA GRASS
ROCK AND CORAL
A
10 M
C
15 M
E
505
SUPERMARKET WRECK
502
20 M
SHIP WRECKS SAND
501
D
N
0 100
METERS

Figure 5

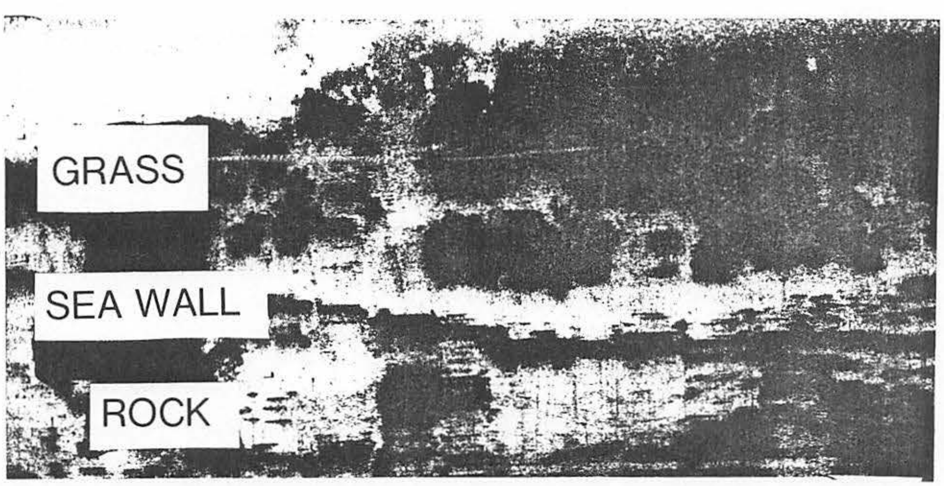
SIDE SCAN SONAR

BOTTOM TYPE



LOCATION A

ROCK AND CORAL HEADS ON SAND BOTTOM, ORANJE BAAI, ST. EUSTATIUS.



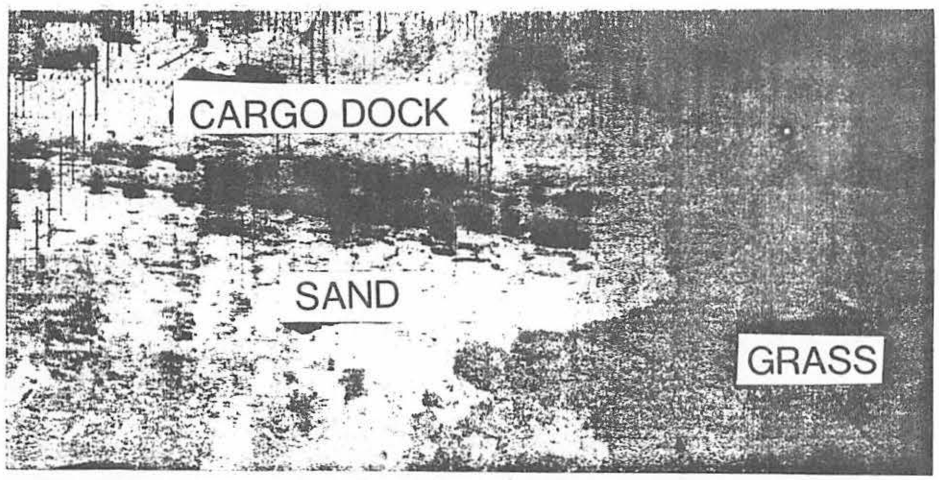
LOCATION B

THE SEA WALL AND GRASS PATCHES, ORANJE BAAI, ST. EUSTATIUS.

Figure 6

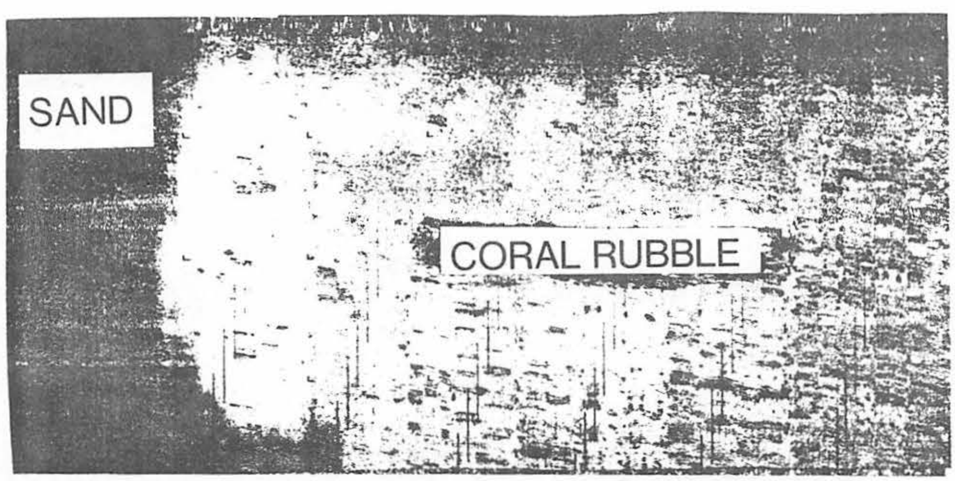
SIDE SCAN SONAR

BOTTOM TYPE



LOCATION C

SAND SCOUR AROUND THE CARGO DOCK AT ORANJE BAAI, ST. EUSTATIUS.



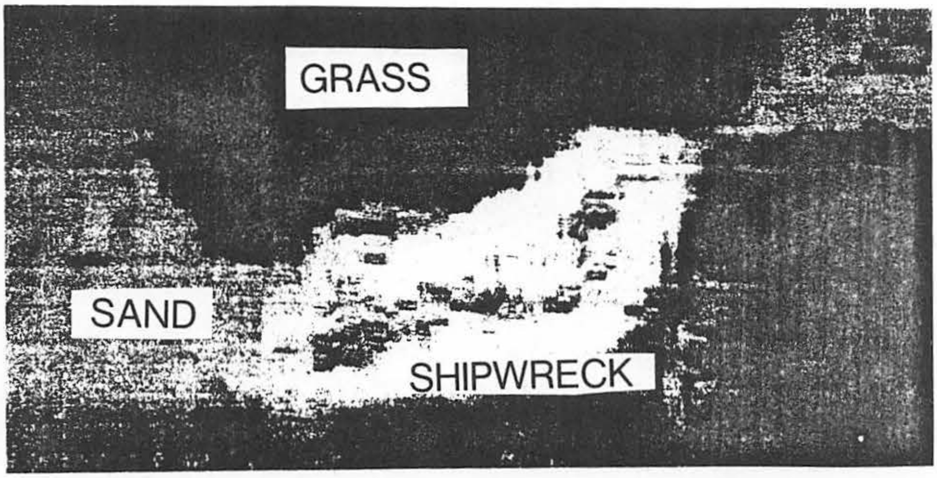
LOCATION D

CORAL RUBBLE NEAR THE CARGO DOCK AT ORANJE BAAI, ST. EUSTATIUS.

Figure 7

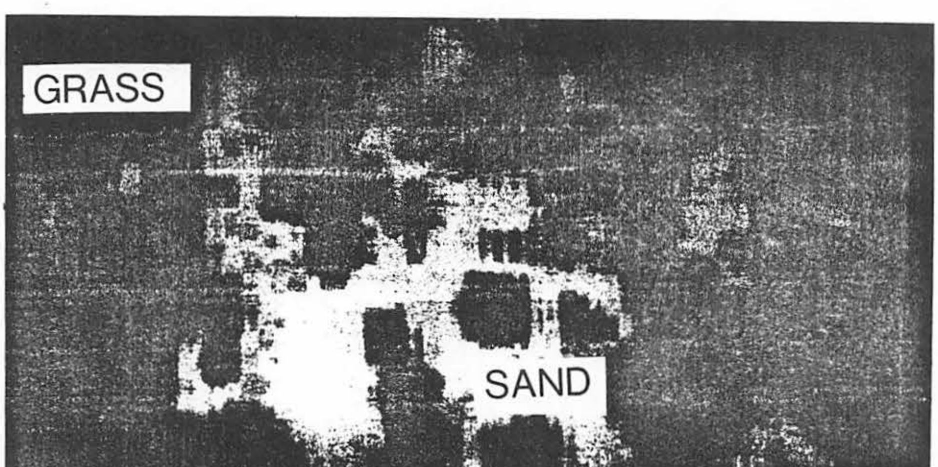
SIDE SCAN SONAR

BOTTOM TYPE



LOCATION E

SAND SCOUR AROUND SHIPWRECK IN ORANJE BAAI, ST. EUSTATIUS.

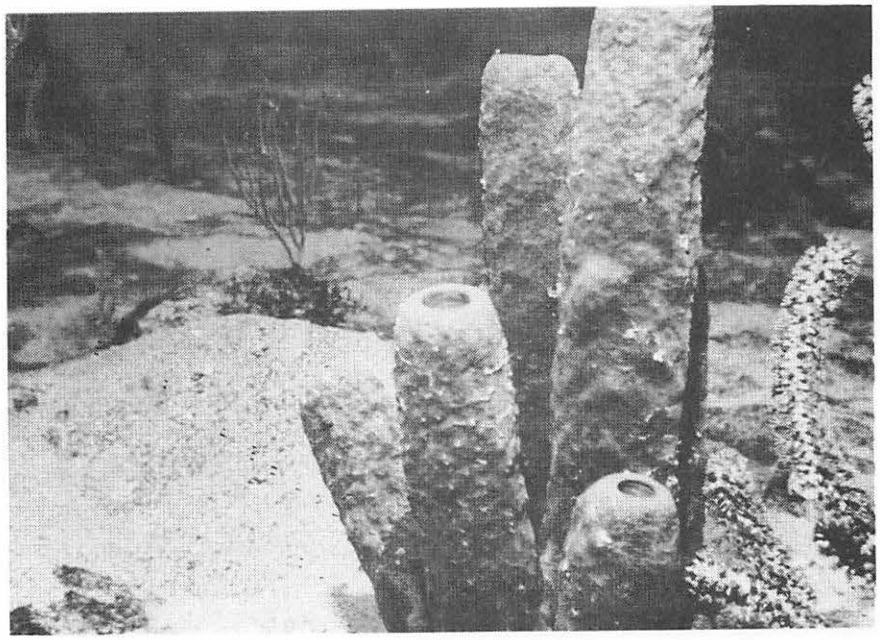


LOCATION F

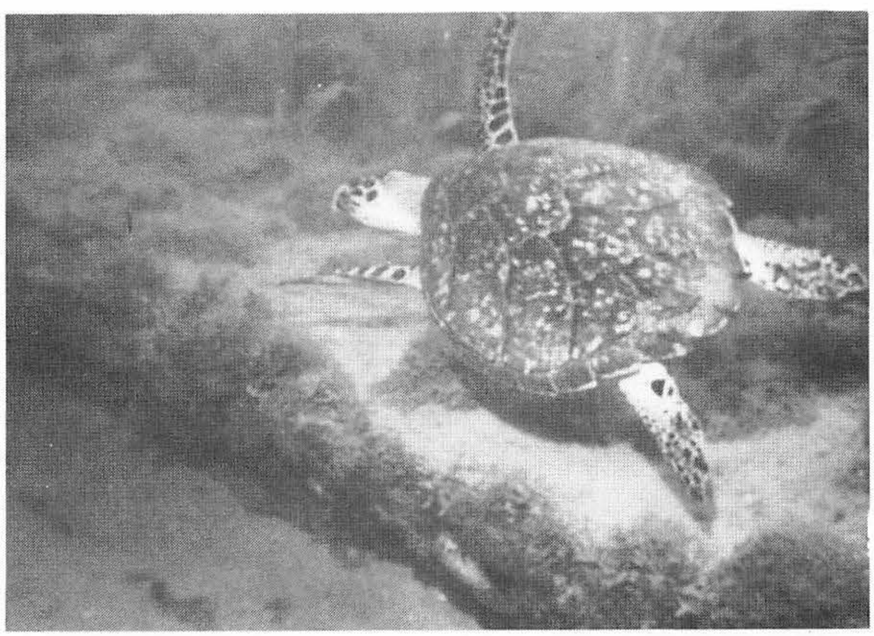
GRASS BED WITH SAND PATCHES IN ORANJE BAAI, ST. EUSTATIUS.

