No. 95 May 15, 1963

ATOLL RESEARCH BULLETIN

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on the British Honduras Reefs and Cays,
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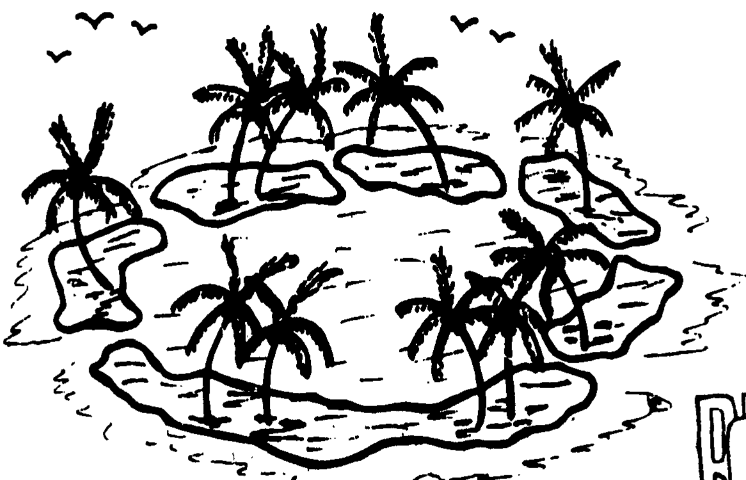
D. R. Stoddart



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THE PACIFIC SCIENCE BOARD
National Academy of Sciences—National Research Council
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ACKNOWLEDGMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs during the past fifteen years.

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PREFACE

Hurricane Hattie passed across the British Honduras coast on October 30-31, 1961, and this paper presents in some detail the effects of the storm on coral reefs and particularly on reef islands in its track. I am much indebted to the Royal Society of London for supporting the re-survey expedition, which lasted from February to May 1962: and also to Miss Evelyn L. Pruitt, Head, Geography Branch, Office of Naval Research, Department of the Navy, Washington, who arranged trans-atlantic transportation for me. Without this great assistance, this investigation would not have taken place. Much of this report necessarily deals with pre-hurricane conditions - in outline only for the atolls (Turneffe, Lighthouse and Glover's Reefs) which have been described in a previous paper (Stoddart, 1962b), in greater detail for the hitherto undescribed cays of the barrier reef. This material was gathered during two earlier expeditions: The Cambridge Expedition to British Honduras 1959-60, led by J.E. Thorpe, and an expedition in 1961 sponsored by the Coastal Studies Institute, Louisiana State University, and the Office of Naval Research, Washington. I am most grateful to my companions on the first expedition; and to Professor R.J. Russell and Miss E.L. Pruitt for their great help on the second. A special word of thanks must go to my assistants, Mr. J.D. Poxon and Mr. Stephen P. Murray, for their aid. On all these expeditions, my plant collections have been identified by Dr. F.R. Fosberg; to Dr. Fosberg, and to Dr. M.H. Sachet, both of the Pacific Vegetation Project, go my very best thanks, not only for this, but for many other kindnesses. This whole project has been carried out under the direction of Professor J.A. Steers, of Cambridge, who has given encouragement and advice at all stages; I trust his influence may be seen in the following pages. Since 1959 I have been supported by funds from the Department of Scientific and Industrial Research, London, held at the Department of Geography, Cambridge, England.

One is embarrassed by the numbers of people who have so freely given their help during these investigations, especially after the hurricane, when most had more to occupy their minds than wandering geomorphologists. I must thank in particular Sir C.H. Thornley and Sir P.G.H. Stallard, successively Governors of British Honduras, for very practical assistance, and the Government of the Colony for customs exemption and other favours; my good friends Dr. and Mrs. Stuart Heap and Mr. and Mrs. Norman Stalker, for their unflagging hospitality; Mrs. Olivia C. Stuart, who both before and after the hurricane welcomed me to her home at no small personal inconvenience; and Belize Estate and Produce Company Limited and the Harrison Line for invaluable help with shipping stores and specimens. My thanks also to the local fishermen who have at one time or another taken me from cay to cay: especially Mr. Philip Young in the Ramrod in 1961, and Mr. Pete Young in the Sunshine and Mr. Maurice Miller in the Joy in 1962. I am grateful also to Government Departments in British Honduras who gave assistance, notably the Forestry Department, Survey and Lands Department, Information Department, Customs Department and British Honduras Broadcasting Service; and in England especially to the Hydrographic Department, Admiralty, under Admiral E.G. Irving, O.B.E. R.N., the British Museum (Natural History), and the Royal Geographical Society. The Coastal Studies Institute of Louisiana State University helped with the loan of instruments. Many persons have given freely of their knowledge and advice, including Dr. Adrian

Richards, Office of Naval Research, London; Dr. Gordon E. Dunn, U.S. Weather Bureau, Miami; Dr. Michael Nancoo, Palisadoes Airport, Jamaica; Captain W.S. Eustace, Master, m.v. Tactician; Mr. M.S. Porcher, Chief Secretary, British Honduras; Colonel Fairweather, British Honduras Volunteer Guard; and Colonel Charnock Wilson, Lately of the British Honduras Coconut Marketing Board. Figure 5 is reproduced by courtesy of the U.S. Weather Bureau; and Figures 2 and 3 are based on information supplied by Dr. Gordon E. Dunn. Figures 23 and 33 are based on Admiralty charts, by permission of Admiral Irving; Figure 14 on the air photographs taken by the R.A.F. in 1962, loaned by Admiral Irving; and Figures 15, 16 and 34 on United States Navy photographs of 1945, supplied by Coastal Studies Institute.

