U.S. DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Typhoon Russ Effects on the Shoreline of Guam

by

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ABSTRACT

Typhoon Russ passed to the south of Guam on December 20-21, 1991 causing extensive wind damage over most of the island and significant overwash along the east and south coasts. Overwash, an increase in water level over land, resulting from a combination of storm surge, wave set-up, and wave swash, was documented up to 11 m above sea-level. An inverse relationship was found between reef flat width and overwash elevation on the adjacent coast. The highest overwash occurred along steep coasts adjacent to narrow reef flats. In addition to 28 sites where overwash elevation was determined, four beach profile sites were established and detailed profiles measured.

Some of the severest overwash damage occurred on low-lying Cocos Island at the exposed southern tip of Guam. Post-storm morphology revealed four distinct shore-normal zones which are thought to be representative of different processes affecting the coast. From seaward to lagoonward these are: a) Platform abrasion where unconsolidated sediment and most of the vegetation is stripped from the underlying limestone platform. b) Rubble deposition and sediment transport zone which occupies most of the islets' surface and are characterized by deposition of extensive sheets of coral rubble. c) Channelization accompanied by erosion along the lagoonside (leeward) of the islet. d) Washover lobes on the lagoonside reef flat from material eroded from the islet.

INTRODUCTION

On December 20 and 21, 1991, the eye of Typhoon Russ passed within 65 km (40 mi) to the south of Guam (Fig. 1) causing extensive wind and overwash damage. Russ traveled in a southeast to northwest direction creating sustained winds on southern Guam of 190 km/hr (120 mph) with gusts up to 240 km/hr (150 mph). Overwash, a super elevation of the water level resulting from a combination of low barometric pressure, wind set-up, wave set-up, and wave swash, caused extensive property damage along the south and east coasts. The last typhoon of this magnitude to strike Guam was Pamela in May 1976. Because storm surge information from previous typhoons on Guam is poorly documented (Weir, 1983), the present study measured evidence for maximum water-level elevations on the coast in an effort to determine the pattern of overwash. In addition, a general assessment of shoreline changes included beach profiling at selected sites and re-profiling of beach profiles established on Cocos Island as part of 1990 SOPAC*-USGS Coastal Mapping Workshop.

Summary of Typhoon Russ (adapted from C. P. Guard, U.S. Air Force; written commun., 1991)

Typhoon Russ was first detected as a tropical disturbance on December 13, 1990, south of Majro (Majuro) Atoll in the Republic of the Marshall Islands. From the 14th to the 18th, Russ intensified, moving at a speed of 19 to 22 km/hr (12 to 14 mph) in a west-northwest direction toward Guam (Fig. 1). On December 15, Russ was upgraded to a tropical storm and was later upgraded to a typhoon on December 17 by the Joint Typhoon Warning Center (JTWC). Russ slowed to about 11 km/hr (7 mph) as it approached Guam, then accelerated and veered toward the west sparing Guam a direct blow. Russ passed about 65 km (40 miles) south of Guam at about 0300 hours (local time) on December 21. Maximum sustained winds on Guam (Fig. 2) were about 190 km/hr (120 mph) with gusts up to 240 km/hr (150 mph). Wind speeds were greatest to the south and at higher elevations (many anemometers failed and no direct measurements were available for the south end of the island). The estimated minimum barometric pressure in the center at sea-

*SOPAC - South Pacific Applied Geoscience Commission, Suva, Fiji level was 922 mb. Damage to structures and vegetation occurred throughout the island but was heaviest on the south and southeast coasts. Because Russ accelerated as it passed over Guam the major rainbands were south of the island and rainfall was less than expected for a storm of this size. Coastal areas received 2.5 to 13 cm (1 to 5 in) of rain and mountainous areas were interpolated to have up to 23 cm (9 in). No tide gauges are present along the south and east coasts -- the areas of expected maximum water-level elevations.

Previous Tropical Cyclones Affecting Guam (after Weir, 1983)

Tropical cyclones develop over tropical oceans and consist of a relatively narrow band of intense winds encircling a relatively calm center (the eye). Guam lies within the development zone for tropical cyclones (typhoon >64 kts; tropical storm 34-63 kts; tropical depression <34 kts sustained wind speed). Within 180 nm (207 mi; 330 km) of Guam, an average of nearly three tropical cyclones can be expected to occur annually. Because Guam lies within this generating area, it is more likely to be threatened by a developing typhoon rather than one of full strength. Cyclones occur throughout the year but the majority strike during the rainy season between August and November. Typhoon frequency varies from year to year, with some years experiencing no activity whereas in other years several typhoons may impact Guam.

Most of the typhoons affecting Guam originate to the south and east in an area between Chuuk (Truk) and Kwajalein. They typically travel to the west and north, often in a direction towards Guam. About 60 percent of the typhoons affecting Guam follow this pattern, the remainder take a variety of different paths.

Recent typhoons of similar magnitude to Russ include Pamela in 1976 (maximum wind speed 220 km/hr; 140 mph); and Karen in 1962 (maximum wind speed 250 km/hr; 155 mph). On the basis of these two previous storms, Russ was about a one-in-ten-to-fifteen-year event. Since 1800, twenty-seven typhoons have had a severe impact on Guam (an average of one every seven years). Particularly strong typhoons include Pamela (1976), Karen (1962), and unnamed ones occurring in 1940, 1918, and 1900. Perhaps the most catastrophic typhoon occurred in 1693 where reports indicate severe overwash affected the coast and "not a house or building remained standing."

The effects of Typhoon Pamela (1976) on the shoreline and reefs were described by Randall and Eldridge (1977). Unconsolidated deposits underwent significant modification and shoreline vegetation was severely defoliated, but there appeared to be little damage to the reef flats and reef margins. Most of the reef modification was limited to reef front areas which are beyond wave base under "normal" conditions.

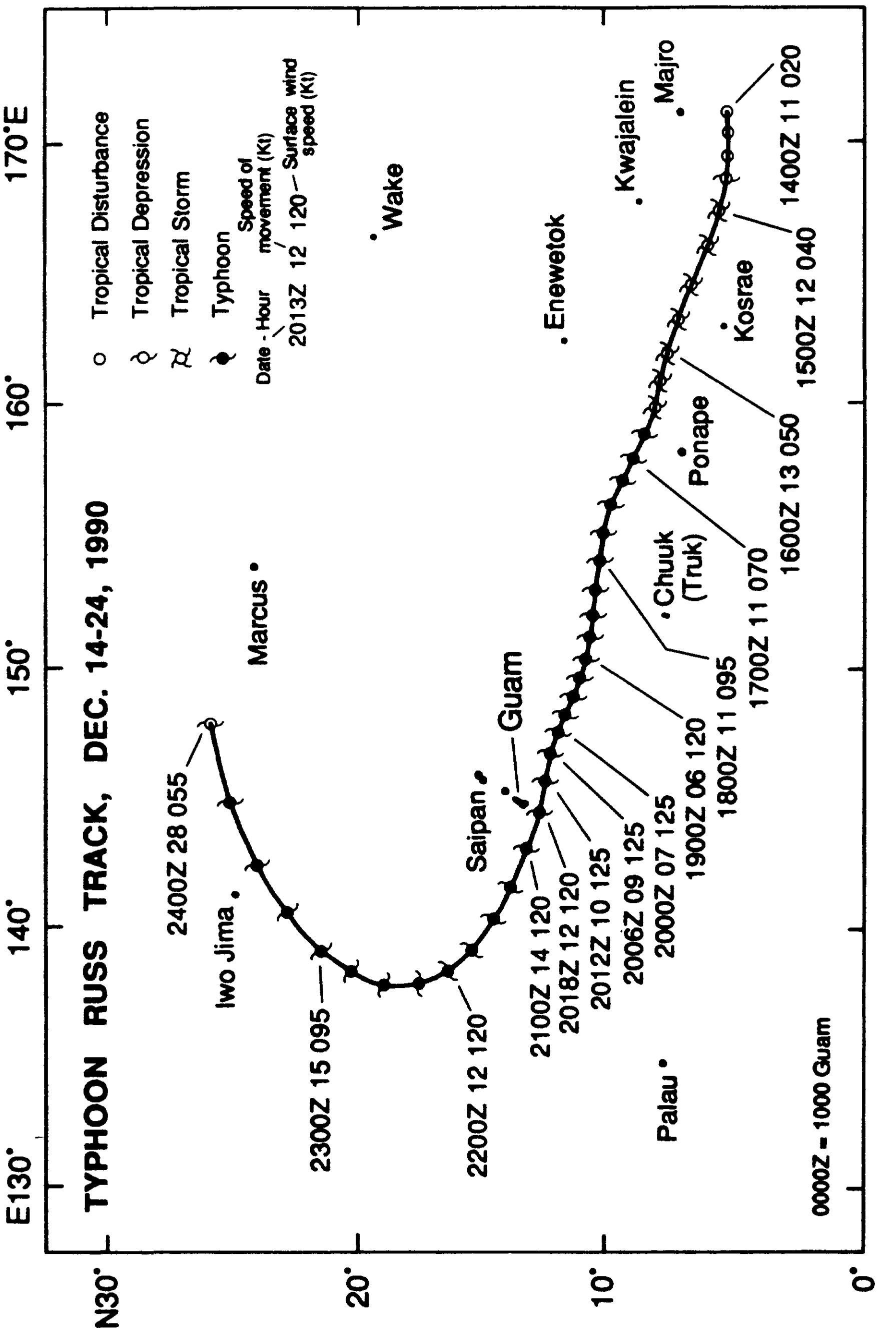

Figure 1. Track of Typhoon Russ from Dec 14-24, 1991. Modified from C.P. Guard, written commun., 1991.