Figure 8

BOTTOM TYPE



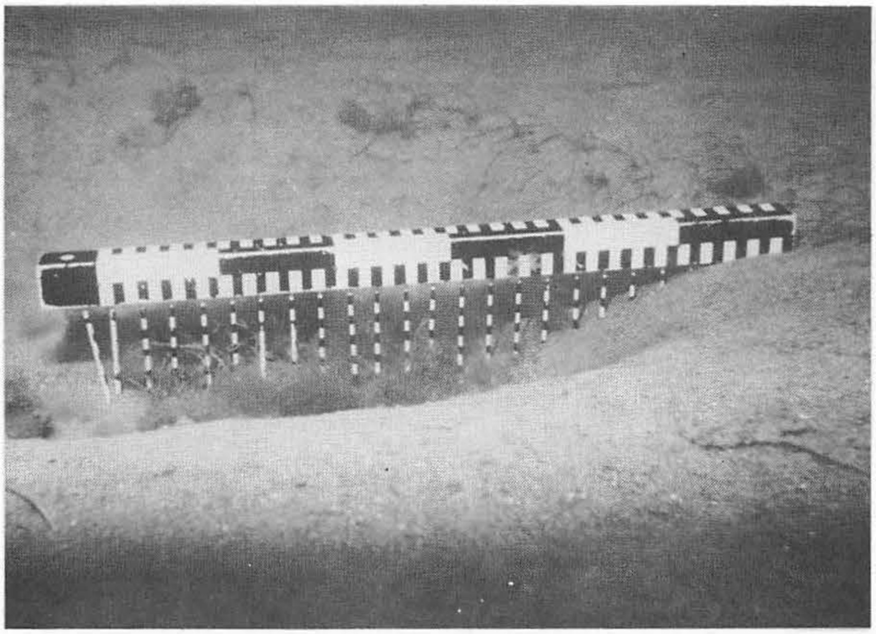
LOCATION A ROCK AND CORAL HEADS ON SAND BOTTOM



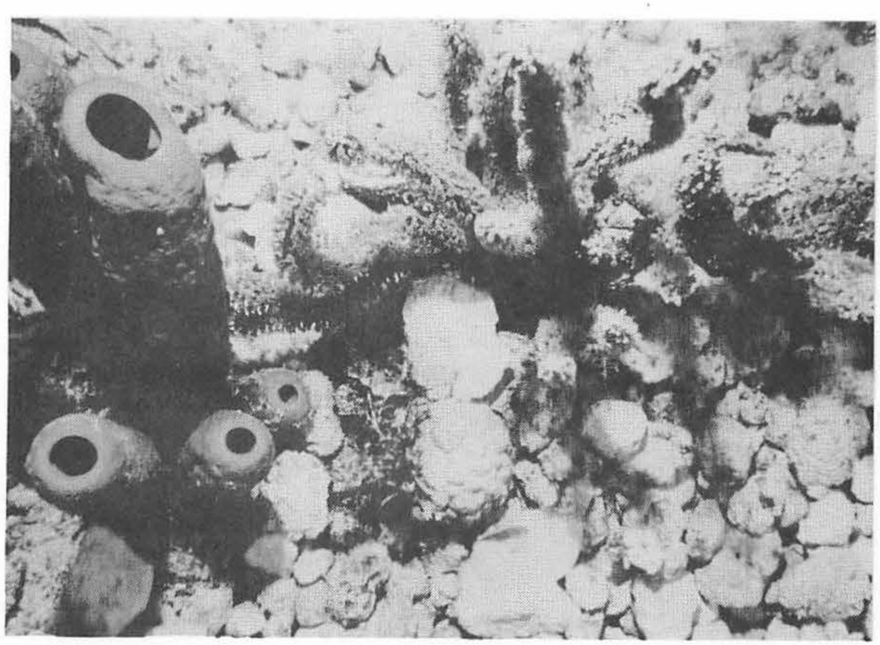
LOCATION B THE SEA WALL AND GRASS PATCHES.

Figure 9

BOTTOM TYPE



LOCATION C SAND SCOUR ORANJE BAAI,ST.EUSTATIUS.

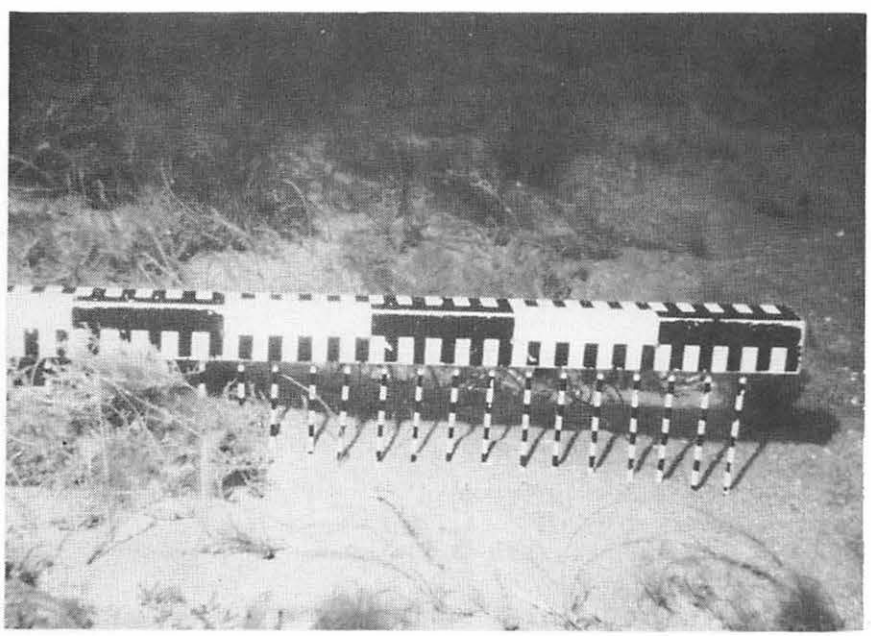


LOCATION D CORAL RUBBLE

Figure 10

BOTTOM TYPE

LOCATION E SHIPWRECK,ORANJE BAAİ.



LOCATION F GRASS BED WITH SAND PATCHES.

Figure 11

The seagrass present in Oranje Baai (out to a limiting depth of about 20 meters) is primarily the thin-bladed, tubular Manatee grass (Syringodium filiformis) which lacks the lime-secreting red algae and serpulid worms commonly living as epibionts on wide-bladed turtle grass (Thalassia testudinum). Turtle grass beds were not observed anywhere within the area. In addition to the calcareous remains of small pelecypods and other molluscs that habitually dwell within turtle grass communities, the epibionts themselves are estimated to produce more than 100 grams of carbonate per square meter of bottom per year in certain areas of Florida (Nelsen and Ginsburg, 1986). Their absence in Oranje Baai, along with Halimeda and other calcareous marine algae common to Caribbean islands, is somewhat unusual and may have significant implications regarding the sediment budget of the nearshore region and adjacent beach zone.

Nearshore Sand Thickness - **Figure 12** shows the approximate thickness of inferred surficial sand deposits in the nearshore zone of Oranje Baai as indicated by sub-bottom acoustic profiling. These thickness are as yet unverified by coring of the deposits locally. The indication given by the data presented is that a fairly substantial volume of sand exists near the 10 meter depth contour where maximum sand layer thickness varies between 3 and 6 meters. Beyond the 20 meter depth contour the indicated sand thickness decreases from 2 meters to less than 1 meter as one reaches a small shelf outlined by a large seaward bulge in the 30 meter depth contour (**Figure 1**). A dive conducted near the outer edge of this shelf at the 28 meter depth,

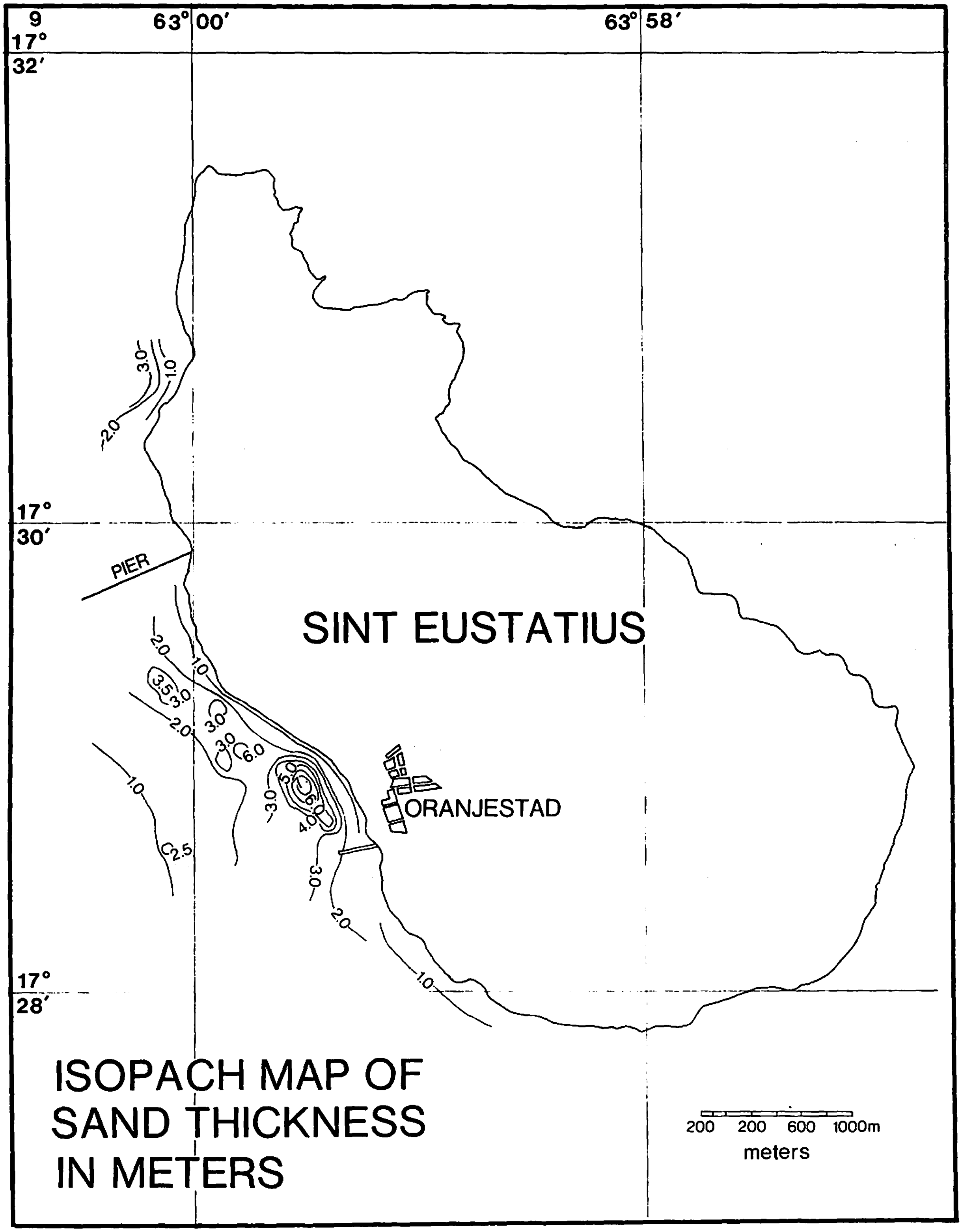
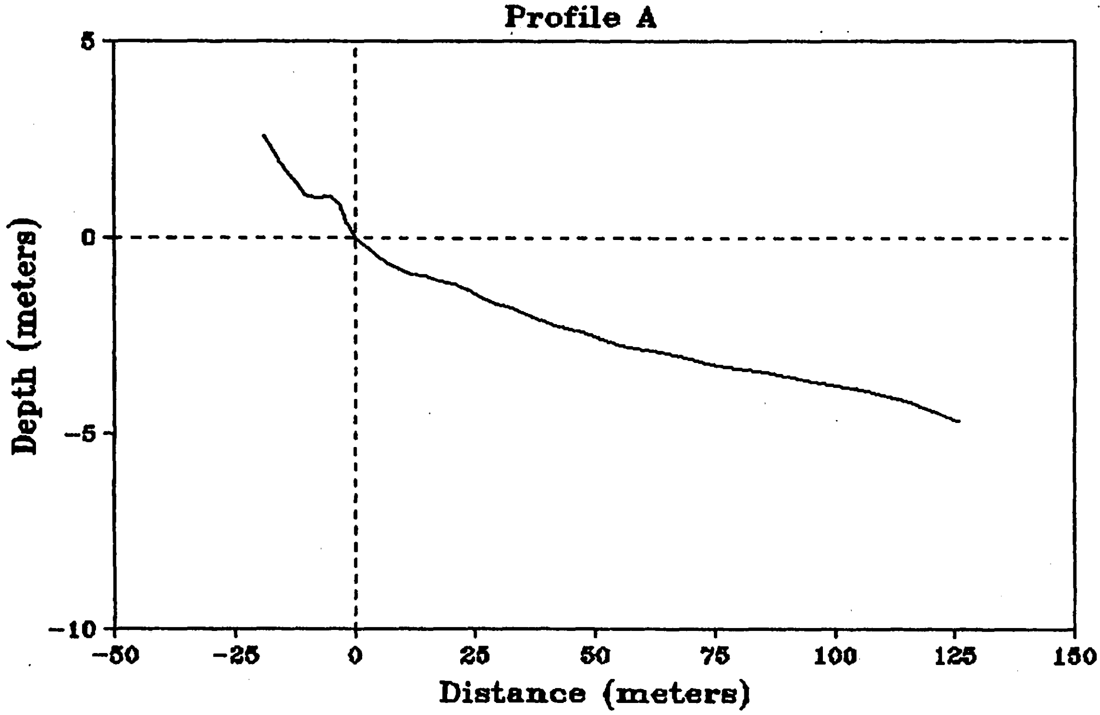

9
17°
32′
63° 00′
63° 58′
17°
30′
17°
28′
PIER
SINT EUSTATIUS
ORANJESTAD
3.0
1.0
2.0
3.5
6.0
5.0
4.0
2.5
ISOPACH MAP OF
SAND THICKNESS
IN METERS
200 200 600 1000m
meters

Figure 12

however, revealed a bottom covered by small nodules of coral rubble but virtually no sand. Sand thicknesses south of Oranje Baai are minimal and it seems unlikely that the region to the south is actively supplying sand to Oranje Baai. It is to be noted that seagrass beds cover much of the area of the deposits. This is discussed later.