There are inevitably many other persons and organisations I ought to mention; my appreciation is by no means lessened by my inability to name them all here. Perhaps my thanks can best be phrased in the words of one of the first English students of the corals, John Ellis, who in 1755 wrote as follows:

> "Many hints I owe to the conversations of my Friends; and I cannot but acknowledge, that whatever else may have accrued to me from these Pursuits, they, at least, have been the Means of procuring me many valuable Friendships, and an Acquaintance with Men who do Honour to their Country, and their Species."
> (Ellis, 1755, 100).

1. INTRODUCTION

The effect of hurricanes and catastrophic storms on reefs and reef islands has long been appreciated - Charles Darwin cited numerous examples in his "Structure and Distribution of Coral Reefs" (1842, 95-97) - and the literature on reefs is scattered with abundant references to such effects. Wells (1951, 5-7) for example, has catalogued the tremendous morphologic changes resulting from the 1905 and 1918 typhoons at Arno Atoll, Marshall Islands. Yet the fact remains that very few studies have been made of hurricane effects either during or soon after their occurrence. For many years the only such study was Moorhouse's report on the effects of the 1934 cyclone at Low Isles, Great Barrier Reef of Australia (Moorhouse, 1936), and the subsequent comments by Steers (1937) and Fairbridge and Teichert (1948, 75-83). The work at Low Isles has been continued with the excellent report by Stephenson, Endean and Bennett (1958) on the effect on the corals themselves of the 1954 cyclone. In recent years, there has been a great increase in interest in the physiographic, geologic, botanical, biological and human effects of severe storm action, largely as a result of Typhoon Ophelia, which struck Jaluit Atoll, Marshall Islands, on January 7-8, 1958. Seven scientists studied the changes three and a half months after the passage of this storm, and their reports form the only detailed survey of severe storm effects on atoll land areas (Blumenstock, 1958; McKee, 1959; Blumenstock, editor, 1961). Nearly three years after the passage of Ophelia, Jaluit was revisited by a second party to investigate the modification of the hurricane-induced changes, and a preliminary report has already appeared (Blumenstock, Fosberg and Johnson, 1961). Further detailed investigations have also recently been carried out at Ulithi Atoll, Caroline Islands, struck by a typhoon, also named Ophelia, on 30 November, 1960; Blumenstock led a party to that atoll in January 1961, and a report is anticipated. Emery (1962, 59-61) has recently described typhoon effects on Guam.

Hurricane Hattie is of special interest in the study of catastrophic storms in reef areas. While long neglected, the reefs of British Honduras have recently seen increasing activity by a number of workers. Vermeer (1959) has published a general account of the whole reef area based on a reconnaissance study made in 1957. Dr. Edward G. Purdy, currently investigating barrier reef lagoon sediments, spent several seasons in the area before the hurricane, and has returned since. The present writer began work on the cays in December 1959, and in the course of two expeditions (December 1959 - June 1960; May - August 1961) completed mapping of some seventy reef islands, with comprehensive ground and air photo coverage, plant collection, and incidental reef observation. Accounts of part of this work have already appeared (Stoddart, 1960, 1962a, 1962b). The programme of mapping was completed less than three months before Hurricane Hattie struck the area on October 30-31, 1961. This afforded what is probably a unique opportunity to study in detail the effect of hurricanes on reef islands, on the basis of maps and other data obtained immediately before the hurricane struck. First reports indicated appalling devastation at the capital, Belize (e.g. Boga, 1961), and it was soon apparent that the hurricane must have affected much of the northern barrier reef and probably Turneffe and Lighthouse Reefs also. With Royal Society support I was able to spend February-May 1962 in British Honduras: during this re-survey expedition I was able to fly over the whole length of the atoll and barrier reefs, re-photograph all the cays from the air, fly along the whole coastline of the country, and, in a number of sea trips, re-map cays in the devastated areas of the barrier reef, Turneffe Islands and Lighthouse Reef.

Description of the Reef Area

British Honduras is situated in the south-eastern part of the Yucatan Peninsula, Central American mainland. The southern part of the country consists of an upfaulted block of Palaeozoic metamorphosed sediments and igneous intrusions, rising to 3650 feet above sea level. South of these Maya Mountains is a lower-lying hilly area of Cretaceous and Eocene limestones, shales and sandstones; the limestones also overlap the western part of the Maya Mountains, and constitute the whole of the northern lowlands of British Honduras. The Yucatan Peninsula north of British Honduras is also built of low-lying limestones, previously thought to become younger northwards, but now shown by Butterlin and Bonet (1961) to exhibit a less regular pattern and to be mainly Eocene. Fault systems in the British Honduras highlands are dominantly east-west, and in the northern lowlands northeast-southwest (Ower, 1929; Flores, 1952; Dixon, 1956).

The greater part of the east coast of Yucatan is straight and featureless, apart from two mangrove-fringed embayments at Bahia Espiritu Santo and Bahia de la Ascension. Reef development along this coast appears to be poor (Edwards, 1957). South of the British Honduras border, however, the coastline becomes widely embayed and overlooks a broad but shallow coastal shelf, fringed on its outer edge by a barrier reef and cays. This reef extends with few breaks, following an arcuate course, for 130 nautical miles, to within 16 miles of the mainland Honduras coast at the foot of the peninsula. It encloses a lagoon, on the coastal shelf, which increases gradually in depth from 1-2 fathoms in Chetumal Bay to 25-30 fathoms at its southernmost extent. Cays on the barrier reef are of several types: on the barrier itself, sand and shingle islands have been built by wave refraction at many major reef gaps. Lagoonward from the barrier, a number of larger cays, with sandy seaward rims and mangrove swamp to leeward, rise from a "low platform" at 2-4 fathoms depth, which extends along the whole length of the shelf edge, and from which the present reefs rise. Clusters of mainly mangrove islands within the coastal lagoon are rather localised: one group lies south-east of Belize, at the inner end of a remarkable sinuous channel which intersects the barrier reef with depths of up to 33 fathoms; a second group is found in the central part of the lagoon, between Placencia village and the prominent Gladden Spit elbow; and a third group is found near the mainland coast between Punta Ycacos and Punta Gorda.