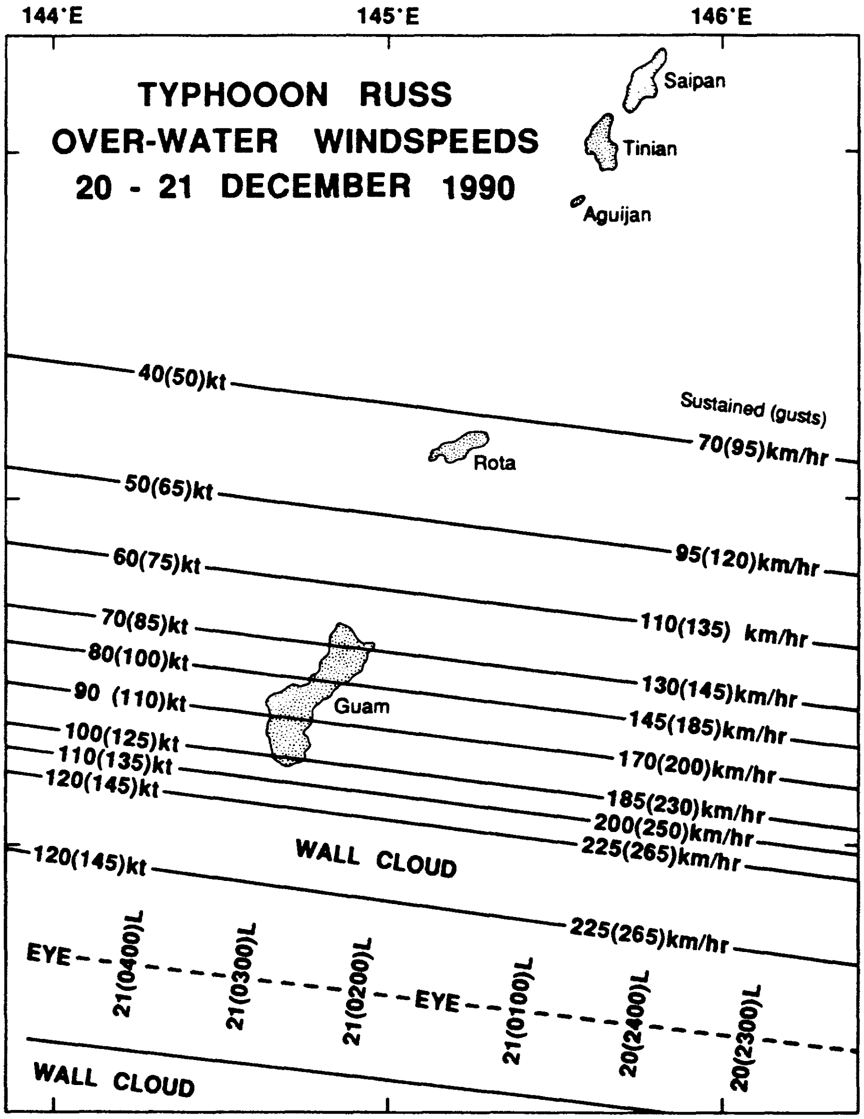

Figure 2. Calculated over-water wind speeds for Typhoon Russ as it passed Guam. Modified from C.P. Guard, written commun., 1991.

Methods

Field work on Guam took place from January 10-19, 1991. The majority of the coastal areas examined contained clear evidence of high water-levels attained during the passage of Russ. Evidence of inundation included: a) presence of a debris wrack line containing material such as wood, fish, and sediment; b) erosion of surficial sediment layers overlying limestone surfaces as indicated by a "bleached" appearance of the limestone (limestone that has undergone subaerial exposure for a period of time is a dull gray color caused by a surficial coating of filamentous algae), and c) water marks on trees, buildings, and other structures. Care was taken in the field to attempt to differentiate between modifications caused by water versus wind-induced changes. For example, the presence of deposits of well-sorted sand could be formed either by wind or water, but the additional presence of coral debris indicates water as a principal transporting agent.

Once the position of maximum overwash at a site was determined, the water-level elevation above sea-level was measured using a modified Emery (1961) method where the sea horizon is used as a level reference surface. An operator using binoculars at a known height above the ground, determines the elevation from a stadia rod while sighting on the horizon. Horizontal distances were determined by tape measure. In addition, all reference sites were photographed and videotaped.

OVERWASH MEASUREMENTS

The maximum elevation of overwash was determined for twenty-eight locations on the east and south coasts of Guam (Table I; Overwash Map). These values represent the maximum height above mean sea-level of "probable" water-deposited debris. They have been corrected for tide height at the time of measurement. The values vary from a low of 0.65 m asl (above sea-level) along the south coast near Merizo to a maximum of 11.0 m asl at Tagachan Beach on the east coast. We did not see evidence of any significant overwash along the west coast.

Table I presents the overwash measurement locations from north to south, the date and time of measurement, overwash height, reef width, reef facing direction, and the shoreline facing direction at the measurement site. The reef width and facing directions were determined from USGS 1:24,000 topographic maps. The shortest distance between the shoreline and the edge of the reef is the distance used as the reef width (this is not neccesarily orthogonal to the shore). Overwash height versus the reef width, reef facing direction, and shoreline facing direction are presented in Figures 3,4, and 5 respectively. There is a strong inverse relationship between reef width and overwash height (correlation coefficient = 0.73, significant at the 99 percent level). The narrower the reef, the higher the overwash. The three highest measured overwash sites, Fadian Point (10.75 m), University of Guam Marine Labs (9.8 m), and Tagachan Beach (11.0 m), are bordered by a narrow fringing reef backed by a steep coastline. The relationships between overwash height and facing directions are less dramatic. In general, it appears that east-facing coastlines underwent somewhat higher overwash than those facing south.

#	Location	Date / Time	OH	RW	RFD	SFD
1	Tarague Beach	Jan. 11 @1530	6.35	185	043	047
2	Fadian Point	Jan. 16 @1300	10.75	15	155	160
3	South Fadian	Jan. 16 @1330	7.25	90	135	135
4	UOG Marine Labs	Jan. 16 @1400	9.80	60	178	172
5	N. Pago Bay	Jan. 17 @1745	3.00	715	128	123
6	S. Pago Bay	Jan. 17 @1735	2.80	830	070	084
7	Tagachan Beach	Jan. 11 @1130	11.00	120	100	093
8	N. Ylig Bay	Jan. 11 @1350	1.70	730		070
9	S. Togcha Cemetary	Jan. 11 @1430	4.15	410	093	093
10	Togcha Bay	Jan. 11 @1530	5.15	590	079	082
11	Ipan Beach	Jan. 11 @1630	5.25	365	098	092
12	S. End Camp Dealy	Jan. 17 ~@1645	5.65	275	093	093
13	S. Asanite Pt.	Jan. 17 @1614	4.90	185	096	105
14	Between Ypan Pt. and Adoulan Pt.	Jan. 17 @1600	7.15	90	113	108
15	Talofofo Bay	Jan. 17 @1010	2.30	915		059
16	N. Inarajan Bay	Jan. 17 @1500	3.05	550	215	213
17	Salaglula Baths	Jan. 17 @1445	4.40	60	144	151
18	S. Tipoco Cemetary	Jan. 17 @1430	3.85	170	151	144
19	Agfayan Bay	Jan. 17 @1420	3.75	685	116	081
20	S. Agfayan Pt.	Jan. 17 @1355	4.85	460	120	121
21	Agfayan Pt.	Jan. 17 @1355	3.60	440	119	111
22	Inarajan Garden Hotel	Jan. 17 ~@1100	4.15	395	118	118
23	Leon Guererro's Beach	Jan. 17 ~@1130	2.25	365	152	203
24	Ajayan Bay	Jan. 17 ~@1200	2.15	365	150	144
25	Asmaile	Jan. 17 @1345	4.20	380	157	185
26	W. of Liyog River	Jan. 17 @1335	2.60	395	179	192
27	Sumay Maleso	Jan. 17 @1320	1.35	760	186	202
28	Merizo	Jan. 17 @1300	0.65	2900	172	211

#- Station Number
OH- Overwash Height Above Sea Level (m)
RW- Reef Width (m)
RFD- Reef Facing Direction
SFD- Shoreline Facing Direction

Table I. Overwash measurement locations, time of observations, overwash heights above sea level, width of the adjacent reef, and reef and shoreline facing directions. The locations and elevations are shown on the accompanying overwash map.

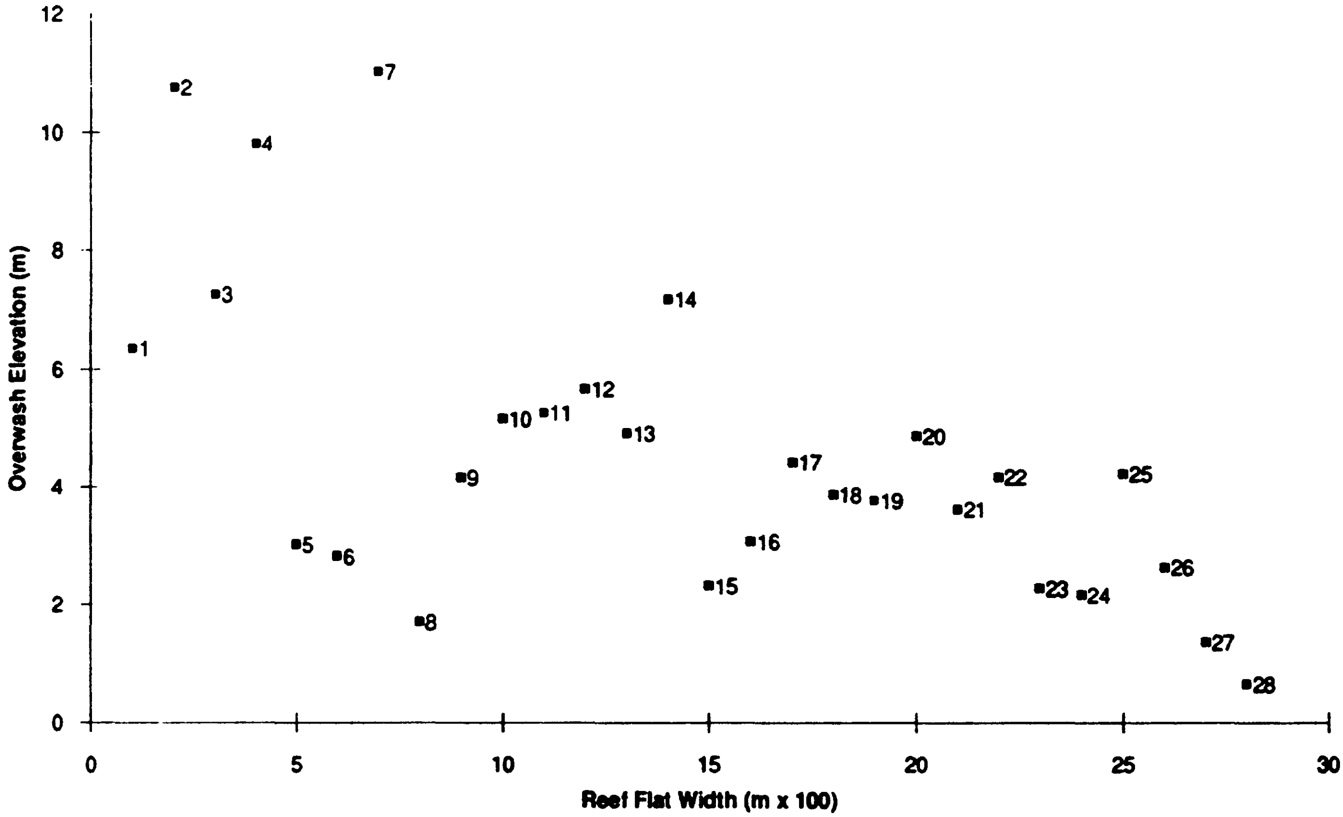

Figure 3. Plot of measured overwash height versus adjacent reef width for twenty-seven locations and the best-fit line (location 28, Merizo, is not shown, OH = 0.65 m, RW = 2900 m).