Beach Profile Analysis - Three beach profiles (A,B and C) were measured at Windmill Beach on Oranje Baai and are shown in **Figures 13a - 16a**. Measurements of one of the profiles (B, **Figures 14a and 15a**) were repeated on a subsequent day as a check on the precision of the results. The primary reason for making these profile measurements was to compare them with existing models for beaches judged to be in approximate equilibrium with local hydrodynamic conditions. In particular, we wished to know whether the beach and nearshore bottom on the lee side of the island would conform to a model recently advanced for barless, reflective profiles considered typical of carbonate sand beaches in the Caribbean (Boon and Green, 1988). Quantities of beach sand required in nourishment programs will depend in part on the characteristics represented in this model. For example, a profile with a shallow bottom gradient will contain relatively more sand volume than a steeper, more concave profile that reaches greater depth at a shorter distance offshore. These types of bottom profiles are illustrated in the following diagrams.

Windmill Beach, St. Eustatius 20 July 1988



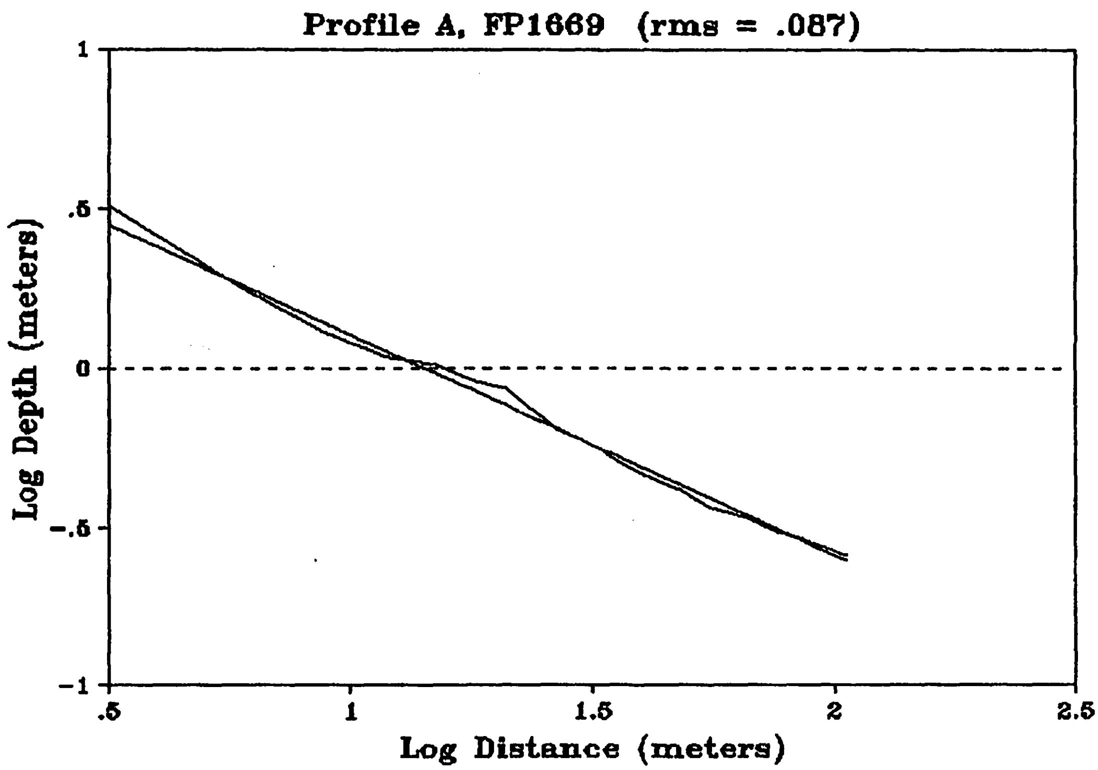


Figure 13a

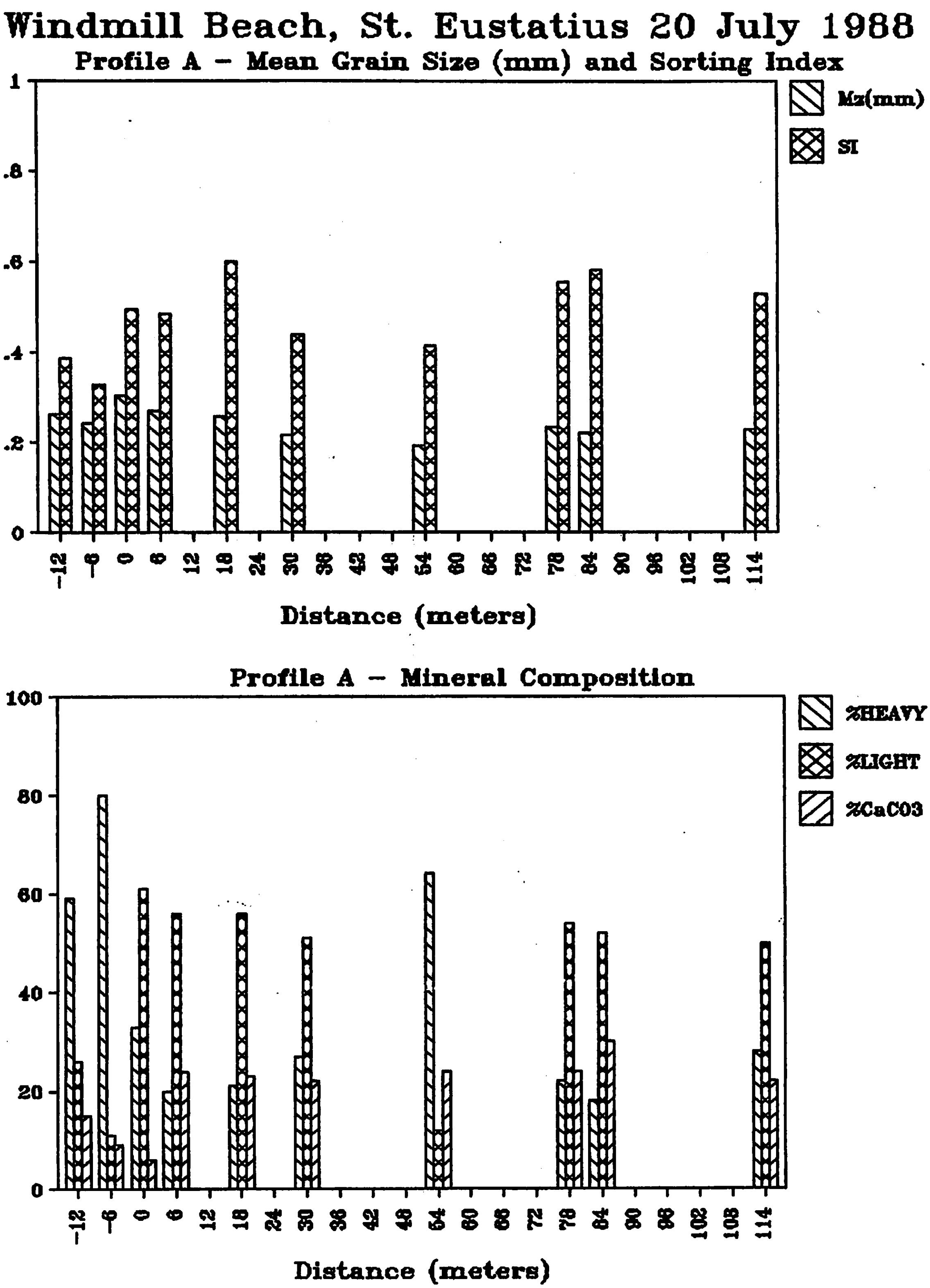

Windmill Beach, St. Eustatius 20 July 1988
Profile A - Mean Grain Size (mm) and Sorting Index
Mz(mm)
SI
1
.8
.6
.4
.2
0
-12
-6
0
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
Distance (meters)
Profile A - Mineral Composition
%HEAVY
%LIGHT
%CaCO3
100
80
60
40
20
0
Distance (meters)

Figure 13b

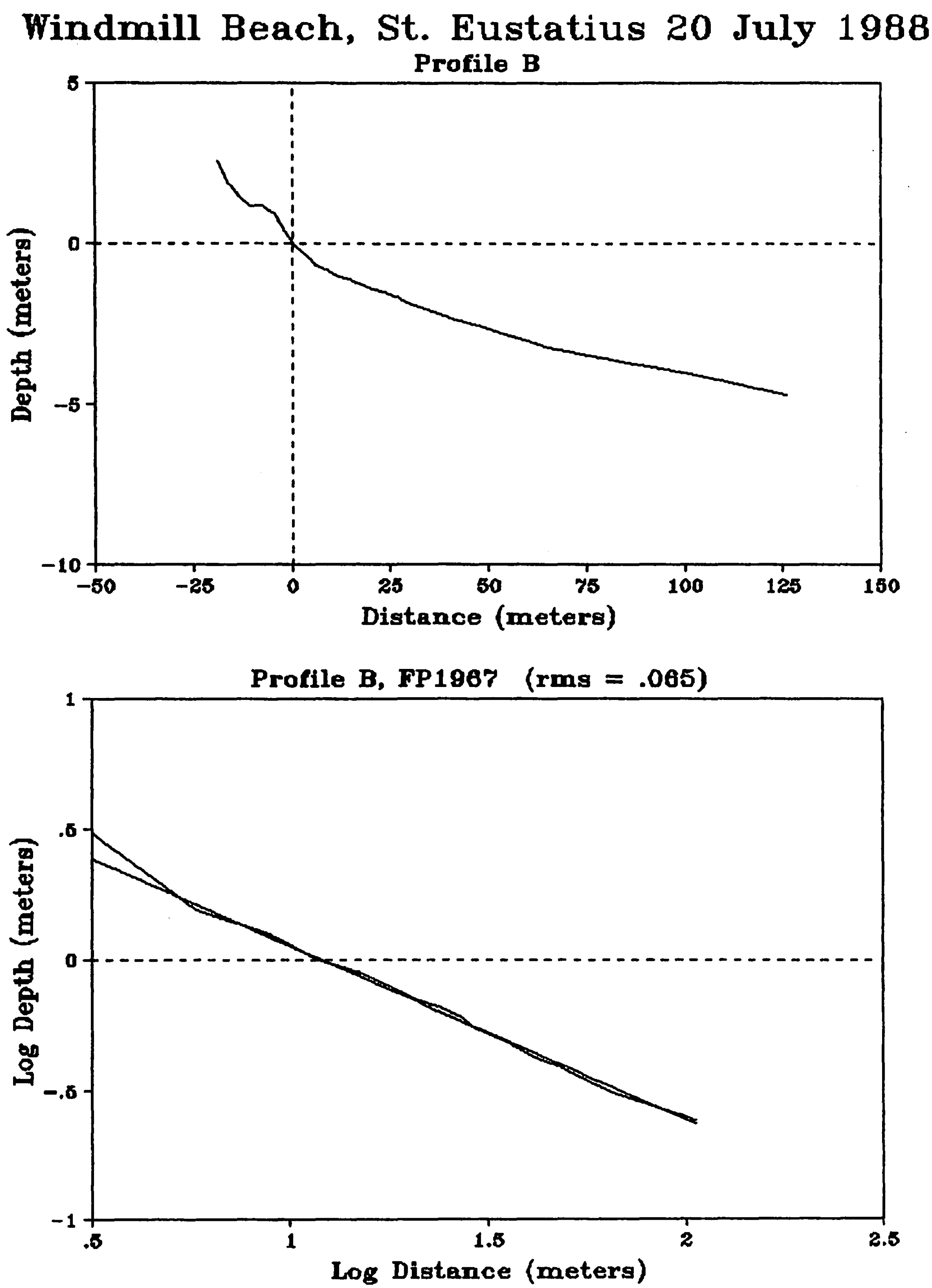
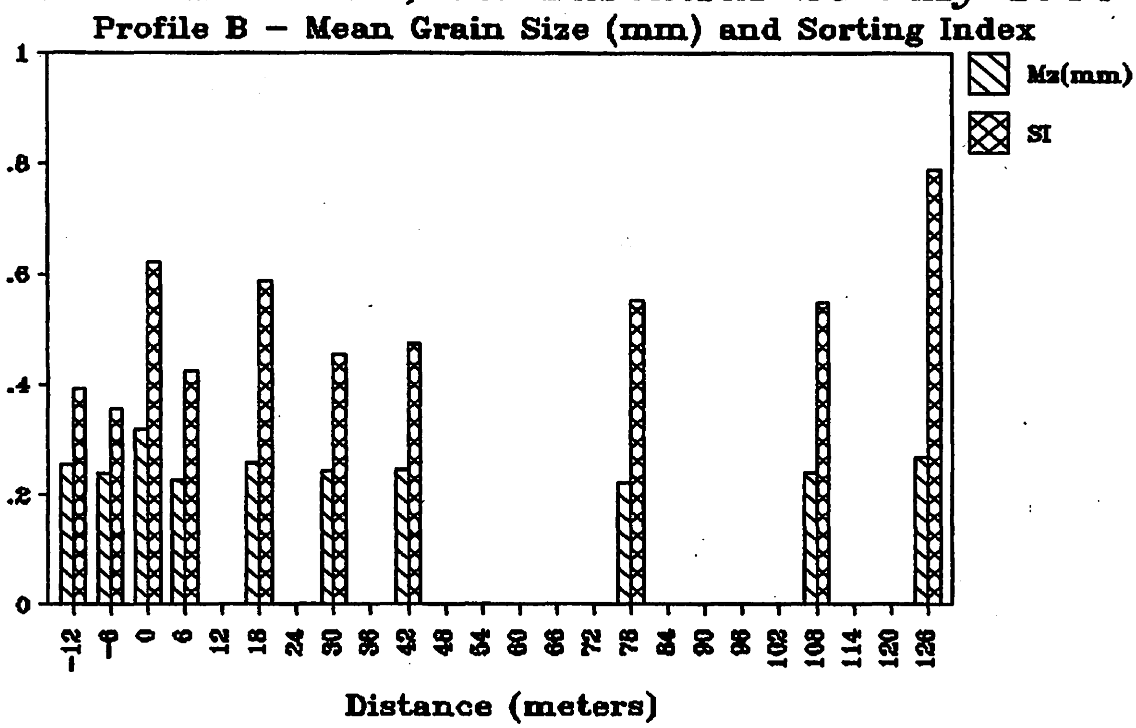