Outside the barrier reef the sea deepens rapidly - soundings of 4800 feet are found within 3½ miles of the southern barrier reef at

Ranguana Entrance. Three atolls rise to the surface from this deep water outside the barrier. Turneffe Islands, more properly a shallow, reef-fringed bank covered with much mangrove, has a number of small sand and shingle cays on its exposed eastern reefs. Lighthouse Reef, a true atoll with lagoon depths averaging 2-3 fathoms, lies 11-18 miles seawards from Turneffe Islands. Before the hurricane there were four small sand cays on this atoll, and two much larger sand and mangrove islands. Finally, the Glover's Reef atoll, with lagoon depths of up to 24 fathoms, lies south of Turneffe and Lighthouse Reefs; it has six sand and shingle cays on its south-east reef. All these atolls are elongated in a generally NNE-SSW direction, and are 30½, 22 and 16 miles long respectively. All of them, too, appear to be bounded by steep slopes, especially on their east sides: thus there are soundings of up to 1100 fathoms within 3½ miles of the east reefs of Lighthouse Reef. It seems quite probable that these gross features of the reefs are the result of coastal faulting, resulting in alignment of the reefs and pronounced submarine relief. The atolls are described in detail in my previous Bulletin (Stoddart, 1962b; hereafter referred to as ARB 87).

Maximum elevations of reef islands are greatest on the exposed cays of Lighthouse and Glover's Reefs: 10.5 feet before the hurricane at Half Moon Cay, Lighthouse Reef, and 9-10 feet at Long Cay, Glover's Reef. On the east reefs of Turneffe most of the sand cays are 3-5 feet high; shingle is present in lesser amounts than on the more exposed cays, and what is found is of finer calibre. On the sections of the barrier reef sheltered from the prevailing winds by the atolls the cays are wholly built of sand, lack protective shingle ridges, and rarely rise more than 3 feet above the sea. Along the southern barrier reef, not protected by the atolls, shingle ridges are found, rising 5-6 feet above sea level (Stoddart, 1962a).

Climatic data for this area are meagre in the extreme, and the only long-term records available are for the coastal capital, Belize (Wallace and Spano, 1962); the most recent survey of mainland climate is by Romney and others (1959, 15-22). Rainfall increases on the mainland from less than 20 inches on the north coast of Yucatan to more than 170 inches on the southern coastal lowlands of British Honduras, and to probably over 200 inches on the Maya Mountains. Belize itself has an average of 69.6 inches. On the barrier reef, conditions probably reflect the coastal pattern: Ambergris Cay in the far north probably has 50-60 inches per annum; the southernmost barrier reef cays may exceed 80-90 inches. The three atolls may have about 70 inches per annum. Most rainfall falls from June to December, with heaviest monthly totals in September and October, and a pronounced dry season from March to May. Variability from year to year is considerable. Winds are dominantly easterly, except for short periods in winter, when cold "northers" reach the area from North America. Temperatures are high, with mean maximum monthly temperatures at Belize varying from 81-88°F and mean minimum monthly temperatures from 68-75°. The highest temperatures are experienced from April to September. At Rendezvous Cay, barrier reef, mid-day temperatures from September 1959 to May 1960 ranged from 79 to 89°.

The main coastal current flows from the south-east, from Cabo Gracias á Dios northwards to the Yucatan Channel. However, British Honduras waters experience a counter-current, flowing anti-clockwise in the Gulf of Honduras, giving predominantly southerly water movements over most of the coastal shelf, sometimes extending out to the atolls, depending to a considerable extent on local wind conditions. Mean monthly sea temperatures at Rendezvous Cay ranged from 26.5 to 29.8°C, September 1959 to May 1960. Tides are less than 2 feet throughout the area, and local movements of sea level may reflect wind influence to a greater extent than purely tidal movements.

Apart from villages on Ambergris Cay and Cay Caulker, barrier reef, each with about 300 inhabitants, the population of the reef islands is restricted to a semi-permanent lighthouse staff on certain cays, and a number of temporary residents, mainly fishermen and coconut workers. On the three atolls, for example, before the hurricane, there were seven settlements on Turneffe (two associated with lighthouses), four on Lighthouse Reef (two of them associated with lighthouses), and three on Glover's Reef. The total population of the atolls probably never exceeded 50 persons. On the barrier reef, apart from lighthouse stations and the two villages, only a dozen or so cays were occupied, and the majority had no permanent houses and were visited infrequently. Most of the temporary visitors had permanent homes in Belize or the coastal settlements, chiefly Stann Creek, Mullins River, Monkey River and Placencia. The greatest temporary increase in population occurred during public holidays at St. George's Cay, with about 40 houses, used as a holiday resort by people from Belize.