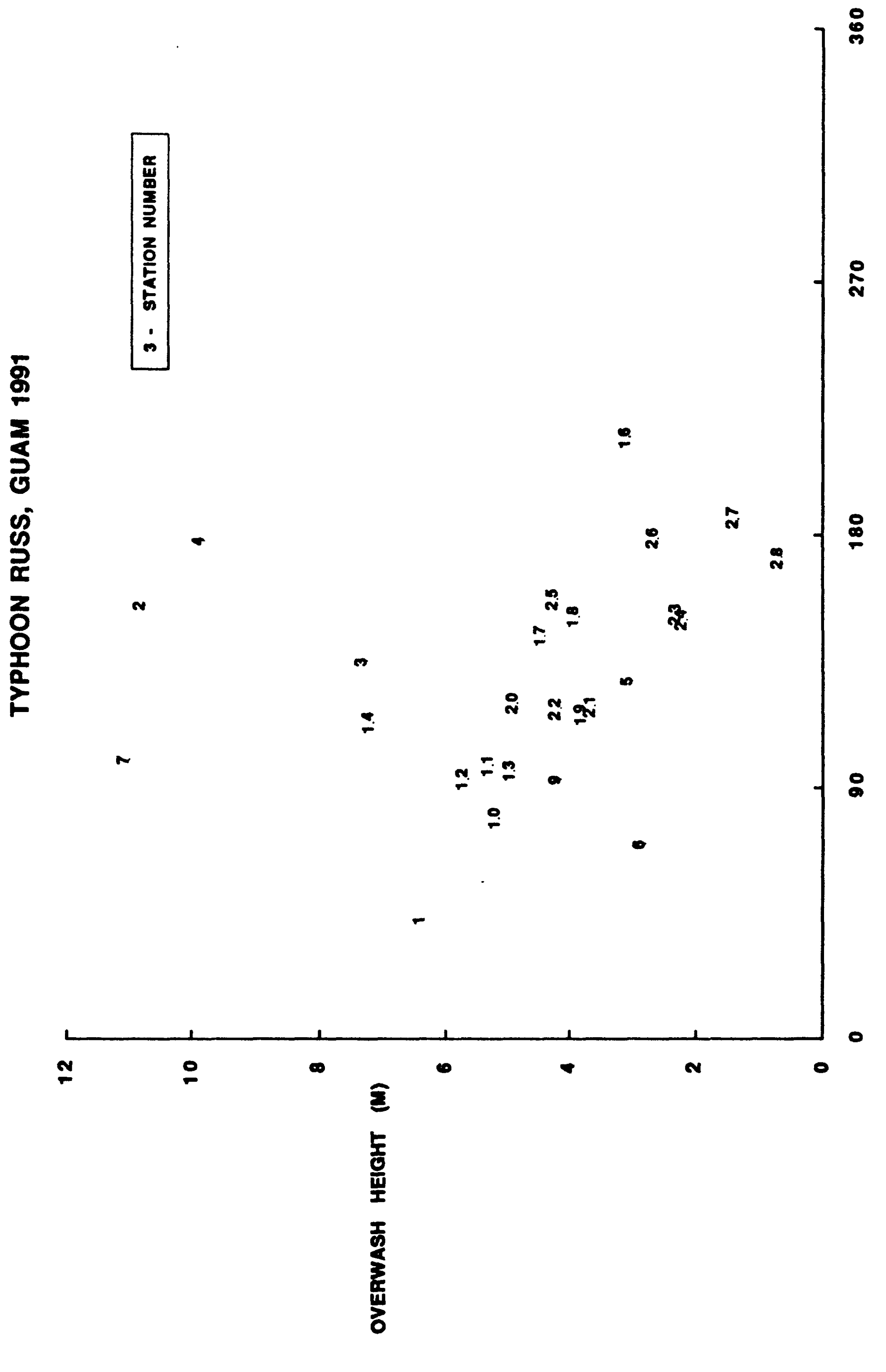

Figure 4. Plot of overwash height versus reef facing direction.

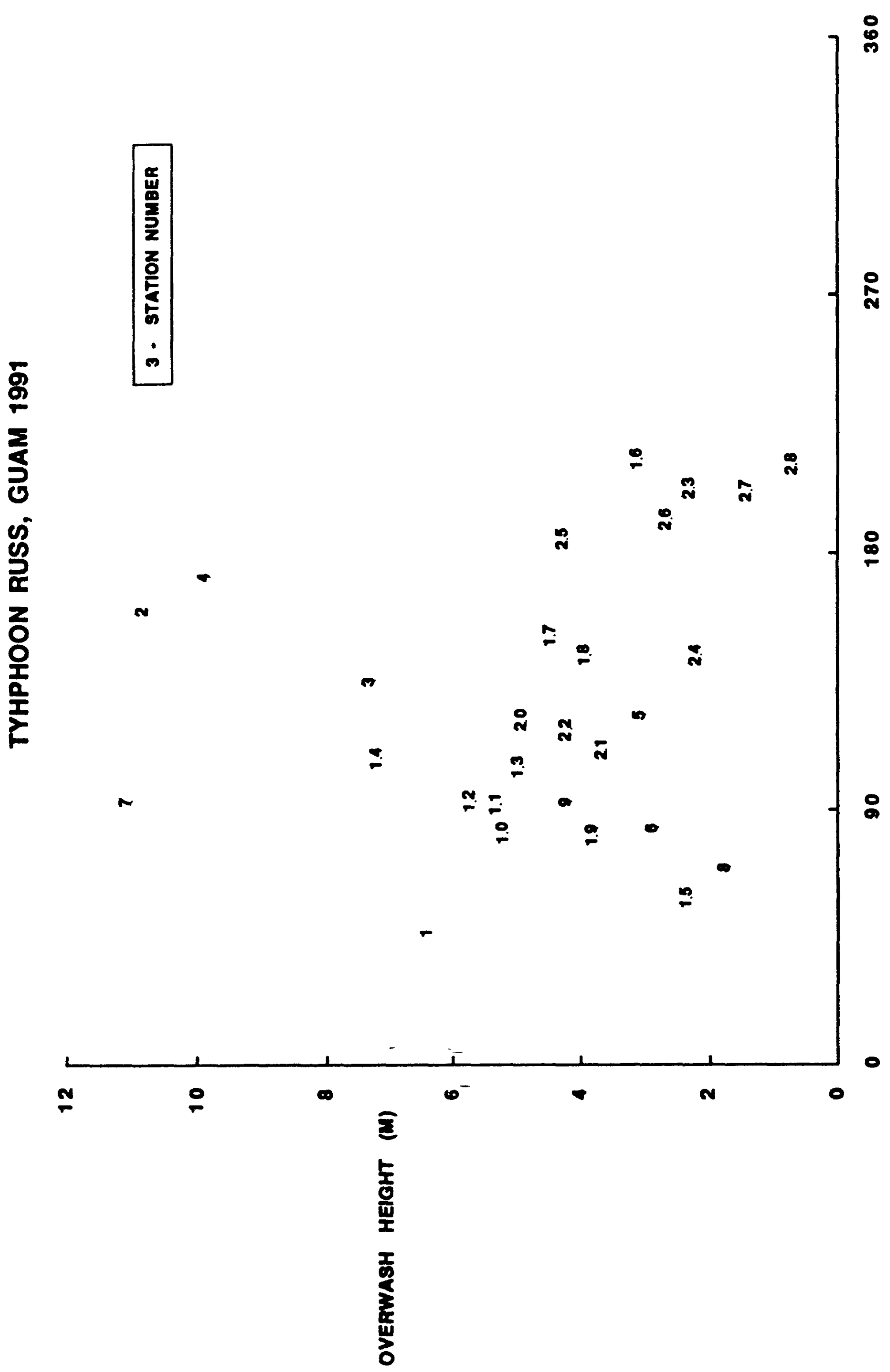

Figure 5. Plot of overwash height versus shoreline facing direction.

BEACH PROFILES

Four coastal sites on Guam were profiled in detail for the purpose of documenting the present state of the beach and in the hope that they would be re-profiled at later dates to determine temporal beach changes. The sites chosen were easily accessible and they appeared to be representative of a particular stretch of coastal morphology and hydrodynamic conditions. The four sites are Tarague, Tagachan, Ipan and Talofofo. It is also hoped that other sites might be established around the entire island in the future. Regular beach profiling is a cost-effective method of accurately monitoring shoreline response to extreme events, measuring long-term changes in shoreline position, and it provides a basis for determining sediment budgets within the coastal zone.

The measured beach profiles and representative photographs are shown in Figures 6 through 9 and the raw profile data and field notes are included in Appendix I. A brief description of each site follows.

Tarague beach is located on the northeastern tip of the island within the confines of Anderson Air Force Base. It is a wide (100+ m), northeastern-facing, carbonate-sand beach fronted by a narrow (<200 m) fringing reef. At the time of profiling a small, active berm crest was developed at the upward limit of the swash zone (Fig. 6a). The back-beach area is a near-planar, gently-sloping, slightly-vegetated surface extending to a level approximately 6 m asl where it flattens out. This flat surface is in part due to the road which traverses it and contains numerous coconut palms. There were small patches of beachrock exposed in the inner surf zone, but overall, there was very little evidence suggesting an erosion problem.

Tagachan Beach is an east-facing, carbonate sand and rubble pocket beach (Fig. 7) located within a relatively steep and rugged section of coastline. It is fronted by a narrow (about 120 m wide) fringing reef, the inner surface of which is a reef pavement with a thin, patchy veneer of sediment. The gently-sloping backbeach is composed of a mixture of carbonate sand with large amounts of coral rubble. At the south end of the beach the sediment had been stripped away exposing a bare limestone platform (Fig 7c). Other evidence of erosion, presumably Typhoon Russ induced, included erosional scarps and exposed soil horizons.

Ipan Beach is another east-facing, carbonate sand beach (Fig. 8). It is bordered by a fringing reef that is about 365 m wide. The beach has less than 50 m of non-vegetated sand and is narrower than either Tarague or Tagachan beaches. The backbeach has numerous stands of *Casuarina* trees and large grassy areas. Ipan Beach is part of a five kilometer stretch of sandy shoreline that extends from Ylig Point to Asanite Point. There were no obvious signs of erosion on Ipan Beach at the time of observation.