Windmill Beach, St. Eustatius 20 July 1988
Profile B
Depth (meters)
5
0
-5
-10
-50
-25
0
25
50
75
100
125
150
Distance (meters)
Profile B, FP1967 (rms = .065)
Log Depth (meters)
1
.5
0
-.5
-1
.5
1
1.5
2
2.5
Log Distance (meters)

Figure 14a

Windmill Beach, St. Eustatius 20 July 1988



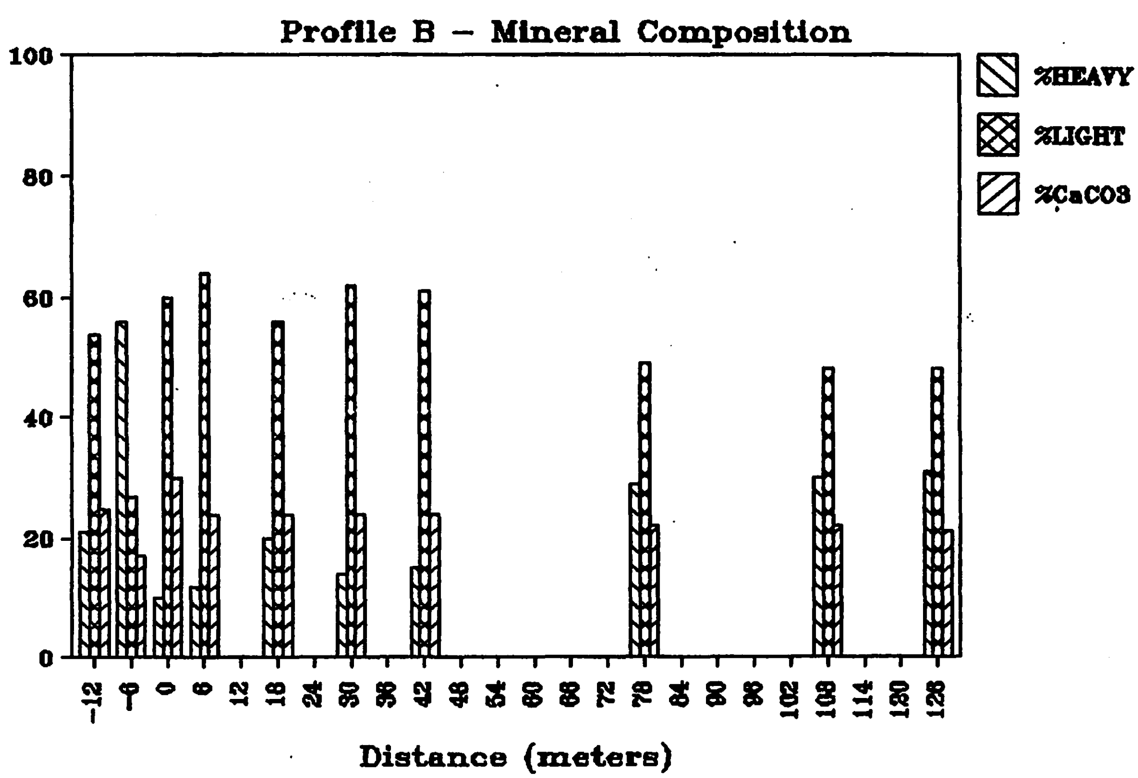


Figure 14b

Windmill Beach, St. Eustatius 25 July 1988

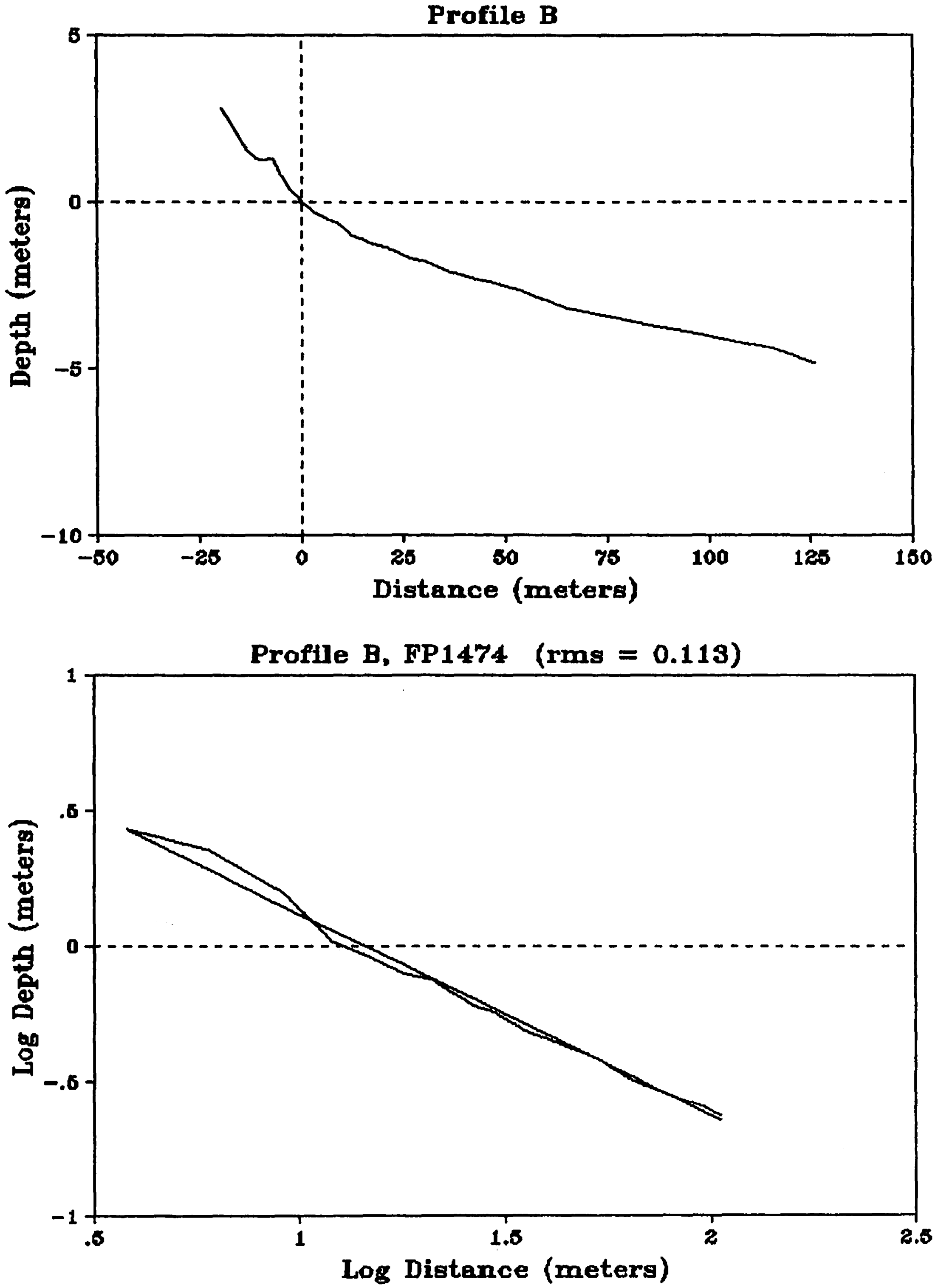
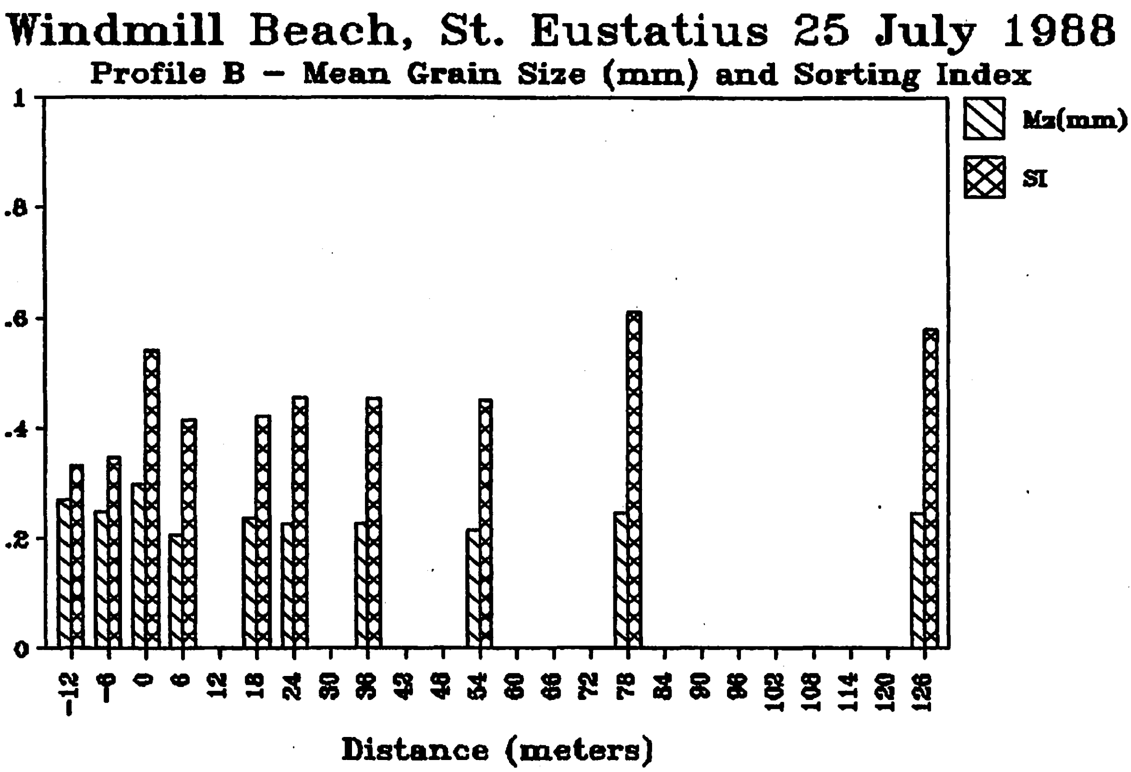


Figure 15a


Windmill Beach, St. Eustatius 25 July 1988
Profile B – Mean Grain Size (mm) and Sorting Index
Mz(mm)
SI
Distance (meters)