For charts of the atolls, reference should be made to Figures 14, 27 and 37 in ARB 87. Detailed surveys of various dates provide the basis for excellent Admiralty charts of the barrier reef lagoon. See particularly Admiralty charts:

522. Belize Harbour (1957-1958)

959. Approaches to Belize (1921-1922)

1204. West Indies from Belize to Cabo Catoche (1830-1837)

1573. Honduras Gulf (1835-1841)

1797. Ranguana Cay to Columbus Cay (1830-1841)

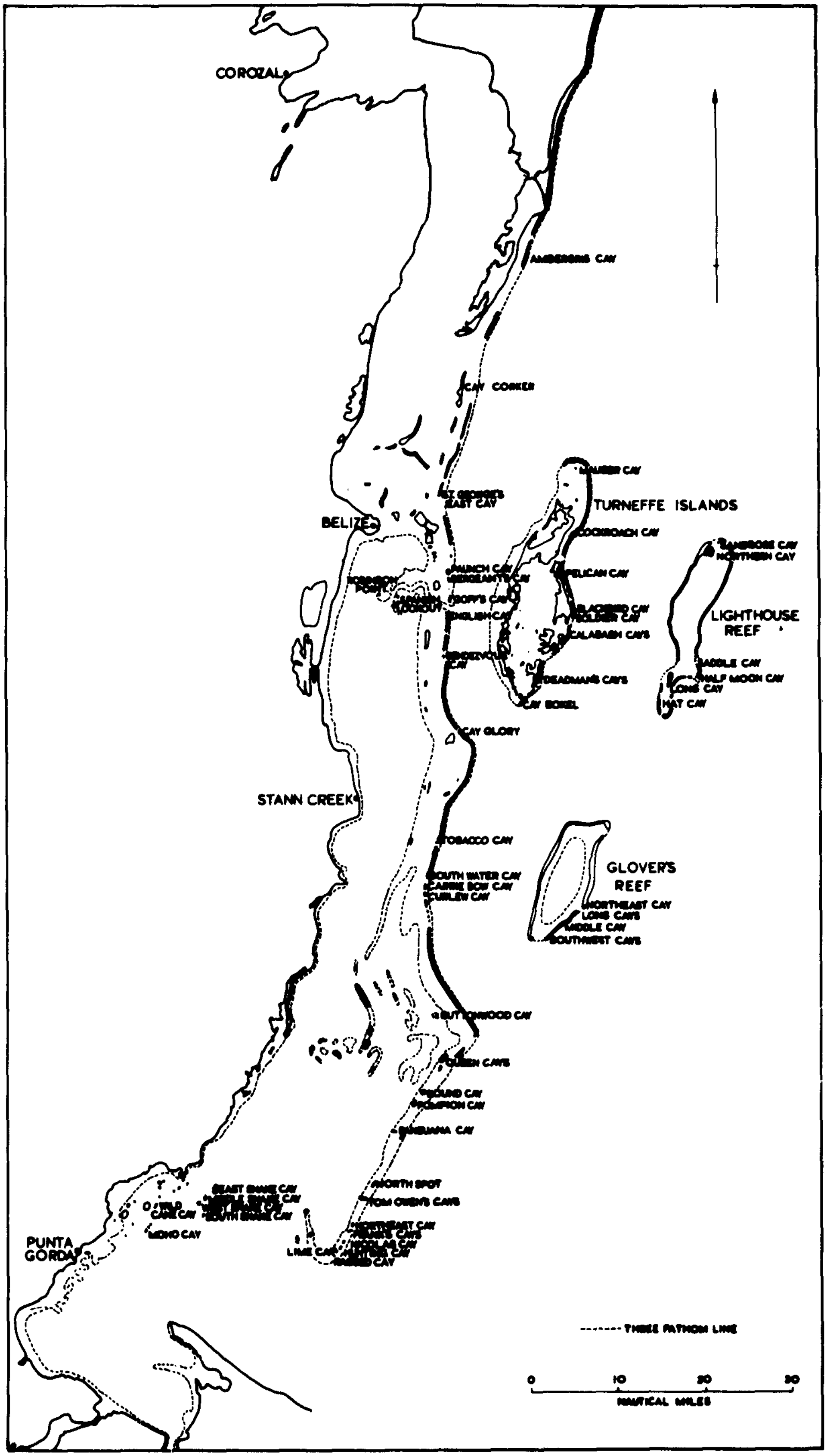


FIG. I – LOCATION OF BRITISH HONDURAS CAYS

II. HURRICANE HATTIE

Hurricane Hattie has been the most important storm to affect the reefs and cays of British Honduras for many years. It is comparable in intensity to Hurricane Janet of 1955, which, however, passed to the north of the main reef area and devastated Corozal and Chetumal (Pagney, 1957). Storms of similar magnitude have occurred in 1945 in Toledo District; in 1931, causing great damage and loss of life at Belize (Cain, 1933); and in 1787, when Belize was almost completely destroyed. Details of these and other earlier hurricanes are given in Appendix 1. Hattie achieved its main notoriety for the great damage it inflicted to life and property in the coastal settlements. Much of Belize and Stann Creek were badly damaged, though not beyond the possibilities of repair, and some smaller villages were almost entirely wiped out. Damage at Belize was so considerable that tentative plans were made for the re-location of the capital at Roaring Creek, 50 miles inland, and the extent of property damage has been roughly estimated at £20 m.* (Rickards, 1962). Of the approximate total of 250-260 deaths, most occurred in the larger coastal settlements: 94 in Belize City, 60 in Stann Creek Town, and 46 in Mullins River, according to the official list. Numbers of deaths on the cays are in the nature of things difficult to determine, but the following list, based on the official list, gives a close approximation; additions have been made on the basis of information collected during the 1962 expedition.

Table 1. Mortality on Cays during Hurricane Hattie

Barrier Reef:	Cay Caulker	14
	Rendezvous Cay	2
Turneffe Islands:	Berry Cays	3
	Soldier Cays	7
	Cay Bokel	6
	Calabash Cays	10
	Bull Bay	1
Lighthouse Reef:	Northern Cay	1
	Long Cay	1
Total:		45

It is said that no person who survived the actual storm subsequently succumbed to disease or other cause contingent on the hurricane, largely as a result of the efforts of United States and British military forces. However, persons were found up to 13 days after the storm stranded on cays, particularly on the Turneffe lagoon mangroves, and some died soon after rescue. It is quite possible that others survived for a period of days and died before being found. Similarly, it is not possible to be certain that all persons in the reef areas have been accounted for.