Talofofo Beach is a small beach developed at the head of Talofofo Bay -- a narrow embayment which extends for about one kilometer (Fig. 9) inland. The beach is composed mostly of terrigenous sand derived from the Talofofo and Ugum Rivers. Because it is developed at the head of an embayment where reef growth has not blocked the entrance, refracted ocean waves reach the beach causing the formation of nearshore bars. The overall profile is much flatter than the other open-coast beaches. A small erosional scarp was developed on the upper beach face and the backbeach area supports grass and coconut palms.

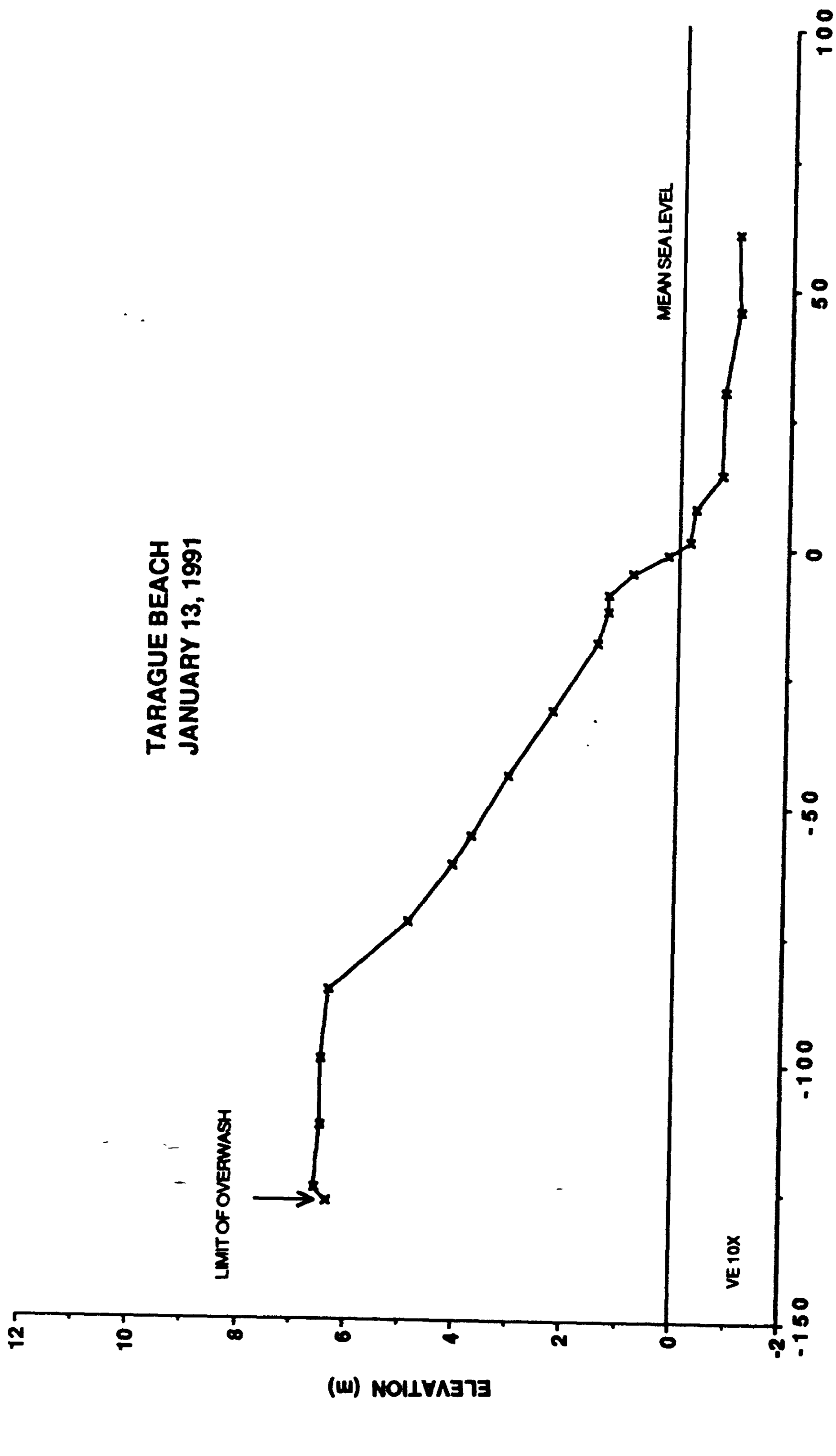

Figure 6a. Beach profile plot of Tarague Beach taken January 13, 1991. Mean sea-level position, for this and the other beach profiles, is approximate and is based on the average water-level at the time of profiling corrected for tide stage. The active berm crest is the small terrace-like feature at about 1.5 m asl.

Figure 6b (top). Seaward-looking view along the profile line showing the sand-covered road and flat surface of the upper backbeach. 6c (bottom). View to the north of the gently-sloping backbeach.

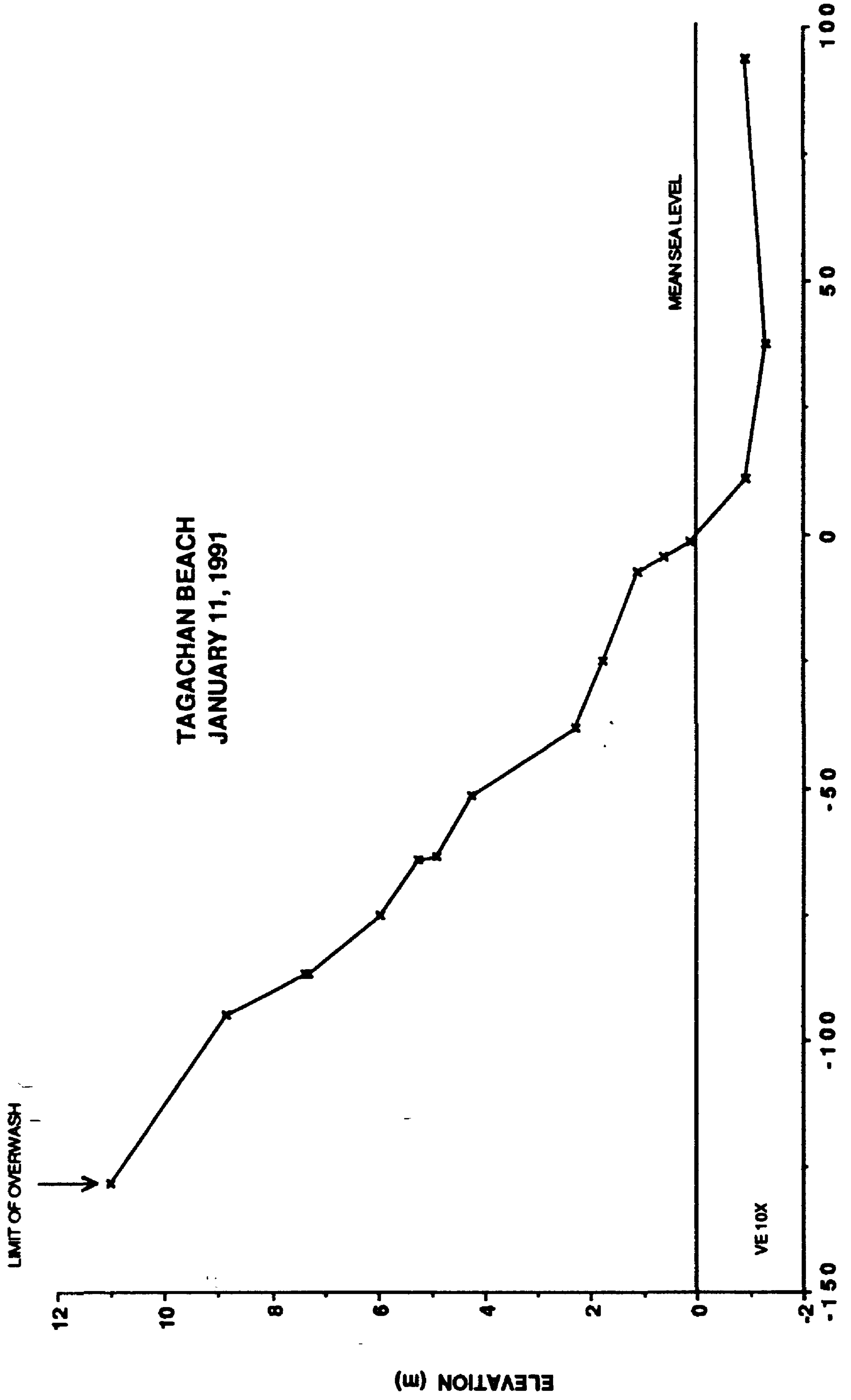

Figure 7a. Beach profile plot of Tagachan Beach taken January 11, 1991. The small step in the profile at approximately 5 m elevation is an erosional scarp.

Figure 7b (top). Landward-looking view at Tagachan Beach showing the main backbeach area. Exposures of white limestone in the central portion of the photograph indicate recent exposure. 7c (bottom). Area on the southern part of the beach where the unconsolidated sediment has been stripped away exposing a bare limestone surface.