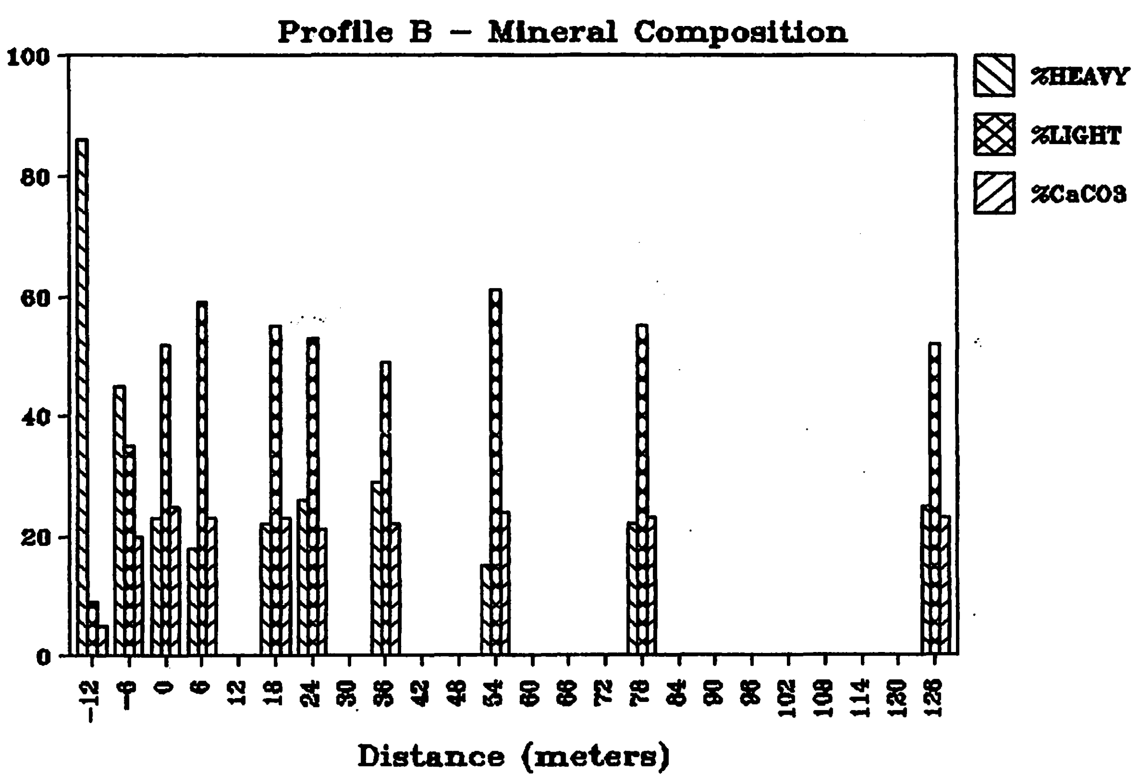

Profile B – Mineral Composition
%HEAVY
%LIGHT
%CaCO3
Distance (meters)

Figure 15b

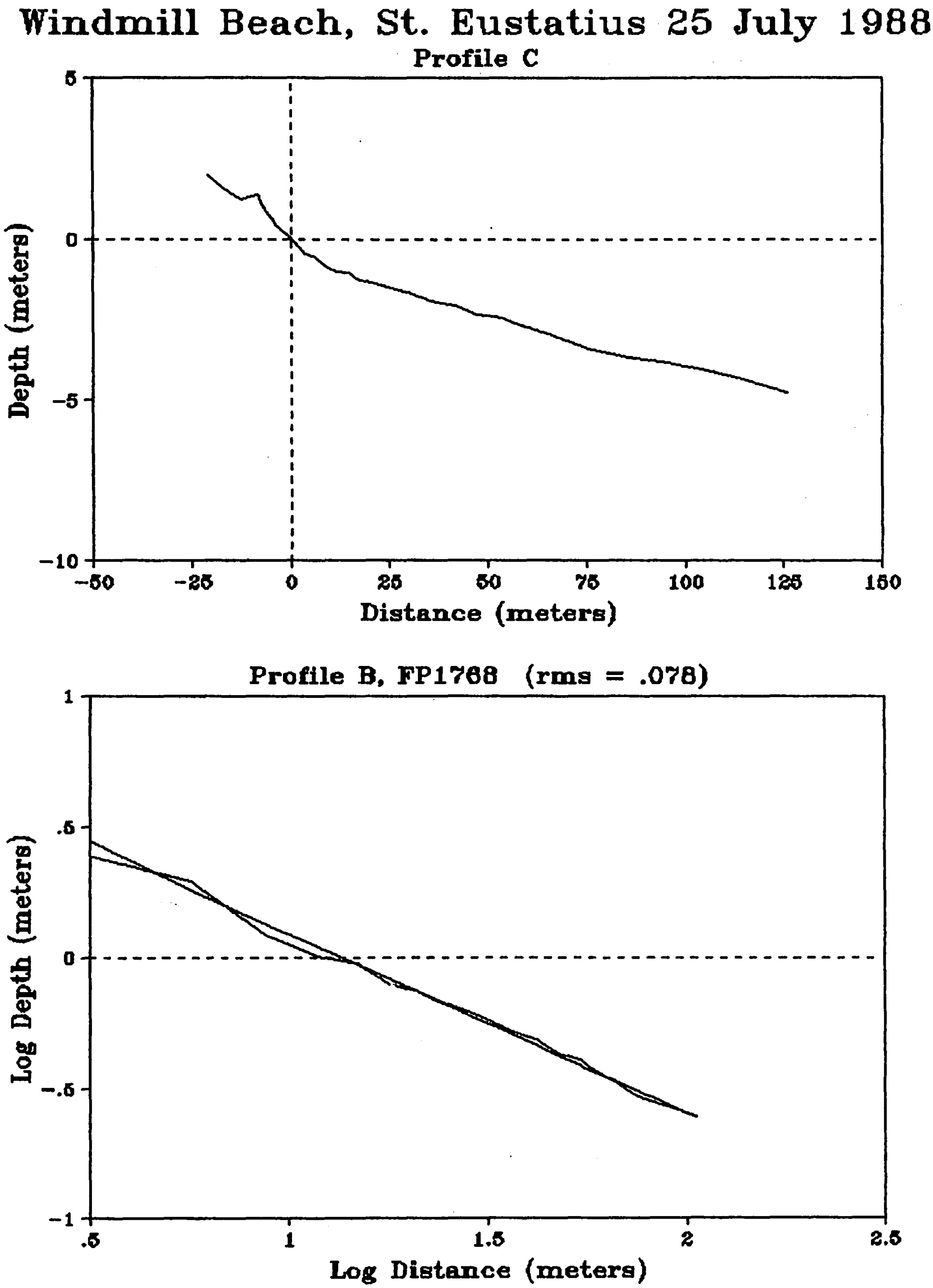
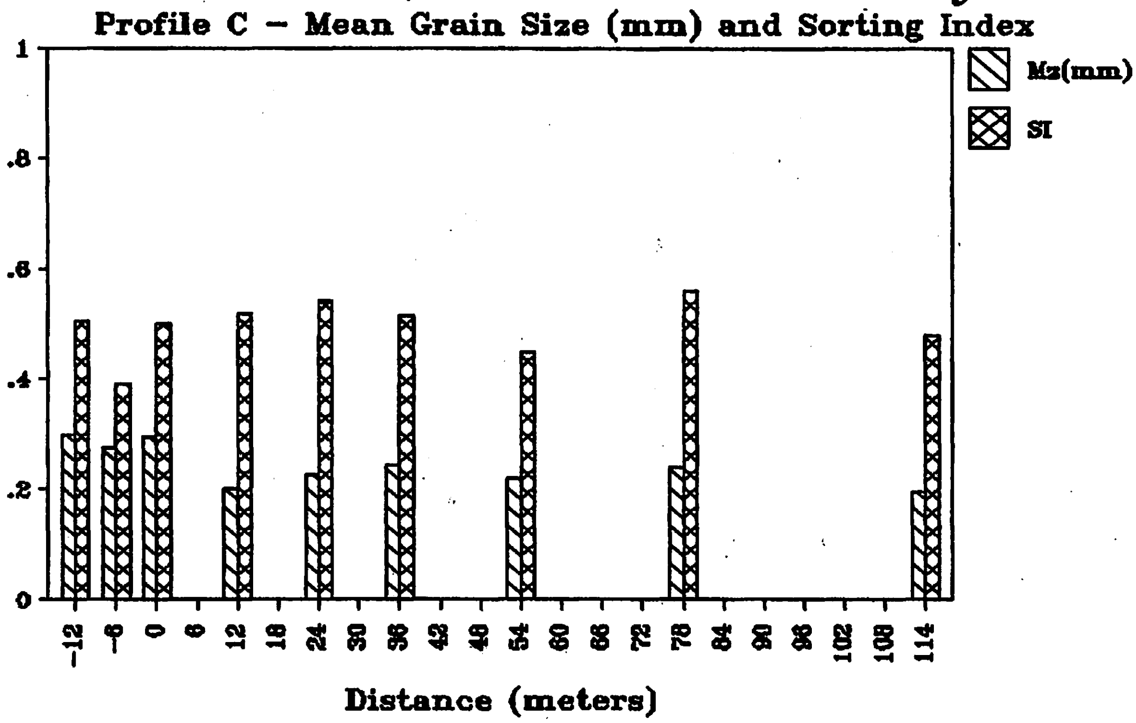

Windmill Beach, St. Eustatius 25 July 1988
Profile C
Depth (meters)
5
0
-5
-10
-50
-25
0
25
50
75
100
125
150
Distance (meters)
Profile B, FP1768 (rms = .078)
Log Depth (meters)
1
.5
0
-.5
-1
.5
1
1.5
2
2.5
Log Distance (meters)