It is not the purpose of this chapter to discuss the meteorology of Hurricane Hattie, or the reasons for its unusual westward recurvature on 29-30 October. For discussions of the purely meteorological aspects, see Dunn and others (1962) and Nancoo (1962**). This chapter sets out to record as accurately as possible changing wind and wave conditions

* $ 33,600,000

** Nancoo, M.E. 1962. Hurricane 'Hattie'. Weather 17: 295-304.

during the passage of Hurricane Hattie, as a necessary preliminary to understanding the resulting changes on reefs and cays. The first part is based on meteorological information collected by the U.S. Weather Bureau (U.S. Weather Bureau, 1962); the second on information gathered at numerous localities in British Honduras.

Development of Hurricane Hattie

Hurricane Hattie was first identified as a tropical storm at Lat. 12.9°N, Long. 82.4°W, near San Andres Island, off the east coast of Nicaragua, during the afternoon of 27 October 1961. The disturbance followed an afternoon of light winds on the morning of the 27th and on the previous afternoon. The first advisory for the tropical storm was issued at 1600 h Belize time, 27 October, at about the time that Hattie passed close to San Andres (all times in this report, except where otherwise stated, are correct for Belize; add 1 hour to convert to Eastern Standard Time, and 6 hours to convert to Greenwich Mean Time). Steady winds of 70 knots were experienced at San Andres, gusting to 90 knots, with a minimum pressure at 0800 h, 28 October, of 991 mb. At this time gale force winds extended 125 miles to the north and 60 miles to the south of the storm centre, which was moving slowly northwestwards at about 8 mph. Northerly movement is usual with hurricanes originating in the San Andres area, and Hattie continued along this course on 28 and 29 October, at 6-7 mph. During the morning of 28 October (1000 h), the storm intensified: minimum pressure reported by aircraft penetration fell to 28.62 in (969 mb), with hurricane force winds extending 40 miles from the centre at 13.9°N, 81.6°W, maximum winds near the centre of 125 mph. and gale force winds extending 140 miles to the NE and 70 miles to the SW. Minimum pressure fell during the afternoon to 28.23 in (956 mb) at 1600 h, and gale force winds extended for 150 miles in all quadrants. During the night the hurricane continued to intensify, pressure falling to 28.11 in (952 mb) at 2200 h, 28 October. The following morning the storm continued to move northwards at about 9 mph; at 1000 h, 29 October, gale force winds extended for 185 miles in the eastern and 140 miles in the western semi-circle from the centre, now at 17.4°N, 81.3°W. Advisory 8 issued by the Miami Weather Bureau at this time warned of destructive winds and high tides in the Cayman Islands and Cuba.

During 29 October, however, Hurricane Hattie began to move toward the northwest at a slightly faster rate (13 mph). Reconnaissance aircraft reported wind speeds of 128 mph in the northern sector and 113 mph in the southern sector at 5000 ft. By 1600 h, gale force winds extended for 200 miles northeast of the centre and for 140 miles southwest. When the storm reached within 100 miles of Grand Cayman Island, however, the rate of forward movement decreased sharply, and late on the 29th and early on the 30th October, Hattie began to move slowly towards the Yucatan Peninsula. At 0100 h, 30 October, gale force winds extended 200 miles to the northeast and 140 miles to the southwest of the storm centre, but winds at both Grand Cayman and Swan Islands remained below hurricane force as Hattie passed between them.

In the early hours of 30 October, Hattie entered its third phase, moving westward at the rapid rate of 12-15 mph, and intensifying, with central pressure falling to 27.82 in (942 mb) at 0400 h. Advisory 11, issued at this time, was the first to warn of high winds and tides along the east coast of the Yucatan Peninsula. Advisory 12, at 1000 h, 30 October, estimated storm tides at 15 feet above normal where the centre reached the coast, probably between Belize and Chetumal, Quintana Roo. Minimum pressure was now down to 27.29 in (924 mb); gales extended 230 miles to the NE and 140 miles to the SW. An intermediate bulletin from Miami stated that "During the forenoon Swan Island has been experiencing winds of 50 to 60 mph, with gusts of 60 and 70 mph. Waves 20 to 25 feet high have been lashing the island. About eleven and one half inches of rain fell at Grand Cayman Island during the 24 hours ending at 7 a.m. (i.e. 0600 h) with 7.80 inches during the six hours between 1 and 7 a.m. (0000-0600 h, 30 October)". An extreme minimum pressure of 920 mb was calculated for Hurricane Hattie at 1600 h the same day (Dunn and others, 1962, 116). As the storm moved landwards during the afternoon and evening of 30 October, it became clear that the centre would cross the coast nearer to Belize than Chetumal, and would cause great destruction. Winds near the centre were estimated at 150 mph, gusting to 200 mph, accompanied by high tides, torrential rains, and gale force winds, extending at 2200 h for 230 miles in the NE semi-circle, and over all of the Gulf of Honduras to the south-west.

At 2200 h, 30 October, Hattie was located at 17.8°N, 86.6°W, 100 miles ENE of Belize. At 0100 h, 31 October, it was 75 miles ENE of Belize. At 0300 h, 31 October, Hattie was within 30 miles of Belize, at 17.4°N, 87.8°W. Figure 2 shows the track of the hurricane based on aircraft penetration and radar fixes up to this time. Advisory 15 from Miami stated:

> "The area from Belize to Chetumal will have hurricane force winds all morning and tides will be 10 to 15 feet above normal with salt water flooding the low areas for many miles inland. Torrential rains will also add to the flooding. Highest winds are estimated at 150 mph near the centre and gales extend from the coast to 200 miles east of the centre. The most extreme conditions, 150 mph winds and 15 foot tides with huge waves, will occur at Belize in the next few hours and all precautions for the protection of life and property should be continued."