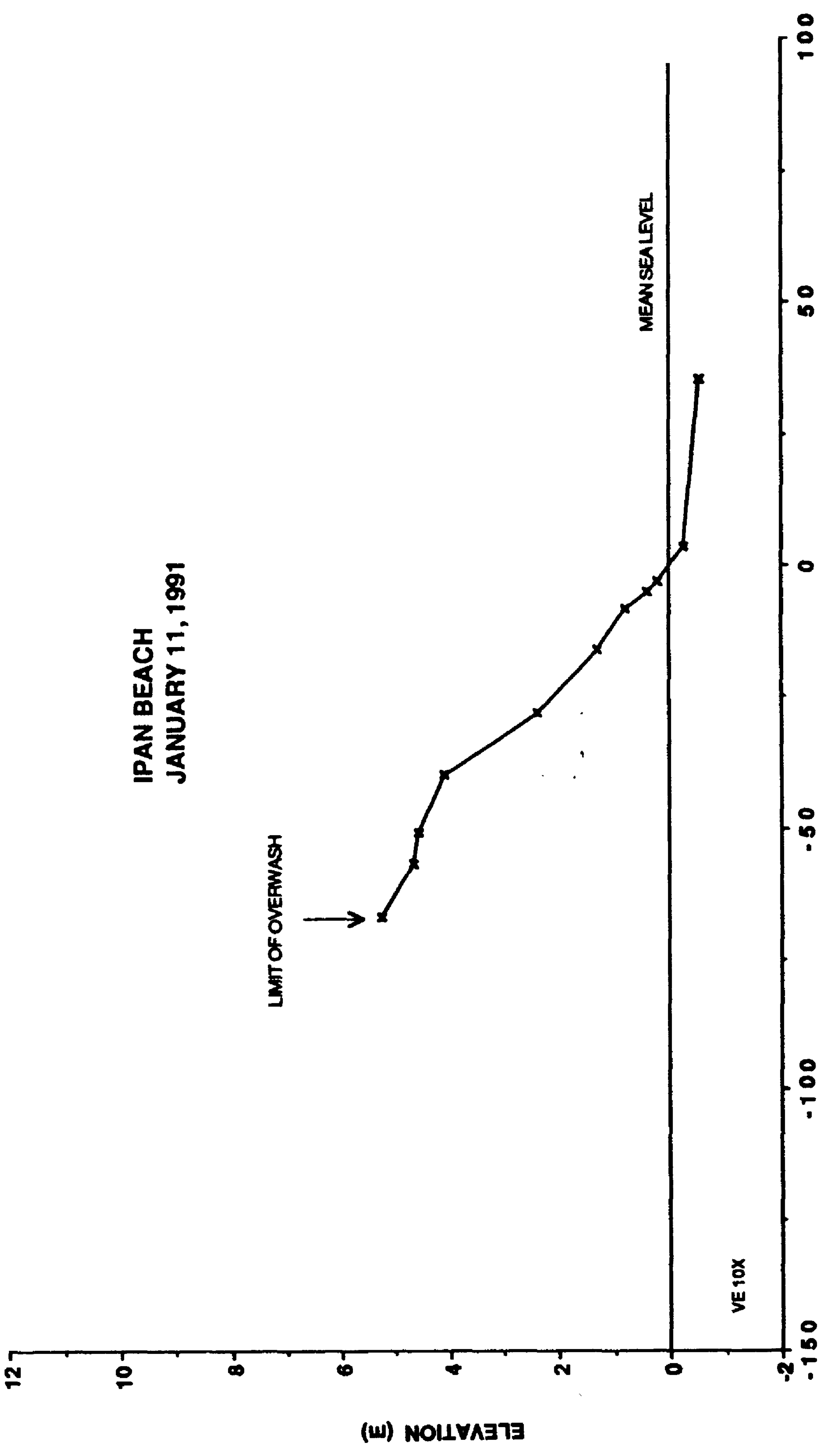

Figure 8a. Beach profile plot of Ipan Beach taken on Jan. 11, 1991.

Figure 8b (top). Seaward-looking (to the east) view of Ipan Beach from the backbeach area showing overwash sand deposits. 8c (bottom). Landward view of the backbeach area.

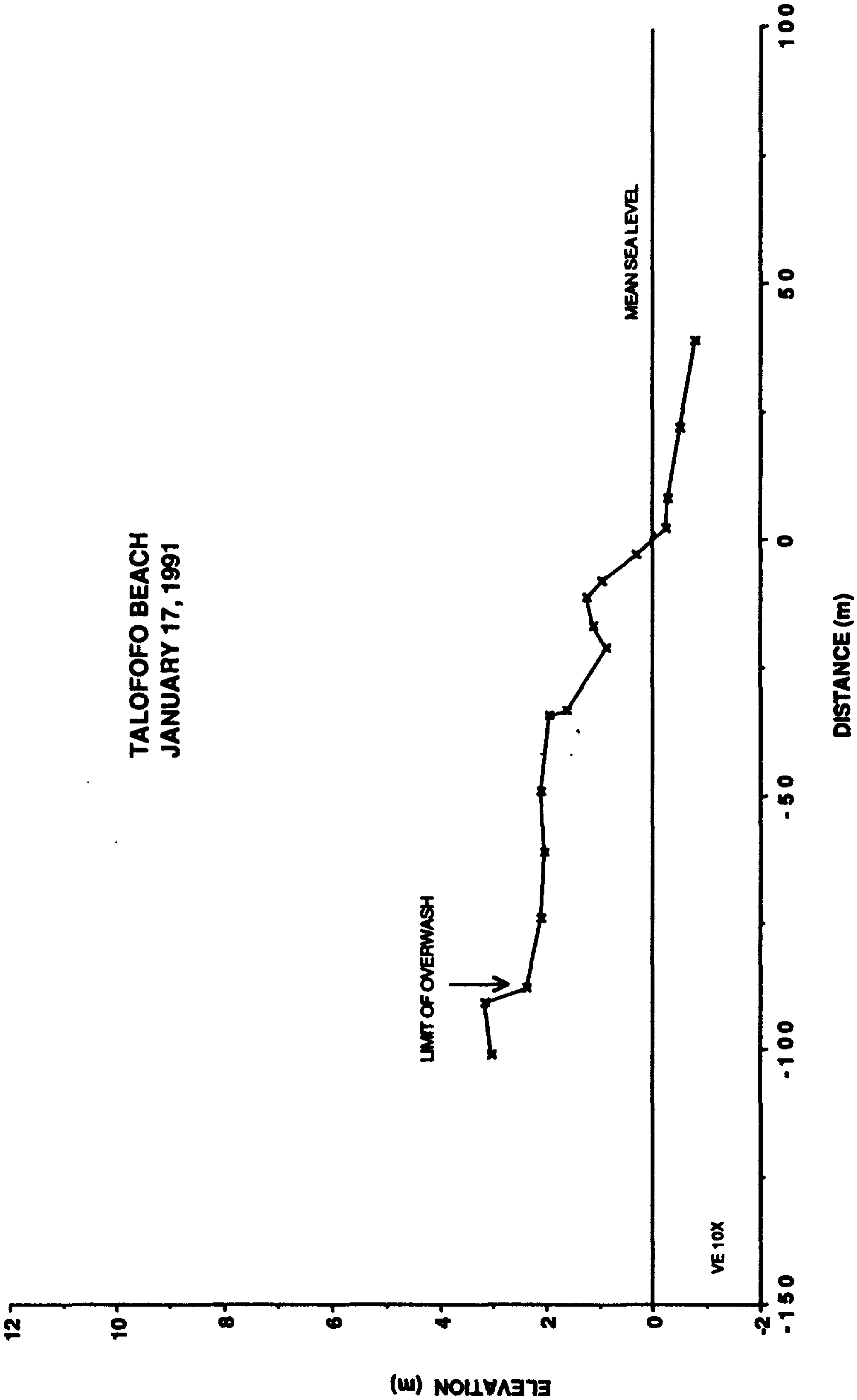

Figure 9a. Beach profile plot of Talofofo Beach taken on Jan. 17, 1991.

Figure 9b (top). Landward view of Talofofo Beach from the upper beach face showing a small erosional scarp and minor erosion at the base of the front-left coconut palm. 9c (bottom). North-looking view from the berm crest showing the active swash zone.

COCOS ISLAND STUDY

Cocos Island is a sand and rubble islet built on the southern margin of the barrier reef rim surrounding Cocos Lagoon. The islet is just under 6 km (3.6 mi) long and averages about 700 m wide. The eastern end of the islet was mapped as part of the 1990 SOPAC-USGS Coastal Mapping Workshop. In addition to coastal morphology mapping, five beach profile sites were established in June, 1990. These pre-Russ profile sites were re-occupied as part of the present study.

Cocos Island Resort, a private complex on the eastern half of the islet, was extensively damaged by wind and water during the passage of Russ. Most of the housing units were either destroyed or severely damaged. Evidence of water deposition on the higher parts of the islet indicate a minimum of 3.1 m of overwash and possibly up to 5m. It appears much of the eastern half of the islet and parts of the west were underwater during the peak of Russ' passage. Several of the housing units along the exposed seaward side of the islet were transported several tens of meters.

Four types of water-induced typhoon effects were recognized on the islet (Figure 10). In a seaward (southerly) to lagoonward (northerly) direction these effects are: a) Platform Abrasion. The oceanside reef flat and seaward islet margins underwent erosion of unconsolidated sediment and vegetation (Fig. 11b). Most of this area is underlain by emergent Holocene Merizo Limestone which consists of in-place reef and reef flat deposits. The pre-Russ sediment of this platform consisted mostly of storm-derived reef rubble and sand. b) Rubble Deposition. Landward of the zone of extensive erosion and abrasion is a zone of sediment reworking and deposition. Extensive gravel sheets covered large areas of the islet surface (Fig.11c). Some of this material was presumably derived from the abraded platform, other from reworking of islet deposits, and, in some cases, destruction of man-made structures. In areas of mostly sand deposits, bedforms were produced which, in every case examined, indicated lagoonward flowing currents. c) Channelized Zones. Widespread channelization occurred along the lagoonward margin of the islet producing erosional scarps up to 1.5 m in height. Some of this channelization was clearly directed by the presence of man-made structures which acted to funnel and concentrate water flow (Fig. 11d). In natural parts of the islet (ie. the western part where there are no large man-made structures), the pattern of abraded platform - rubble deposition - channelization was also present. d) Washover Lobes. Several large washover lobes of predominantly sandy sediment were deposited on the lagoonside reef flat (Fig.11e). These deposits occurred opposite areas of extensive channelization and along the eastern tip of the islet.

Comparison of pre- and post-Russ beach profiles are shown in Figure 12 and the profile data are presented in Appendix II. Modification of each profile from a west to east direction can be summarized as follows: Profile 1) This is the only profile west of the pier, it consists of a gentle-sloping beach backed by a scalloped shaped vertical seawall. Overall profile change was minor with slight erosion of the upper beach face and deposition of the lower beach face. Profile 2) A well-developed back-beach scarp was eroded adjacent to road. Slight erosion of the entire profile line occurred, however this may be an artifact attributed to difficulties in occupying the exact bench mark location. Profile 3) This profile started on the causeway which crosses an older washover channel. Channelization underneath the causeway eroded the former beach face; an extensive washover lobe was deposited offshore on the reef flat with a thickness approaching 0.5 m. Profile 4) Consists of a gently-sloping beach fronting several housing units. The berm crest was displaced landward (and upward) while a washover lobe in excess of 1.5 m thick was deposited lagoonward. Profile 5) This profile was on the northeastern tip of the islet in front of several housing units. The beach face aggraded lagoonward and there appears to have been some slight erosion (< 0.2 m) of a previously developed depositional lobe. Visual inspection of the site suggested an extensive washover lobe was present both pre- and post-

Russ but the lobe was larger after the typhoon. Some of the enlargement was probably due to reworking of the previous deposit, hence, the slight erosion of the lobe profile.