Figure 16a

Windmill Beach, St. Eustatius 25 July 1988



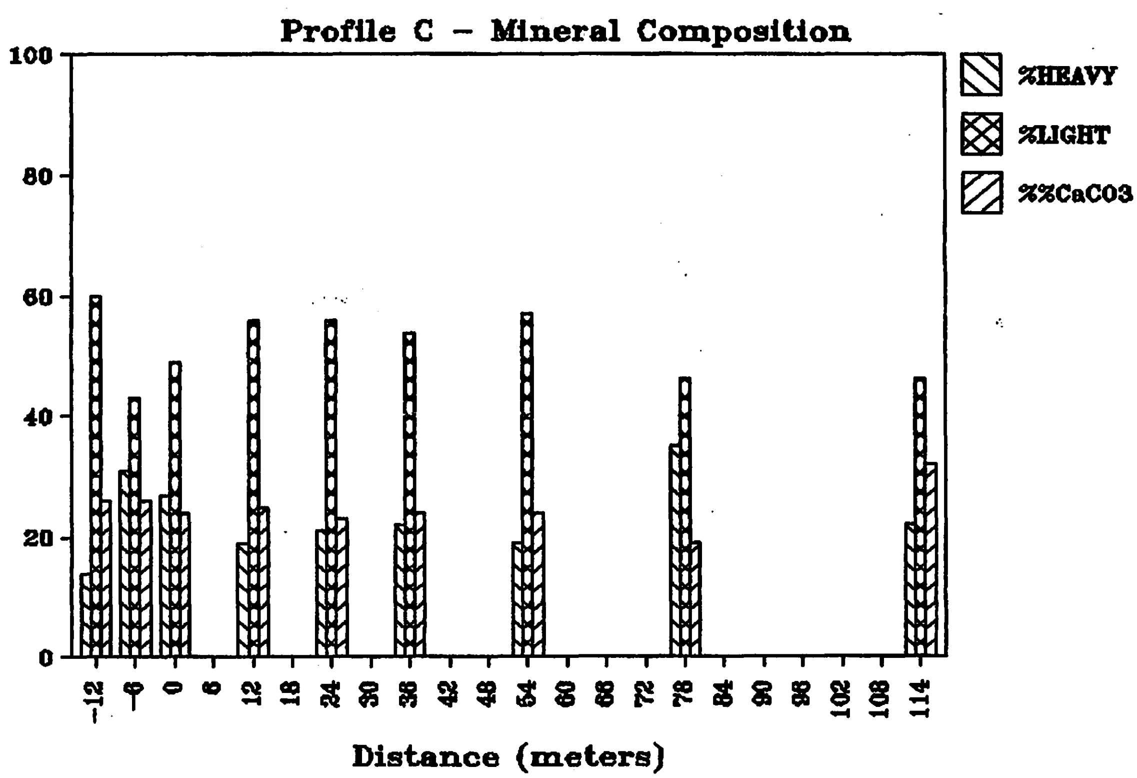


Figure 16b

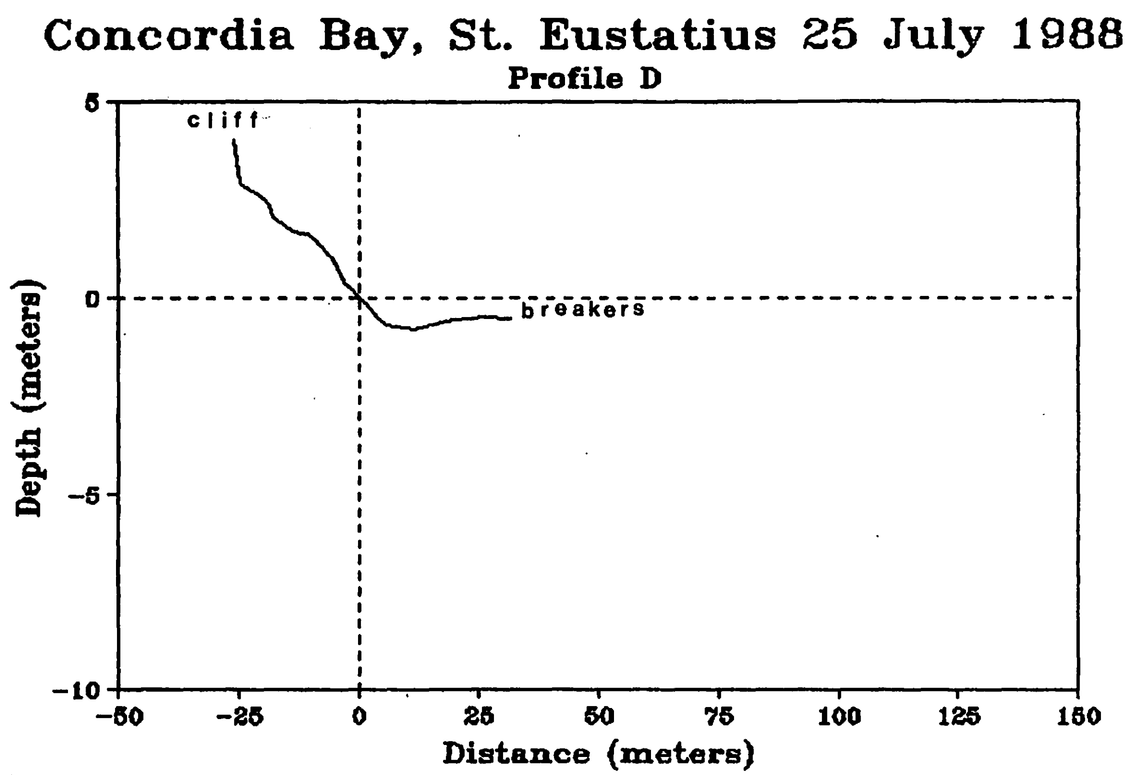

Concordia Bay, St. Eustatius 25 July 1988
Profile D
cliff
breakers
Depth (meters)
5
0
-5
-10
-50
-25
0
25
50
75
100
125
150
Distance (meters)

Figure 17

The general model developed by Dean (1977) is

$$h = A x^{m}$$

where h is the depth at a horizontal distance, x, from the shoreline and A, m are constants found by a least squares line of best fit to field data plotted on log-log axes. Dean (1977,1983) reported a value of m = 0.67 as typical of quartz sand beaches on the U.S. East and Gulf coasts with various values of the coefficient, A, depending on grain size. Boon and Green (1988) found m = 0.55 to be more representative of low-energy, carbonate sand beaches in the Caribbean. Essentially, m = 0.55 defines a steeper, more concave profile than m = 0.67; beyond a certain point, steep profiles cause incident waves to reflect from the beach face rather than to plunge and break dissipating their energy within a well-defined surf zone.

Our profiles for Windmill Beach on Oranje Baai show a very good fit to the Dean model given above but with closer agreement to m = 0.67 rather than to m = 0.55. Lines fitted to the measured profiles shown in **Figures 13a - 16a** are identified by their labelling; for example, FP1967 refers to the fitted profile with A = 0.19 and m = 0.67 (e.g., Profile B, 20 July, 1988). The reason for this apparent departure from Boon and Green's finding for carbonate beaches is unclear but is believed related to the fact that beaches on St. Eustatius consist of non-carbonate, volcanic sand rich in heavy minerals as discussed below. This composition, along with possible grain shape differences, may account for the slightly shallower profiles observed in this case.

Among other things, smaller beach slopes imply that a greater volume of sand may be required to maintain an equilibrium beach profile. Using volcanic sand, this may also depend on the hydraulic equivalent grain size (or more directly, the grain settling velocity) and sorting characteristics of the source material selected.

The beach at Concordia Bay does not exhibit a profile fitting the model of Dean. Located on the windward side of the island on a coastal segment with no fringing reef or other coastal barrier, it possesses a well-developed nearshore bar and an energetic surf zone with spilling breakers in the outer surf zone (**Figure 17**). There is a steep cliff terminating the backshore zone. The cliff is actively eroding and supplying ferromagnesian sands to the beach at this location, making it one of the few beaches on the island with adequate sand nourishment from an identifiable source.

<u>Sand Grain Size and Mineral Type</u> - **Figures 13b - 16b** display the grain size and sorting data as well as the mineral composition of the bottom sediments sampled along Profiles A, B and C in Oranje Baai. With respect to their textural properties, these sediments are somewhat unusual in that the mean grain size is somewhat small and surprisingly uniform in the onshore-offshore direction, varying between 0.20 and 0.30 mm (fine to medium sand) and most often between 0.22 and 0.25 mm (fine sand) in the sampled locations, without the usual seaward-fining trend observed on most beaches. The bottom seaward of Windmill Beach consisted of fine, loose sand with wave-induced bedforms out to a

distance of approximately 100 meters from shore where thin grass beds (Syringodium filiformis) began to occur. The sorting index indicates a moderate to well sorted sand out to this point. Samples of beach sand collected at Concordia Baai indicate essentially the same textural characteristics as those of Oranje Baai.

With regard to mineral composition, beach sands at Oranje Baai are not as uniform as their textural properties suggest. Between 60 and 80 percent of the backshore and beach face sand at Oranje Baai, as well as Concordia Baai, consists of ferromagnesian minerals with lesser quantities of feldspar-rich light minerals and a trace of carbonate material (see **Figures 13b - 16b**). In most samples, the bulk of the ferromagnesian minerals present consist of magnetite, hypersthene and augite. Seaward of the surf zone along the nearshore bottom at Oranje Baai, the light minerals tend to dominate (50 - 60 percent by weight) with carbonate sand fractions increasing to about 20 - 30 percent of the sediment by weight. The increased carbonate component is attributed to biogenic production offshore which is nevertheless limited compared to other tropical areas.

Hydrodynamic factors in conjunction with mineral density differences are believed responsible for the observed tendency for light and dark minerals to separate themselves between the subaqueous and subaerial portions of the profile, respectively. The abundance of the dark (denser) minerals on the subaerial beach can be explained by the fact that such grains have a greater hydraulic equivalent size (greater settling velocity) than lighter (less dense) grains of the same physical size. On beaches with uniform mineral density but varying grain size, coarser grains tend to occur in the subaerial as opposed to the subaqueous (nearshore) region. Why is this important? The hydraulic equivalent grain size of sand selected for beach nourishment will be key in terms of its ability to remain on the subaerial beach after its placement there.

Microscopic examination of nearshore bottom sediment samples revealed no evidence of the remains of calcareous marine algae (e.g., Halimeda sp.) which often contribute 60 percent or more of the sand on Caribbean beaches (Folk and Robles, 1964). No living specimens of carbonate-producing algae were observed on the nearshore bottom nor did we observe an abundance of small bivalved organisms dwelling in the grass beds that began approximately 120 meters seaward of the shoreline. The source of the carbonate material probably consists of coral fragments produced in the areas adjacent to Oranje Baai.

DISCUSSION

Areas of Extraordinary Environmental Sensitivity. While the entire island and its coastal water must be considered as an area of environmental sensitivity, our comments are directed to those areas along the coastal fringe, areas that should be given particular consideration as developments on the island proceed.

Coral Reef Communities. Coral reefs fringe much of the island in intermediate water depths (St. Eustatius Preliminary Data Atlas, 1980). Our particular concern addresses those in very shallow water. **Figure 18** depicts the location of the obvious nearshore coral reef communities determined from our aerial photography and diver transects. Immediately adjacent to the shoreline, these reefs are particularly sensitive to sediment influx from onshore developments. Development of the upland adjacent to these areas should employ extraordinary measures to inhibit the entry of sediments into the coastal waters.

Seagrass Beds. Seagrass bed exist in three areas adjacent to the island. These are primary nursery habitats for juvenile conch, spiny lobsters, and commercial species of fish (R. Lipcius, VIMS, personal communication, 1989). Locations of the seagrass beds are shown in **Figure 19** as determined from sidescan sonar and diver surveys. One extensive grass bed occurs between the cargo pier in Oranje Baai and the oil pier at Tumbledown Dick Bay. Another major seagrass nursery habitat occurs off White Wall in depths of 12 to 30 meters (R. Lipcius, VIMS, personal communication, 1989). Seagrasses require light for photosynthesis. Habitat destruction can be caused by high turbidity if light penetration is sufficiently reduced. Moreover, it has been demonstrated (Herrnkind et al., 1988) that post-larval spiny lobster have reduced recruitment to bottom habitats undergoing siltation.

Turtle Nesting Area. The windward beaches of Borgine and Schildpadden Bays are reported turtle nesting sites (St. Eustatius

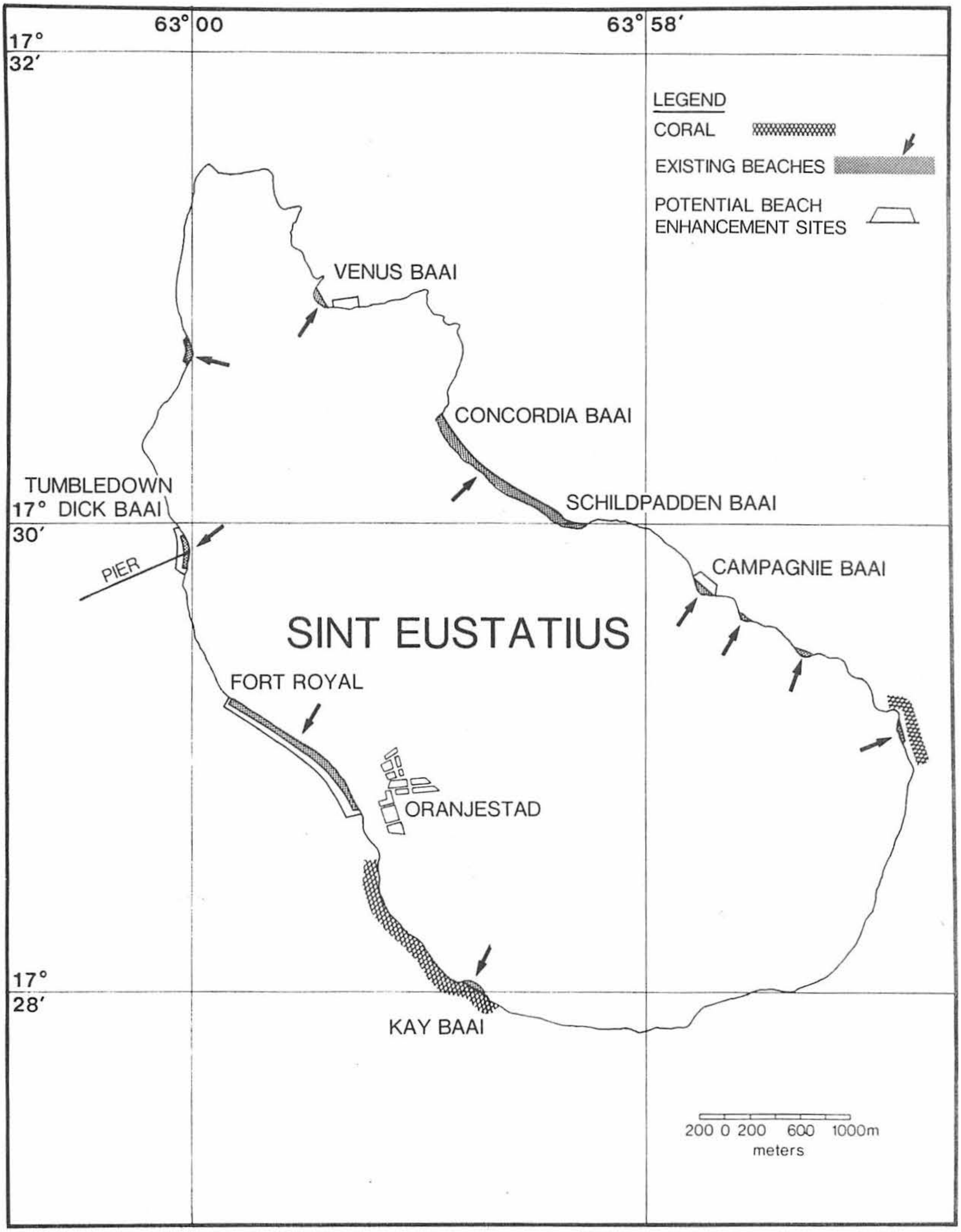

63° 00
63° 58′
17° 32′
17° 30′
17° 28′
LEGEND
CORAL
EXISTING BEACHES
POTENTIAL BEACH ENHANCEMENT SITES
VENUS BAAI
CONCORDIA BAAI
TUMBLEDOWN DICK BAAI
SCHILDPADDEN BAAI
PIER
CAMPAGNIE BAAI
SINT EUSTATIUS
FORT ROYAL
ORANJESTAD
KAY BAAI
200 0 200 600 1000m
meters