Even before this Advisory was issued, Belize radio had ceased to function (at 0300 h, 31 October) and the northern barrier and atoll reefs were experiencing hurricane conditions.

Hurricane Hattie in British Honduras Waters

The track followed by Hattie across the coastal area of British Honduras can be plotted from a variety of sources. These include (a) a few radar positions, given in Figure 2; (b) local barometric records; (c) eyewitness accounts of wind, weather and sea conditions; (d) physiographic effects on reefs and cays; and (e) vegetation effects, chiefly direction of fall of coconut palms. Eyewitness accounts in the reef area are few in number for several reasons. The hurricane passed during the night and early morning, and this, together with the unusually severe conditions, impeded observation. The total population of the cays is at any time small; many moved to the mainland before the hurricane struck; many who remained were drowned, and a high proportion of those who survived have since moved to the mainland and cannot be easily traced. Appeals for information from persons on the cays at the time of the storm, made over the British Honduras Broadcasting Service Radio, met with no response. The most important sources of information are the lighthouse keepers, and also the Master of the m.v. Tactician, then in Belize harbour. Information from these sources is collected here; data derived from study of physiographic and vegetation change are not considered here, and have not been directly used to reconstruct hurricane events.

Half Moon Cay, Lighthouse Reef

Half Moon Cay lies 60 miles due east of Belize, and with Sandbore Cay at the north end of the same reef, was the first to experience Hurricane Hattie. Mr. Austin Garbutt, lighthouse keeper, and Mr. George Young, resident on the cay since 1928, state that the first sign of the storm came during the afternoon of Sunday, 29 October. Heavy swells from the east refracted into the southeast bay and washed over the main seaward sand ridge, 9-10 feet high, from about 1530 h. This heavy swell continued until dawn on 30 October, and was followed by calmer seas. It is interesting to note that this wave action is comparable to that experienced at the height of Hurricane Abby (1960) and Hurricane Anna (1961), and Mr. Young, who had seen many hurricanes before, including those of 1931 and 1945, was of the opinion on the morning of 30 October that the storm had passed. At 1530 h, when the swell began to break, Hurricane Hattie was just beginning to turn to the west, and the centre was located some 400 miles east of Half Moon Cay.

During the morning of 30 October, the wind was northerly, force 2-3, freshening in the afternoon and shifting to westerly about 1500 h. Force 5 winds continued from about 1500 to 2300 h, when they began to draw to the southwest and freshen further. Heavy seas began to overtop the seaward sand ridge continuously from about 2200 h. The aneroid barometer was falling rapidly at this time. By 0100 h, 31 October, the wind was southerly, blowing with hurricane force, and the aneroid reached its lowest level of 27.85 in, where it remained steady for 2-3 hours. Between 0100 and 0200 h the wind reached its maximum force, blowing from the south and southwest, and knocking many coconut trees down. South and southwesterly winds continued to blow hard until 0400-0500 h, and waves continued to wash across the cay until about 0400 h. By 0900 h, 31 October, the storm was clearly over, and the winds had fallen to force 4 or 5.

Sandbore Cay, Lighthouse Reef

Mr. Roy Young, Lighthouse keeper, survived the storm in a concrete hurricane shelter on the cay, despite extreme devastation which demolished the lighthouse and all other buildings and cut the cay into three parts.

As at Half Moon Cay, heavy swells were experienced on 29 October, but the leading edge of the storm itself did not approach the cay until the afternoon of 30 October. At 1300 h, 30 October, winds from the northwest did not exceed force 3-4. Heavy wave activity in advance of the storm had begun by 1430 h, and refracted waves broke heavily on both north and south shores. The concrete walk, 75 yards long, connecting cay and lighthouse, built in 1945, was very soon completely destroyed. At 1530 h Mr. Young was in wireless communication with Half Moon Cay for the last time. By 1600 h it was decided to move into the concrete hurricane shelter, as the wind was still rising. By this time the cay surface was covered with $1\frac{1}{2}$ feet of water; an hour later this had increased to 2-$2\frac{1}{2}$ feet, and kerosene drums were beginning to float away. The wind was still northwesterly. By 1930 h, the wind was "very high", and the barometer was falling rapidly. At 2230 h, the sea had risen so much that the floor of the hurricane shelter, approximately 8 feet above the sea, was flooded to a depth of one foot. At midnight the wind dropped suddenly and the aneroid barometer reached its minimum of 27.4 inches. It remained at this level until 0130 h, 31 October, when it began to rise. Hurricane force winds returned from the south at 0100 h, and at the same time the water level began to fall. Mr. Young considered that the southerly winds following the calm were "much harder" than the northwesterlies preceding it. From about 0200 h, however, the wind began to fall, and drew round to the east. By dawn, 0700 h, the wind had fallen to force 7, northeasterly, with much rain.

All houses on the cay disappeared except the single concrete hurricane shelter. The lighthouse was demolished and all fishing boats disappeared. During the hurricane the shelter held four adults and five children, who would otherwise have lost their lives; afterwards they were joined by nine others from Northern Cay, and all managed to survive until taken off by a passing ship six days later.