DISCUSSION

Because Guam lies within a region of prolific tropical cyclone activity, storm events the magnitude of Typhoon Russ can be expected to occur every one-to-two decades. One of the important findings of the present study is the inverse relationship between reef flat width and the maximum overwash excursion on the adjacent coastline. Although the exact mechanisms responsible for this relationship remain unclear at present, it appears the wave set-up and swash contribution to overwash elevation are very significant in reef settings. This is in contrast to coastal areas with wide shelves where storm surge (the response of mean water level to high winds, lowered atmospheric pressure, and rainfall) is usually the dominant parameter. Important implications of these findings for development in the coastal zone suggest that reef width and coastal slope should be considered when planning development near the coast. Coastal hazard recognition due to storm overwash require both an analysis of adjacent reef characteristics and and on-land geology including slope and sediment cover. Rather than implementing uniform set-back limits for coastal development, it may be possible to develop variable limits based on the local physical setting.

Observations on Cocos Island revealed a dramatic difference in response between the developed eastern part of the islet and the relatively undeveloped western half. Platform abrasion was effective along the entire seaward margin, but dense vegetation limited the overwash in the west. Overwash lobes on the lagoon reef flat were primarily limited to the ends of the islet and the developed eastern margin even though there were seawalls constructed to prevent such occurrences. The causeway vicinity is an area of previous historical washovers and will probably be prone to washovers in the future. In general, sand cay islets of this type owe their existence to major storms where washover events deposit material from the adjacent reefs in a subaerial accumulation forming an islet. However, in our examination of Typhoon Russ deposits we saw very little evidence that fresh coral had been eroded, rather, most of the deposits consisted of previously reworked material.

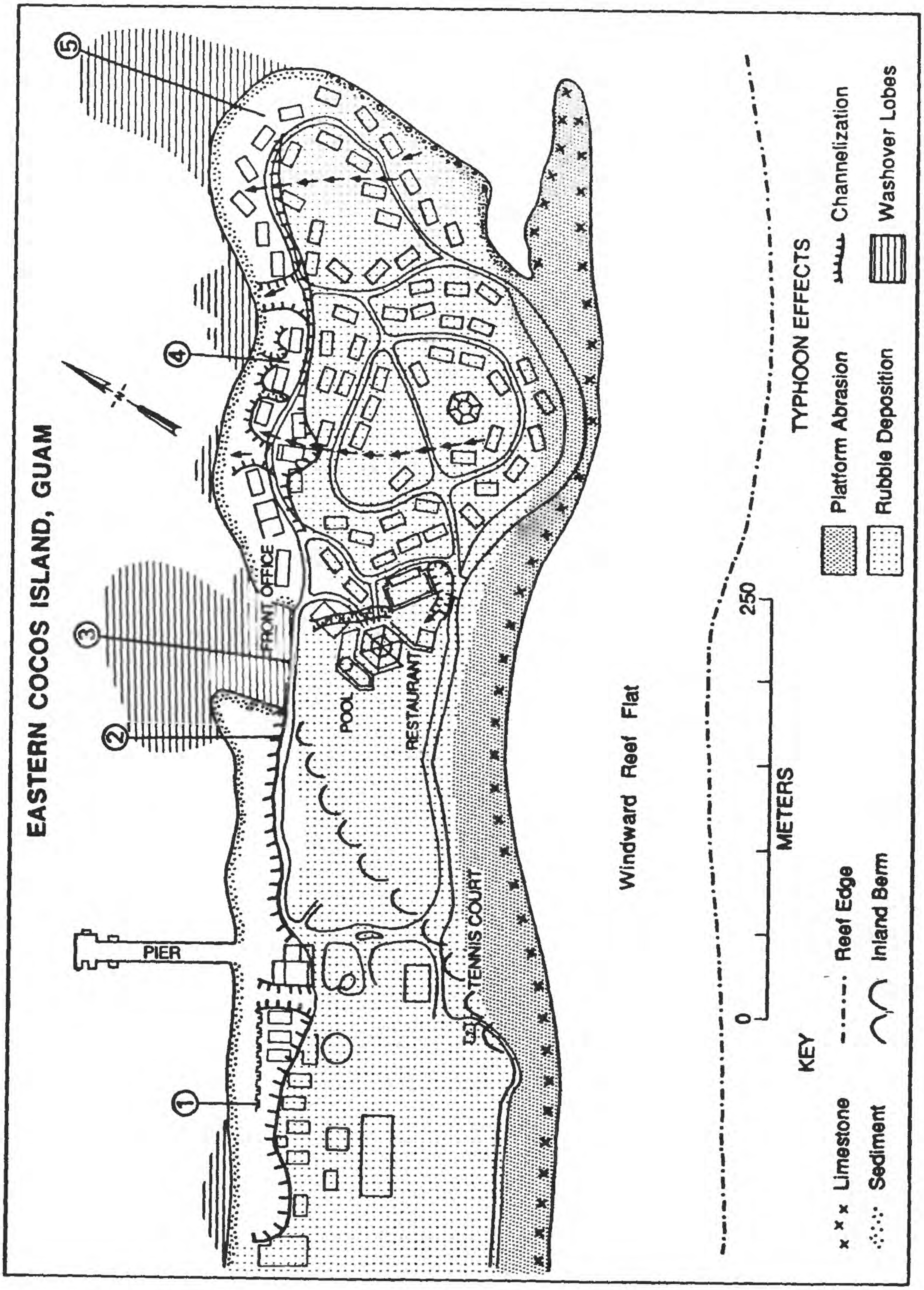

Figure 10. Interpretative sketch map of eastern Cocos Island showing pre-Russ building locations, beach profile locations, and the general distribution of the various typhoon effects.

Figure 11a (top). Oblique aerial photograph of washover channel on the eastern end of Cocos Island. A washover lobe is developed in the center foreground opposite the causeway. A seawall is visible across the center of the islet. View to the south. 11b (bottom). View of the seaward margin of the islet showing the area of principal erosion (the abraded platform).

Figure 11c (top). Much of the central portion of the islet underwent sediment transport and deposition; here coral rubble is deposited on the tennis courts. 11d (bottom). Severe erosion and channelization occurred along the northern (leeward) side of the islet undermining buildings and roads.

Figure 11e. Deposition of mostly sand-sized sediment occurred as lobes opposite channels along the lagoonside reef flat.

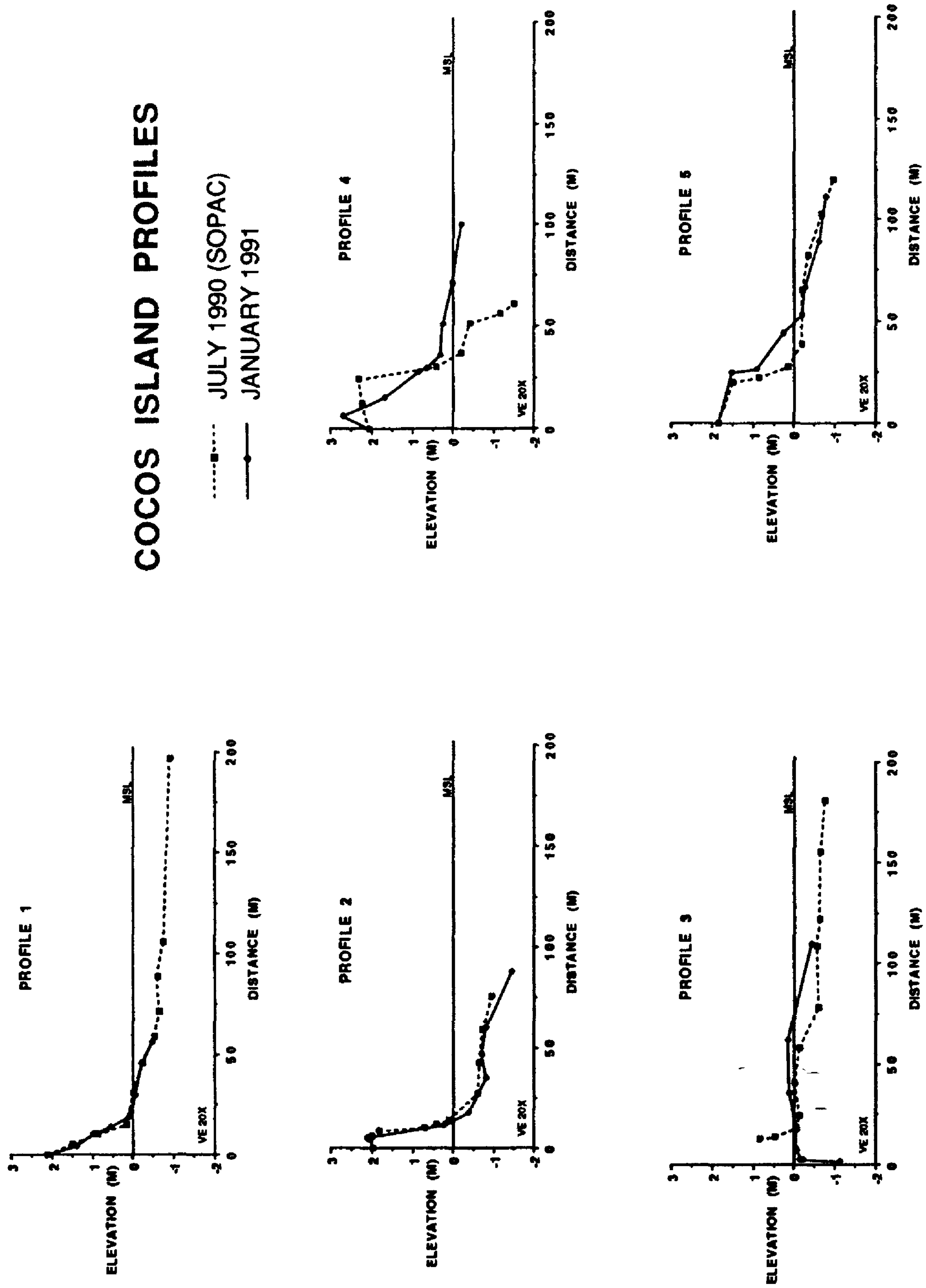

Figure 12. Cocos Island Beach profile plots at locations 1,2,3,4,5 from pre-Russ (June 1990) and post-Russ (January, 1991) measurements. Profile locations are shown in Figure 10. Mean sea-level used here is the temporary vertical datum established during the SOPAC-USGS Coastal Mapping Workshop.