Figure 18

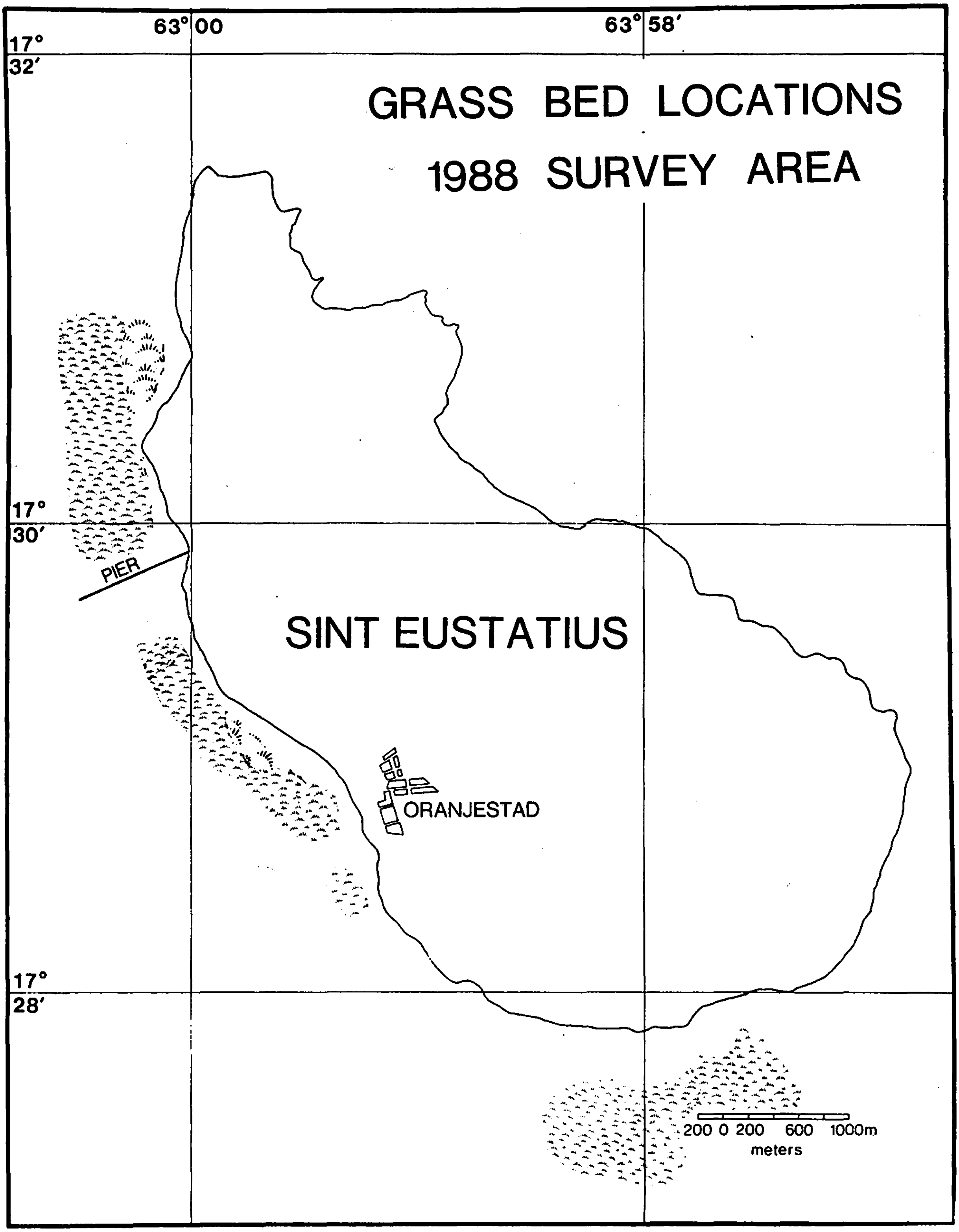

63° 00
63° 58′
17° 32′
GRASS BED LOCATIONS
1988 SURVEY AREA
17° 30′
PIER
SINT EUSTATIUS
ORANJESTAD
17° 28′
200 0 200 600 1000m
meters

Figure 19

Preliminary Data Atlas, 1980). As such, particular attention must be given to the compatability of development and the nesting habitat.

Dangers of Oil Spills. The handling of crude oil and its refined products always entails risk to the coastal environment. Risk can be minimized by assurance that necessary containment strategies are in place. In the case of the handling facility at Tumbledown Dick Bay, the island government should ascertain whether sufficient emergency plans and equipment are in place. This should include verification that the dikes surrounding the storage tanks are sufficient to contain the volume of the tanks under conditions of sudden collapse. This is particularly important for those tanks close to the water.

Effects of Global Climate Change. Significant changes in global climate are projected due to enhancement of the emission of "greenhouse gases" into the atmosphere. Predictive models are as yet unable to provide reliable regional predictions. There is considerable international effort towards improving the predictive capability with a goal of reliable regional predictions within five to ten years. However, these are factors which should be considered in long-range planning of coastal developments. Sea level is projected to rise; estimates vary, but many project an increase of about one meter by the Year 2050. The frequency of tropical storms may increase. These factors have obvious ramifications fore St. Eustatius.

Extractable Sand Resources. As previously discussed, shallow, sub-bottom seismic surveys indicate sediment horizons of substantial thickness (3 to 6 meters) which we infer to be sandy material. Borings will be required to verify the thickness of the deposits and to adequately characterize the material. Only after verification should exploitation of the deposits be considered.

Should future work verify the deposits, the fact remains that ecologically important seagrass beds cover much of the surface. Particular attention should, therefore, be devoted to exploitation of those areas with sparse seagrass as the first option. While recolonization of the substrate is likely, the rate of recolonization is unknown. Perhaps even more important is the reduction in recruitment of postlarval spiny lobster to areas with fine-grained siltation. This makes it particularly important to minimize turbidity during any sand mining project or activity.

<u>Preliminary Assessment of Coastal Sites.</u> St. Eustatius remains particularly significant in the Caribbean Islands for its richness in documented historical and archaeological sites. Amidst tendencies for rapid tourism development on neighboring islands, the citizens of St. Eustatius are faced with the challenge of balanced development which will provide economic advancement while preserving their history. Indeed, such preservation is important to the whole Caribbean region and the adjacent Americas.

Balanced development of the fringing coastline will also be important as natural, sandy beaches are relatively scarce. Within a perimeter length of about twenty-two (22) kilometers, only about three (3) kilometers are natural, sandy beaches (**Figure 18**). Aside from a few small pocket beaches, most of the beach length is divided between those in Oranjestad Bay on the leeward side and Concordia to Schildpatten Bays on the windward side of the island. These beaches are on opposing sides of the low "saddle" elevations between the higher "horns" of volcanic peaks. The sediment supply to these beaches are ash layers of ferromagnesian minerals. Most of the remainder of the island periphery is expressed by strong topographic gradients which restrict access to the shoreline. Thus, by virtue of the island's physiography, St. Eustatius has limited area for beach- oriented tourism and/or marine facilities. Mindful of this limitation, it is particularly important to be watchful of the compatability of development thrusts.

Beaches. It would be presumptuous to offer firm guidelines for coastal development from our limited study. Rather, we offer suggestions based upon a "practiced eye" in coastal processes and in Caribbean coastal development. We address beaches from two viewpoints. Beaches provide a most effective means of dissipating wave energy and thus can inhibit erosion of the fastland. From another viewpoint, beaches are a means to provide access to seaside sunning and bathing - the Caribbean image. We term these respectively as "protective" and "development" beaches realizing that a protective beach can serve both purposes.

With respect to bathing beaches planned to attract tourism, the mineralogy of Caribbean beaches is probably significant. Most of the international tourist clientele associate Caribbean beaches with "white sand beaches;" geologically these are beached derived from coral or other carbonate fragments. The beaches of St. Eustatius are, for the most part, composed of darker, volcanically derived materials. Functionally, the darker sands hold a higher heat from the sun. In the cases where we speak of beach enhancement via the addition of sand, the choice of beach materials is left to the designer, mindful of the purpose.

Finally, and most importantly, our assessment refers to beach development that requires a minimum of structural controls. Given enough hard structural control, an artificial beach can be emplaced in virtually any location. Our purpose is to comment on those sites requiring a minimum of structural control. As well, this preliminary screening has omitted cases where accessibility to the shoreline is limited by steep upland topography. The resulting preliminary screening leaves the following set, as shown in Figure 18.

1. Oranjestad Baai. The coastal reach between Fort Royal and the Gin House in Lower Town, Oranjestad, would benefit from emplacement of a widened beach. With respect to Lower Town, a widened beach would offer protection against erosion of the

historical waterfront area. As will be later described, there are ample offshore sand resources for such nourishment. A series of groynes would be required to hold a reasonably stabilized beach. Extension of the beach length to Fort Royal could be achieved in steps as requirements for bathing beach area increase. The connectivity between beach enhancement and the multipurpose port terminal is later discussed.

Detailed planning of beach enhancement will require additional information, as described later.

2. Tumbledown Dick Baai. This pocket beach is presently occupied by the oil terminal pier and tank farm. There is a small, attractive beach which could be enlarged. It is likely that small terminal groynes would be required.

3. Venus Baai. On the windward side of the island, Venus Baai appears from our photography as characterized by a steep or scarped rock rubble beach. With a convergent geometry, wave action tends to be amplified in approaching the shore, and compensating return flow via rip currents are evident at the apex of the embayment.

In spite of the aforementioned characteristics, it may be possible to emplace a sandy beach. Due to the high upland topographic gradient at the apex of the embayment and the complex surf zone processes, which could endanger bathers' safety, we suggest that any beach emplacement focus on the southern flank, **Figure 18**. This location will require structural control to lock the placement. The relatively mild upland topography on the south side of the apex also provides the most direct access.

Design of an artificial beach in Venus Bay will require field observation of the surf zone processes and careful analysis.

4. Concordia--Schildpatten Baai Beach. This beach, approximately 1.5 kilometers in length, increases in backshore width from south to north. Sand is being supplied by active wave erosion of the ash and cinder bluffs along the southern portion of the beach.

The wave energy level at this site is relatively high, with a broad, dissipative surf zone. Ground level and aerial observations indicate the presence of return flow rip current cells. These conditions present some hazards to a casual bather not familiar with rigorous surf zone conditions. Beach nourishment is not needed at this site since erosion of the backshore bluff provides an ample sand supply.

5. Campagnie Bay. On the windward side, Campagnie Bay is the northernmost of three, small symmetrical embayments. Each embayment has a small beach at its apex. All are surrounded by relatively high steep bluffs. Campagnie Bay is somewhat more

accessible along the northern flank. An expanded beach could be emplaced. It is likely that flanking terminal groynes would be required to assure stability.

Multipurpose Port Facility: Environmental Concerns. We take our understanding of the phased port development project at Oranjestad from the document entitled, "Port of St. Eustatius: Multipurpose Terminal, Programme of Requirements," January 1989, prepared for the Department of Finance. Project implementation is advanced for phased construction. Phase I will provide a general cargo port. The existing open-pile pier (Charles Woodly Pier) would be replaced by a shorter, solid fill, breakwater-roadway. Relatively minor amounts of dredging are required (**Figure** 20, taken from the aforementioned report).

Phases II and III of the project address a container transhipment facility. The breakwaters would be sequentially enlarged to provide a container stacking area, additional berthing, and a sheltered leeward area. Phase II involves dredging an access channel to a depth of 7.5 meters, while Phase III involves dredging an access channel and 300 meter diameter turning basin to a depth of 12 meters. It is proposed that the dredged material would be used as fill to construct the container stacking area.