Mauger Cay, Turneffe

Mr. Thomas Young, formerly keeper of the Mauger Cay light, states that during the evening of 30 October, the wind was from the north, and gradually increasing. At midnight the inhabitants of the cay went to the top of the lighthouse and spent the rest of the night there. By this time the wind was already blowing very hard, and continued to increase, still from the north, until 0400 h, 31 October, when it veered round to the southeast. From 0400 to 0600 h the wind blew with its greatest force, and all the houses on the cay were destroyed at this time. After 0600 h, the wind began to moderate, and continued to do so throughout the morning. There is no precise information on the height of the sea. Mr. Young states that it began rising late on 30 October, and at dawn on 31 October covered the cay to a depth of 5-6 feet.

Cay Bokel, Turneffe

Only sparse information is available from Cay Bokel, where six people died. At 1700 h, 30 October, the wind was already strong, and accompanied by heavy rain. At 2100 h, the wind had intensified to hurricane force, from the northeast, and houses were collapsing. At midnight, 30-31

October, the wind abated suddenly, and there was a lull of 10 minutes, before the wind returned from the southeast. Heavy seas covered the island and washed people away. At 0500 h on 31 October the wind began to fall, and the sea surge to abate. (This information is given in writing in a report at the Chief Secretary's Office in Belize, but I have not been able to discover its source. The times given are clearly incompatible with information from other cays; the occurrence of a brief lull so far south is interesting. Discrepancies are clearly the result of the very severe damage caused by the storm; the island completely disappeared and even the lighthouse overturned.)

Cay Caulker, Barrier Reef Lagoon

Cay Caulker lies to the north of the hurricane track, some 20 miles northeast of Belize. The police constables on the cay made the following report. The wind began to freshen at 1600 h, 30 October, blowing from the northwest. At 1700 h heavy waves were breaking on the beach, and the wind was increasing. At 2300 h, the wind changed from northwest to northeast, and was estimated to be gusting from 175-200 mph. At midnight, large swells were rolling over the cay near Cay Caulker Village. The schoolhouse collapsed under the stress of wave action at 0300 h, 31 October, with the loss of 14 lives. Most of the damage was said to be caused by five large distinct waves. The highest water mark was 15 feet above sea level, and the sea did not recede until 0900 h.

Belize City

Advisory 11 from the Miami Weather Bureau, the first to warn of hurricane conditions on the Yucatan coast, was received in Belize at 0700 h, 30 October. As a result, at 0800 h, Government ordered the hoisting of the warning signal "Red I" throughout British Honduras, and of "Red II" in Corozal District, where the storm was expected to strike. At 1100 h, "Red II" was ordered throughout the country.

A number of instrumental records are available from Belize City (figure 4). The most reliable is probably that from the Meteorological Service, Stanley Field, 14 miles west of Belize, equipped with a barograph and Dines anemometer; copies of these records have been published by Dunn and others (1962, 116-117). The official Belize barograph was inadequate to record the lowest pressures experienced during Hurricane Hattie; the partial trace in Figure 4 has been supplied by Colonel Fairweather, B.H.V.G. I am also grateful to Colonel H.P. Charnock Wilson for the use of his private barograph trace, Figure 4, the only complete record for Belize City itself. Finally, the Police Log Book of Hurricane Hattie contains regular readings of the Police Station mercury barometer, and readings from Mr. M.S. Porcher's aneroid, also at the Police Station.

Pressure in Belize fell slowly but steadily from 1200 h (29.8 in) to 2200 h (29.6 in) on 30 October, and then began to fall more rapidly. At midnight, 30-31 October, with pressure at the Police Station 29.53 in, the wind increased to gale force, from the north-north-west, and rain began to fall. Wind speeds at Stanley Field at this time varied from

15-30 mph, force 5-6. At 0100 h, 31 October, the Police barometer fell to 29.4 in. According to the Police Log Book winds had already reached hurricane force, but the Stanley Field anemometer at this time recorded no gusts in excess of force 8, 47 mph. Electric power failed in Belize at about this time, but radio transmission continued using emergency generators. At 0200 h, the Police Log recorded winds of "probably" 100 mph. (cf. Stanley Field winds ranging from 20-60 mph), still from the NNW; pressure had fallen to 29.2 in. At 0300 h, the emergency generators failed and BHBS ceased transmission. By 0400 h, the Police barometer read 28.68 in, and the wind was reported as rising steadily, and gusting probably to 150-200 mph. Buildings in Belize were beginning to disintegrate, and roofs were being torn off. Stanley Field at this time recorded winds of 30-80 mph. At 0500 h, the lowest reading was made on the Police barometer, 28.35 in. The Charnock Wilson barograph read 28.5 in. at 0500 h, and 28.45 in at 0600 h. High winds and heavy rain continued. At Stanley Field the wind continued to increase, gusting to 115 mph when the record ceased shortly after 0500 h (Figure 5). Between 0400 and 0500 h, the wind direction changed from NNW to N, and then slowly began to draw to the east. Easterly winds were continuous from about 0700 h.

At 0600 h, pressure began to rise rapidly, shown in Belize by the Police and Charnock Wilson barographs, and by the Stanley Field barograph. Minimum pressure as the hurricane centre passed to the southeast of Belize was probably about 28.4 in. in the City and 28.7 in at the airfield 14 miles to the west. According to Dunn and others (1962, 116) the pressure gradient between the airfield and the hurricane eye 20 miles southeast of Belize was some 45-50 mb, 1.5 in. At 0600 h also, the wind reached its greatest intensity. No instrumental records are available, but according to Dunn and others (1962, 117) "reliable estimates" put the wind speed at 140-160 mph, perhaps gusting in excess of 200 mph. Between 0700 and 0800 h the wind fell considerably to about 70 mph, and after 0900 h declined further to 30-60 mph (Stanley Field). As the wind drew to the east and reached its maximum force at about 0600 h, the sea-level began to rise. At 0600 h there was 1 foot of water in the Police Station yard; by 0800 h the depth had increased to 10-12 feet. The whole city was inundated, the streets filled with thick mud, and mud, sand and weed thrown high above the extreme high surge level by the considerable wave action which still continued. By 1030 h the wind had fallen in Belize to "light to moderate", the barometer at the Police Station had risen to 29.5 in, and the water in the streets had receded to a depth of only 3 feet. At mid-day, however, there was still 2-3 feet of water in many streets, and people were paddling about in doreys (dugout canoes). First radio contact with the outside world was made at 1500 h on the day of the hurricane, and first assistance arrived with a scheduled flight of TACA airlines on the early morning of 1 November.