ACKNOWLEDGEMENTS

We would like to thank the entire staff of the Bureau of Planning in Agana and, in particular, Peter Leon Guerrero, Mike Cruz and Ray Caseras for assistance in all phases of this project. The Department of Land Management, Agana, provided valuable survey assistance and we would like to acknowledge the help of Bernardo Ortega, Raymond Cruz, and the Director Francisco Castro. Valuable backgound information was provided by C.P. Guard and Frank Wells, U.S. Air Force (NOCC/JTWC), and Bob Richmond and Lawrence Collins of the University of Guam Marine Labs. Chic Davison of Cocos Island Resort graciously arranged for transport and inspection of Cocos Island. Doug Rearic and Phil Woodward of the SOPAC Technical Secretariat, Suva, Fiji, provided the profile data collected during the 1990 Coastal Mapping Workshop. This study could not have been completed without the untiring assistance and guidance of Frank Kilmer, University of Guam. Funding for the field work was provided by the USGS Center for Coastal Geology, St. Petersburg, Florida.

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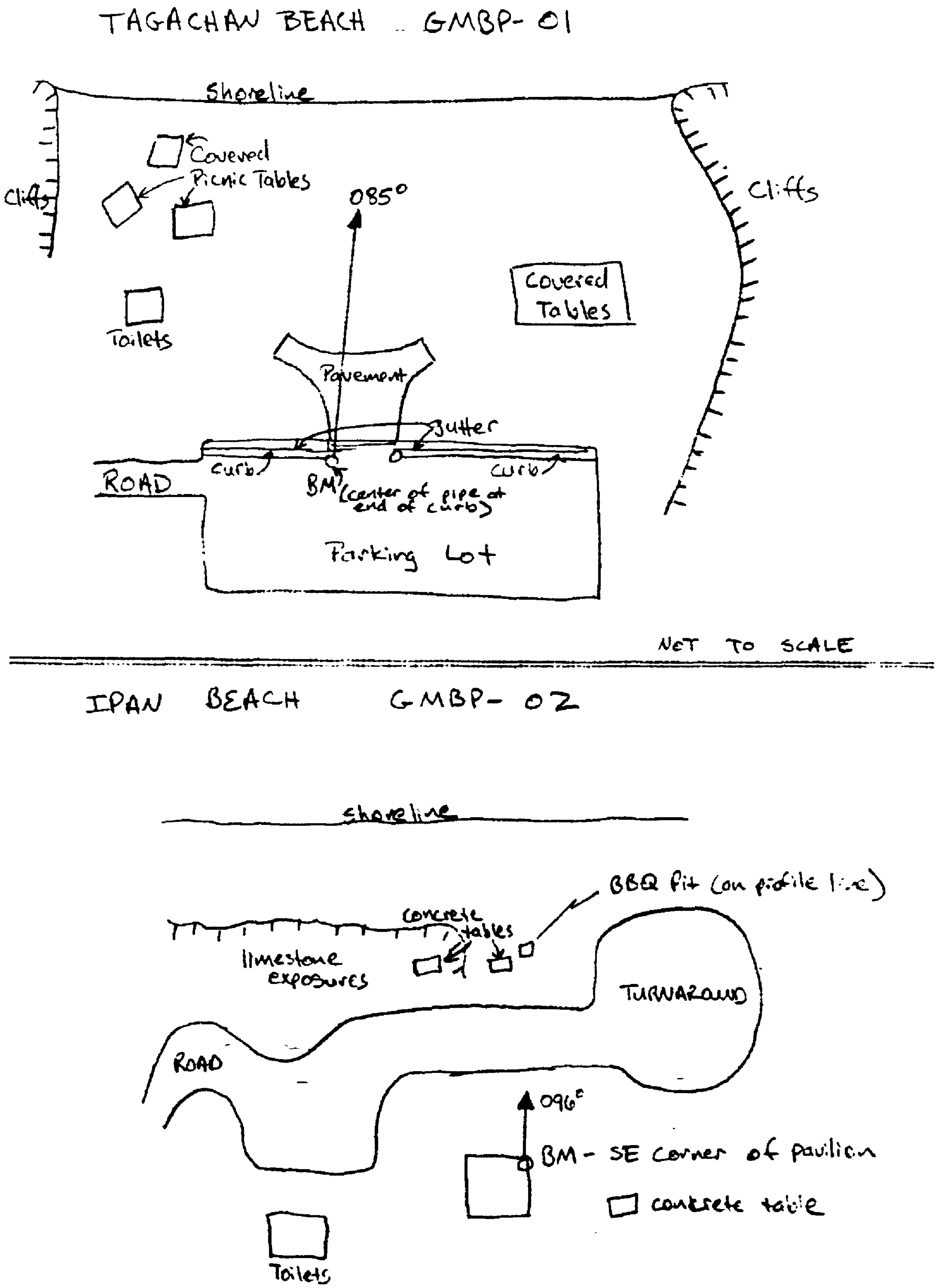
APPENDIX I

FIELD DATA FOR GUAM BEACH PROFILES



Sketch diagrams of beach profile locations for Tagachan (upper) and Ipan (lower) beaches.

Tagachan Beach, Jan. 11, 1991 at 11:30am

GMBP-01.011191.1130

Distance from BM (m)	Elevation (m) rel. to BM	Notes
-33.40	2.15	upper end of parking lot, limit of overwash
0.0	0.0	Bench Mark, round concrete pipe in pavement
8.1	-1.50	edge of concrete ramp
8.2	-1.55	bottom of ramp, sand
19.9	-2.90	new sighting position (nsp)
30.7	-3.60	top of scarp
31.4	-3.95	bottom of scarp
43.5	-4.60	
56.9	-6.55	seaward edge of exposed limestone, (nsp)
69.9	-7.10	
87.9	-7.75	outer raft line, berm crest
90.9	-8.25	current high swash line
93.7	-8.75	current sea level, sand sample GMBP-01.SA, (nsp)
105.9	-9.75	on reef flat
132.7	-10.15	on reef flat
188.7	-9.75	on reef flat

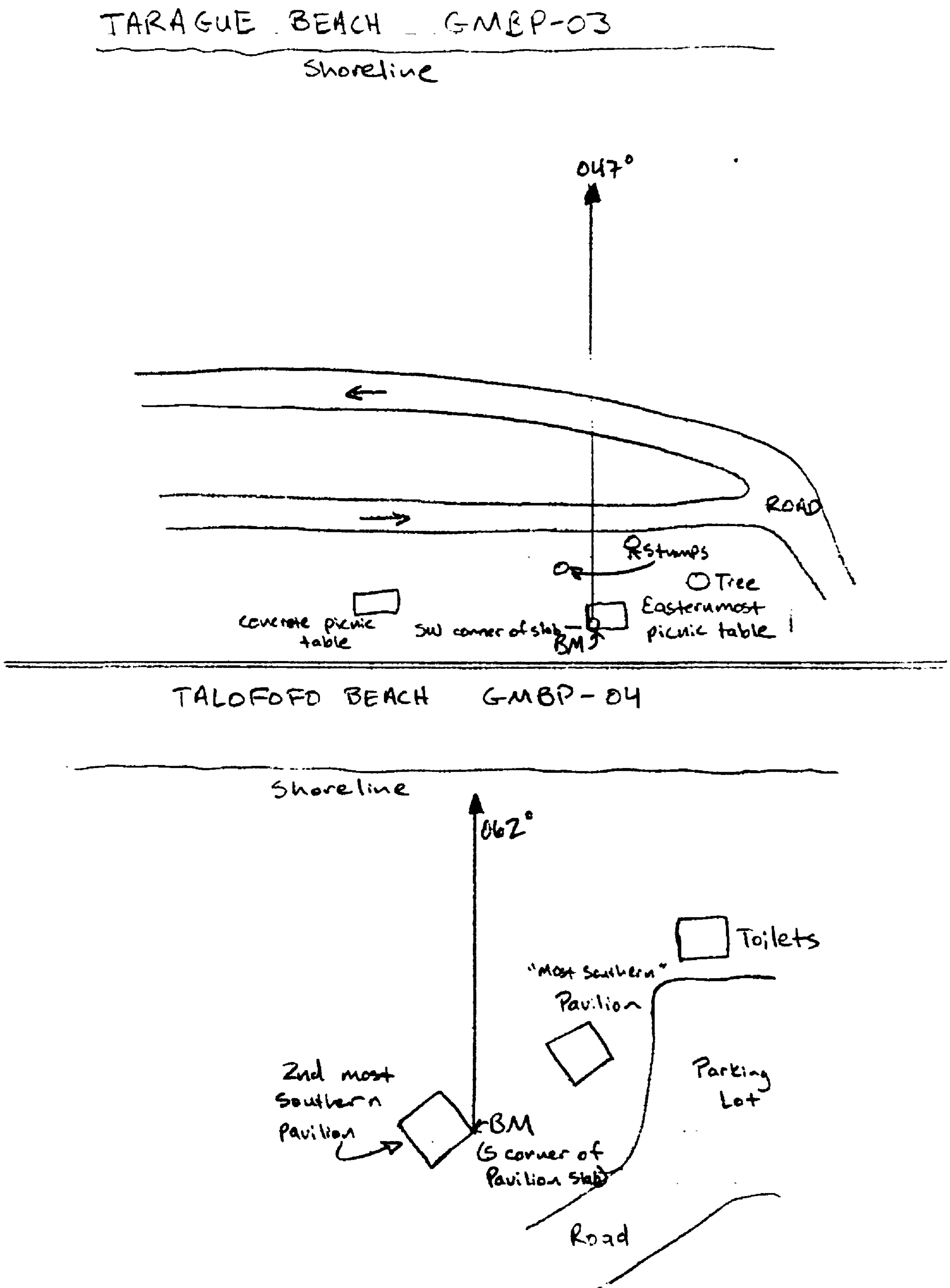
- Positive distances are seaward of the bench mark
- Positive elevations are above the bench mark
- Corrections applied to make measurements relative to mean sea level:
  Distance- subtract 94.9 m
  Elevation- add 8.85 m

Ipan Beach, Jan. 11, 1991 at 4:30pm

GMBP-02.011191.1630

Distance from BM (m)	Elevation (m) rel. to BM	Notes
0.0	0.0	approx. limit of overwash, difficult to tell
10.3	-.6	landward edge of road
16.3	-.7	seaward edge of road
27.5	-1.15	sand level at SW corner of BBQ pit
39.0	-2.85	new sighting position
51.1	-3.95	
58.8	-4.45	upper rack line
62.0	-4.85	recent high tide
64.0	-5.05	current water level, new sighting position
70.9	-5.50	reef flat
102.5	-5.80	reef flat

- Positive distances are seaward of the bench mark
- Positive elevations are above the bench mark
- Corrections applied to make measurements relative to mean sea level:
  Distance- subtract 67.1 m
  Elevation- add 5.25 m



Sketch diagrams of Tarague (upper) and Talofofo (lower) beach profile locations.