The environmental issues addressed herein concern potential impact of the project on:

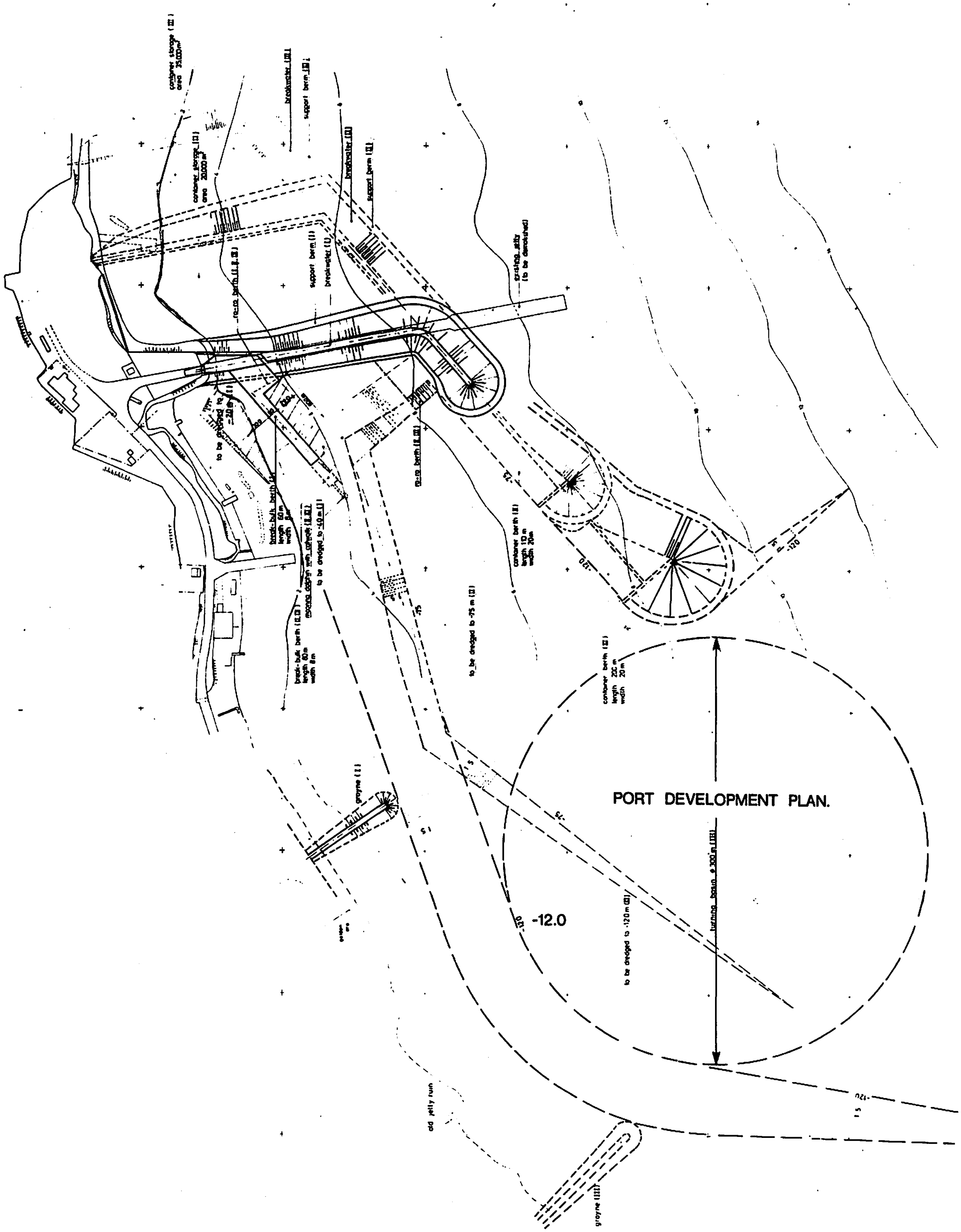

PORT DEVELOPMENT PLAN.
-12.0
container storage (III) area 35,000 m²
container storage (II) area 20,000 m²
ro-ro berth (I, II, III)
breakwater (III)
support berm (III)
support berm (I)
breakwater (I)
breakwater (II)
support berm (II)
to be dredged to -2.0 m (I)
break-bulk berth (I) length 60 m width 8 m
break-bulk berth (II, III) length 60 m width 8 m
mooring dolphin with catwalk (II, III)
to be dredged to -4.0 m (I)
groyne (I)
old jetty ruin
ro-ro berth (II, III)
to be dredged to -7.5 m (II)
container berth (II) length 110 m width 20 m
existing jetty (to be demolished)
container berth (III) length 200 m width 20 m
to be dredged to -12.0 m (III)
turning basin ø 300 m (III)
groyne (III)

Figure 20

1. The nearshore coral reefs (**Figure 18**) which are within several hundred meters south of the existing cargo pier.

2. The seagrass beds north of the project which would be destroyed by Phases II and III of the project. There could be additional impacts arising from turbidity generated during dredging and/or breakwater construction.

3. Water quality.

4. The beach and shore front between Lower Town, Oranjestad, and Fort Royal to the north.

Coral Reef Community. The nearshore coral reefs to the south of the pier which continue to Kay Bay represent a limited but important marine habitat. Aside from their ecological value, these coral platforms offer a valuable attraction to tourists; they are one of only a few areas on the leeward side of the island where swimmers using snorkels can visit a living reef community.

Coral reef communities are highly vulnerable to sedimentation impacts. It will, therefore, be particularly important that the introduction of fine grained sediments (silts and clays) be strictly controlled during construction, even Phase I construction.

Seagrass Beds. The seagrass beds of Oranjestad Baai are a very important, and perhaps critical, nursery habitat for the juvenile conch and spiny lobster and some finfish species. These beds are particularly important to any program of artificial stock enhancement for lobster and conch. Phase III construction of the access channel and turning basin would destroy a substantial fraction of the seagrass beds. If the post-dredging substrate is sandy, eventual recolonization by seagrass can be expected. Given recolonization and pristine water quality, the area may continue to serve as a nursery area for juvenile lobsters and conch. The ecological cost and economic loss from fisheries development must be considered as plans for implementation proceed. The final project design should address whether shipping access can be achieved with less loss of seagrass habitat.

In addition to the direct loss from dredging (and perhaps even more important), there is the additional impact on seagrass areas of fine grained (silt and clay) fallout material from plumes created during dredging or from breakwater construction. Phases II and III construction should utilize dredging techniques which minimize the creation of turbid plumes which will rain fine sediments onto the grass beds. In addition, all possible steps should be taken to minimize turbidity during breakwater construction.

Water Quality. Dredging depressions in the sea floor have the potential to impact local water quality. In these situations, circulation may be restricted, and benthic biological oxygen demand could result in severely depressed dissolved oxygen content in the basin waters. Phase III of the project involves dredging a long access channel and a large turning basin to a depth of 12 meters. The turning basin intersects natural water depths of 10 to 11 meters, which may offer sufficient exposure to avert water quality degradation. However, the inner portion of the access channel penetrates into relatively shallow water depths of 3 to 4 meters. This shore parallel section may constitute a significant depression, and water quality degradation is likely.

Interaction with Beachfront of Oranjestad. At present, the open pile cargo handling pier has little effect on the direction of incoming wave energy. Installation of the solid-fill breakwater will change, via wave diffraction and refraction, the local wave patterns. Changes in the local wave patterns will influence beach behavior. Detailed wave diffraction/refraction analyses will be required to ascertain the degree of change in wave characteristics and to estimate the effects on the beachfront.

Application of Results to Oranje Baai Beaches - Unless appreciable sand returns via natural circumstances, the present sand starved conditions will continue. Emplacement of a beach to protect the historical waterfront and to provide recreational access would then be warranted. The extent and timing of the beach fill would depend upon the schedule of port facility construction.

1. Assuming that Phase II or III construction would not be

initiated for several years, a nourished beach could be emplaced between a point south of the Golden Era Hotel and Smoke Alley. Phase I port construction calls for installation of a groyne just south of the Golden Era which would serve as a terminal groyne to retain the beach fill.

In order to inhibit the loss of beach fill, a system of groynes is suggested. Recommendations as to the amount of beach fill and groyne layout cannot be offered without further study, particularly the execution of detailed wave refraction analysis.

2. Phase III port construction calls for a deep access channel within 100 meters of the shoreline (**Figure** 20). Under these circumstances, it is unlikely that a beach could be maintained along the adjacent shoreline due to offshore sand losses into the channel. The combination of incident natural wave energy and that due to ship wakes will probably require hardening the shoreline with stone.

3. If additional recreational beach length is desired, the beach fill could be extended to the Fort Royal hillside. Again, further study will be required to specify the amount of beach fill and structural controls to inhibit loss of sand. Phase II, and particularly Phase III, port construction entail dredging large quantities of material. Should this material be suitable for beach nourishment, it might be considered for that application.

Careful evaluation of the size, sorting and mineralogy of the sand deposits will be important since medium to coarse sands can generally sustain a steeper beach face slope and remain in place with less volume loss. As noted earlier, the quartzose and carbonate-rich sands reflect sunlight and absorb less heat than dark-colored grains, making the beach more comfortable to walk on.

Recreational Beach Development, Oranje Baai - Depending on utilization, there is at least one location in Oranje Baai with limited potential for enhancement, particularly as a bathing beach. Based on the data at hand, the northernmost segment appears to have the greatest potential for development as a swimming and bathing beach. The optimal segment in our view is the one centrally shown in **Figure 2a,b** extending from just south of Interloper's Point to a point approximately 600 meters in the direction of Fort Oranje where old rock walls of the former Lower Town begin to intersect the present shoreline.

Diver reconnaissance and measured beach transects (Windmill Beach, **Figures 13a - 16a**) show that the nearshore bottom within the recommended segment is free from obstructions, is sand-covered out to a distance of about 110 meters from shore, and conforms well to a theoretical equilibrium profile which allows some of the characteristics of an extended beach to be predicted in advance. We suggest, however, that a certain amount of containment structure (e.g., terminal groynes) may be required to prevent excessive loss of sand introduced on or near the beach face, depending on hydraulic equivalent grain size and sorting. Careful planning and professional advice will be required to determine the dimensions of the needed structures as well as the characteristics of the sand fill material selected to nourish the beach.

RECOMMENDATIONS FOR ADDITIONAL STUDIES

Verification of Sand Deposits. The results from the shallow seismic survey indicate sediment horizons which are likely sandy material. Coring will be required to verify deposit thickness and for evaluation of grain size characteristics.

Oranje Baai Beaches. It is important that a more complete understanding be gained on the temporal variability of the beaches and on the sand sources, sinks, and pathways of sand transport. Such understanding is fundamental to predicting the fate of any beach nourishment project. Studies needed include:

1. Computer Modeling of Waves. In the first instance wave refraction models should be conducted to determine how sensitive the direction of sediment transport might be to small changes in seasonal winds impinging on the windward side. Following this, the output of the large scale model could be used for detailed modeling in the Oranje Baai area. Finally, wave modeling of the proposed port facility needs to be performed.

2. Field Measurements of Wave and Currents. In-situ measurements of waves and currents should be acquired during different seasons of the year. This information, coupled with wave refraction/diffraction model results, will provide required insights into the sediment transport processes responsible for

fluctuations in beach sand volume.

3. Beach Surveys. A program of long-term beach profiling should be established. Coupled with the studies mentioned above, a reasonably clear picture of beach behavior will result.

Other Island Beaches. Field measurements and computer wave modeling will be required at other beach sites if those sites are considered as candidates for beach nourishment projects.

REFERENCES

Boon, J.D. and M.O. Green, 1988. Caribbean beach-face slopes and beach equilibrium profiles. Proceedings, 21st Coastal Engineering Conf., Malaga, Spain, 1618-1630.

Dean, R.G., 1983. Principles of beach nourishment. In: P.D. Komar (Ed.), CRC Handbook of Coastal Processes and Erosion, CRC Series in Marine Science, Chapter 11, 217-231.

Folk, R.L. and R. Robles, 1964. Carbonate sands of Isla Perez, Alacran Reef Complex, Yucatan. J. Geol., 72:255-292.

Herrnkind, W.F., M.J. Butler IV, and R.A. Tankersley, 1988. The effects of siltation on recruitment of spiny lobsters, Panulirus argus. Fishery Bulletin, 86:335-338.

Hine, A.C. M.W. Evans, R.A. Davis, Jr. and D.F. Belknap, 1987. Depositional response to seagrass mortality along a low-energy, barrier island coast: west-central Florida. J. Sed. Petrol., 57:431-439.

Kjerfve, Bjorn, 1981. Tides of the Caribbean Sea. J. Geophys. Res., 86:4243-4247.

Nelsen, J.E., Jr. and R.N. Ginsburg, 1986. Calcium carbonate production by epibionts on Thalassia in Florida Bay. J. Sed. Petrol., 56: 622-628.

Port of St. Eustatius Multupurpose Terminal, 1989. A report by Civil Engineering Caribbean prepared for the Government of the Netherlands Antilles, Curacao, 23 pp. plus drawings.

St. Eustatius, Preliminary Data Atlas, 1980. Survey of conservation priorities in the Lesser Antilles prepared by the Eastern Caribbean Natural Area Management Program, 18pp.