Tarague Beach, Anderson Air Force Base, Jan. 13, 1991 at 2:30pm

GMBP-03.011391.1530

Distance from BM (m)	Elevation (m) rel. to BM	Notes
-2.5	-.2	limit of overwash
0.0	0.0	BM,SW corner of concrete slab under picnic table
12.0	-.1	landward edge of road
25.0	-.1	seaward edge of road
38.6	-.2	new sighting position
52.0	-1.65	
63.0	-2.45	
68.4	-2.80	new sighting position
80.1	-3.45	
92.8	-4.25	
106.3	-5.05	highest rack line, trough, new sighting position
112.2	-5.25	berm crest
115.5	-5.25	berm crest
119.8	-5.70	recent high tide mark
123.4	-6.35	approx. sea level, mid-swash, sample GMBP-03-SA
125.8	-6.75	toe of beach, seaward is exposed beach rock
132.3	-6.85	reef flat, no corals
138.8	-7.30	reef flat, no corals
154.7	-7.35	reef flat, no corals
170.3	-7.60	reef flat, no corals
185.4	-7.55	reef flat, no corals, sand sample GMBP-03-SB

- Positive distances are seaward of the bench mark
- Positive elevations are above the bench mark
- Corrections applied to make measurements relative to mean sea level:
  Distance- subtract 124.5 m
  Elevation- add 6.55 m

Talofofo Beach, Jan. 17, 1991 at 9:30am

GMBP-04.011791.0930

Distance from BM (m)	Elevation (m) rel. to BM	Notes
-39.80	1.00	road, curb?
-29.50	1.10	seaside edge of sidewalk
-26.70	0.35	limit of overwash
-13.00	0.05	
0.0	0.0	BM, floor SE corner roofed pavillion,new shot pt
11.80	0.05	concrete base of water faucet
26.90	-.10	top of scarp
27.90	-.45	base of scarp
40.00	-1.20	beach
44.40	-.95	new sighting point
49.90	-.80	upper swash
53.10	-1.10	sand sample location
58.40	-1.75	water level at 10:07am
63.40	-2.30	
69.30	-2.35	
83.40	-2.55	
100.30	-2.85	

- Positive distances are seaward of the bench mark
- Positive elevations are above the bench mark
- Corrections applied to make measurements relative to mean sea level:
  Distance- subtract 61.1 m
  Elevation- add 2.05 m

APPENDIX II

FIELD DATA FOR COCOS ISLAND BEACH PROFILES
(Profile locations shown in Figure 10)

Beach profile 1, Guam, July, 1990 SOPAC Coastal Mapping Workshop (BMCI 90-1)

Data from T. Bishop, Cook Islands

Lagoon Side of Island, surveyed using an automatic level

Distance from BM (m)	Elevation (m)	Notes
0.0	2.127	BM, plastic pipe set in concrete
5.2	1.537	
10.0	0.893	
15.2	0.195	
31.0	0.023	
45.8	-0.223	
59.0	-0.513	
71.5	-0.598	
89.0	-0.563	
106.0	-0.713	
197.0	-0.873	

- Positive distances are on the lagoon side of the bench mark
- Elevations are relative to approx. mean sea level established by D. Rearic during the workshop at a common survey bench mark
- To correct for incorrect correlation to survey bench mark elevation- subtract 0.041 m

Beach profile 1, Guam after the passage of Typhoon Russ (BMCI 91-1)

Cocos Island, Jan. 15, 1991 at 3:35pm

Lagoon Side of Island, surveyed using an EDMU

Distance from BM (m)	Elevation (m)	Notes
0.0	2.086	BM, plastic pipe set in concrete
4.0	1.391	sighting position
10.0	0.967	high water mark and water level @1535
14.0	0.527	below water level, rock bottom, little sand
18.5	0.082	"
30.0	-0.073	"
46.0	-0.223	"
56.5	-0.493	"

- Positive distances are on the lagoon side of the bench mark
- Elevations are relative to approx. mean sea level established by D. Rearic during the workshop at a common survey bench mark
- To correct for incorrect correlation to survey bench mark elevation- no correction

Beach profile 2, Guam, July, 1990 SOPAC Coastal Mapping Workshop (BMCI 90-2)

Data from Tim Sherwood

Lagoon Side of Island, surveyed using an automatic level

Distance from BM (m)	Elevation (m)	Notes
0.0	1.927	BM
5.7	1.940	
8.5	1.750	
10.2	0.642	erosional scarp
12.0	0.360	high water mark, elev. corrected by B. Jaffe
14.0	0.055	beach edge, elev. corrected by B. Jaffe
27.0	-0.635	
42.5	-0.711	
59.0	-0.783	
76.0	-0.973	

- Positive distances are on the lagoon side of the bench mark
- Elevations are relative to approx. mean sea level established by D. Rearic during the workshop at a common survey bench mark
- To correct for incorrect correlation to survey bench mark elevation- add 0.048 m

Beach profile 2, Guam after the passage of Typhoon Russ (BMCI 91-2)

Cocos Island, Jan. 15, 1991 at 11:15pm

Lagoon Side of Island, surveyed using EDMU

Distance from BM (m)	Elevation (m)	Notes
0.0	1.975	BM
4.4490	2.011	wall
4.644	2.090	wall
5.527	2.096	wall
11.025	0.229	recent high tide mark
13.289	0.007	water level @1113
17.582	-0.377	offshore, under water
35.379	-0.804	"
46.985	-0.699	"
60.146	-0.806	"
87.873	-1.441	"

- Positive distances are on the lagoon side of the bench mark
- Elevations are relative to approx. mean sea level established by D. Rearic during the workshop at a common survey bench mark
- To correct for incorrect correlation to survey bench mark elevation- no correction

Beach profile 3, Guam, July, 1990 SOPAC Coastal Mapping Workshop (BMCI 90-3)

Data from Isireli Nagata, Fiji

Lagoon Side of Island, surveyed using an automatic level

Distance from BM (m)	Elevation (m)	Notes
0.0	1.5	BM, 1.5 m above next point
12.7	0.0	shifted tripod to this location
13.6	-0.388	grass edge
18.1	-0.904	mean sea level
24.5	-1.004	reef flat edge
41.0	-0.856	rubble/rocks
58.4	-1.00	"
78.4	-1.44	reef flat
108.7	-1.402	"
122.0	-1.462	"
155.0	-1.502	"
180.6	-1.595	"

- Positive distances are on the lagoon side of the bench mark
- Elevations are relative to approx. mean sea level established by D. Rearic during the workshop at a common survey bench mark
- To correct for incorrect correlation to survey bench mark elevation- add 0.844 m

Beach profile 3, Guam after the passage of Typhoon Russ (BMCI 91-3)

Cocos Island, Jan. 15, 1991 at ~1:30pm

Lagoon Side of Island, surveyed using an EDMU

Distance from BM (m)	Elevation (m)	Notes
0.0	2.433	BM, top of causeway, 1m from 5th light fixture
1.7	-1.05	scour near piling, survey rod only
2.5	-0.075	channel
2.7	-0.15	"
7.7	0.030	new survey method-
8.276	0.052	
19.330	0.006	
35.611	0.213	landward edge of subareal portion of fan
62.157	0.233	seaward edge of subareal portion of fan
109.707	-0.336	seaward edge of fan

- Survey done from furthest point seaward toward bench mark
- Positive distances are on the lagoon side of the bench mark
- Elevations are relative to approx. mean sea level established by D. Rearic during the workshop at a common survey bench mark
- To correct for incorrect correlation to survey bench mark elevation- subtract 0.089 m

Beach profile 4, Guam, July, 1990 SOPAC Coastal Mapping Workshop (BMCI 90-4)

Data from Michael Ritter, Guam

Lagoon Side of Island, surveyed using an automatic level

Distance from BM (m)	Elevation (m)	Notes
0.0	2.12	BM
12.5	2.30	beach berm
24.5	2.40	"
30.2	0.50	high water mark
37.5	-0.11	low water mark
51.5	-0.32	reef flat
56.8	-1.08	reef flat bottom
61.5	-1.42	

- Positive distances are on the lagoon side of the bench mark
- Elevations are relative to approx. mean sea level established by D. Rearic during the workshop at a common survey bench mark
- To correct for incorrect correlation to survey bench mark elevation- subtract 0.079 m

Beach profile 4, Guam after the passage of Typhoon Russ (BMC1 91-4)

Cocos Island, Jan. 15, 1991 at 2:00pm

Lagoon Side of Island, surveyed using an automatic level

Distance from BM (m)	Elevation (m)	Notes
0.0	2.041	BM, top of sewer inspection vent
6.5	2.67	survey loc.,elev. from graph and notes
15.5	1.686	bottom of slope, limit of erosion
28.5	0.831	high tide water mark
30.0	0.646	water level @1400
36.0	0.296	
51.0	0.241	
71.6	0.011	
100.5	-0.194	

- Water lines in 207 and 208 are at an elevation of 2.896
- Positive distances are on the lagoon side of the bench mark
- Elevations are relative to approx. mean sea level established by D. Rearic during the workshop at a common survey bench mark
- To correct for incorrect correlation to survey bench mark elevation- no correction

Beach profile 5, Guam, July, 1990 SOPAC Coastal Mapping Workshop (BMCI 90-5)

Data from Fale Seneka, Tuvalu

Lagoon Side of Island, surveyed using an automatic level

Distance from BM (m)	Elevation (m)	Notes
0.0	1.838	BM
20.5	1.489	
22.2	0.848	
27.8	0.139	erosional scarp
39.1	-0.201	beach
65.3	-0.210	
82.1	-0.355	
103.0	-0.682	
120.0	-0.972	

- Positive distances are on the lagoon side of the bench mark
- Elevations are relative to approx. mean sea level established by D. Rearic during the workshop at a common survey bench mark
- To correct for incorrect correlation to survey bench mark elevation- no correction

Beach profile 5, Guam after the passage of Typhoon Russ (BMCI 91-5)

Cocos Island, Jan. 15, 1991 at 2:30pm

Lagoon Side of Island, surveyed surveyed using an EDMU

Distance from BM (m)	Elevation (m)	Notes
0.0	1.836	BM, top of sewer inspection vent
25.3	1.511	new sighting location
26.6	0.911	bottom of scarp
44.5	0.236	high water mark
53.3	-0.199	water level @1435
66.8	-0.289	
88.8	-0.624	
111.3	-0.789	

- Positive distances are on the lagoon side of the bench mark
- Elevations are relative to approx. mean sea level established by D. Rearic during the workshop at a common survey bench mark
- To correct for incorrect correlation to survey bench mark elevation- no correction