Barrier Reef Lagoon

The most complete record of changing conditions during Hurricane Hattie comes from m.v. Tactician, a new Harrison Line vessel on its first voyage to Belize. The following account is based on observations made by the Master, Captain W.S. Eustace, and very kindly placed at my disposal.

On 29 October, the Tactician was at Stann Creek. The barometer was steady at 29.8 in; and the wind was northwesterly, force 3. In the evening the ship returned to Belize. On the following day, 30 October, at 1000 h, heavy seas were reported breaking on the outer reefs, and it was decided to move from Belize harbour to a point south of Grennel's Cay (Triangles). The ship anchored in 9-11 fathoms water, 5 miles south of Grennel's Cay, at 1600 h. The barometer was still steady at 29.7 in; the wind had increased to force 5. The sky was overcast, with alto-nimbus, and there were light showers. At 2000 h the barometer read 29.65 in, temperature 75°F, sky heavily overcast, with moderate showers. At midnight, 30-31 October, the wind was west-north-west, and squally; barometer 29.45 in. The showers continued.

In the early hours of 31 October the wind increased, reaching force 10 by 0200 h, but still WNW. The sky was overcast, with frequent showers, and a short sea was rising. Captain Eustace could still see the lights of Belize, English Cay and Colson Point at this time. At 0215 h, the winds reached hurricane force and the ship began to drag her anchors. Observation of the lights showed drift of 2 miles in 25 minutes, beam on to the wind and rising sea. Captain Eustace notes that "Being in the lee of the land it is rather surprising that the latter was so high and rough, as if the wind was blowing down, rather than horizontally." He was unable to bring the ship up into the wind, and continued to go astern on the engines. By 0300 h, Captain Eustace found that "the wind was stronger than any I have ever experienced in my life." It continued from the WNW; the air was full of sea, spray and rain; and the barometer, at 28.5 in, was falling rapidly. The Tactician had developed a list of 20° with the wind, and the steep short sea pushed her another 15-20°. At 0400 h, the wind was estimated at 150 knots (175 mph), WNW. The barometer continued to fall steeply, and had reached 27.67 in. Rainfall was now heavy. At 0500 h the barometer read 27.30 in, and at 0515 h 27.40 in. The wind dropped suddenly at this time to a moderate breeze.

During the lull, which lasted three-quarters of an hour, a "very sickly" moon and a few stars could be seen, partly obscured by scud from the ESE. A confused sea and swell came predominantly from the SE, gradually increasing until at 0600 h the wind settled in again from the SE, force 5-6. The barometer, now reading 27.6 in, continued to rise. By 0615 h, with the barometer 27.72 in, the wind was back at hurricane force, and the sea rose likewise. This time it seemed to have more force than before the lull, partly, Capt. Eustace surmised, because of deeper water over the reefs as a result of the storm surge. Wind, spray and heavy rain penetrated everywhere. The ship again swung beam on and heeled over; and again she was forced to go astern on the engines, dragging the anchors. At 0700 h the barometer stood at 28.10 in. and the wind, from the ESE, was gusting to over 170 mph. Rain came in squalls, but the heavy cloud cover was noticeably higher. By 0900 h the wind had eased to force 12, and the ship began to respond at last to the engines. The barometer had risen to 29.33 in; visibility was 3 miles. At mid-day, with wind force 9, the steep rise of the barometer was checked at 29.63 in. A cay could be seen at a distance of 4½ miles, probably one of the Colson Cays. Cloud was forming and lifting. At 1300 h the Tactician returned to Belize with an easterly gale blowing. "The sea was a milky colour", noted Capt. Eustace, "littered with palm trees and many dead fish. On reaching the Belize anchorage depths about 4 feet more than usual were noted" (as a result of the storm surge).

The Tactician was clearly in the direct path of the hurricane as it crossed the barrier reef lagoon. The lowest pressures recorded were 931.5 mb (27.51 in), corrected to 27.40 in, on the mercurial barometer, and 27.30 in. on the aneroid, both at 0500 h. The instruments were checked a few days later at Houston, USA, and found to be correct.

Tobacco and South Water Cays, Barrier Reef

Brief accounts are available from inhabitants of these islands, which are only 5½ miles apart. Both lie well to the south of the hurricane track. At Tobacco Cay, high winds are said to have begun during the evening of 30 October, mainly southwesterly. In the early hours of 31 October the wind moved to the south and increased in violence; coconut trees began to fall at about 0800 h. The sea level did not rise, but high waves washed over the margins of the cay, especially on the south side. At South Water Cay Mr. Joe Garbutt states that high winds began about 1900 h, 30 October, from the northwest. About 0100 h, 31 October, the winds moved to the southwest and continued in this quarter till 0500 h. From then until 1100 h southerly winds blew with great violence; by midday the wind was abating. The cay was not inundated, but high waves washed over the south and southwest shores.

Stann Creek and Nearby Area

The District Commissioner, Stann Creek, which suffered very heavy damage, reports as follows. At midnight on 30-31 October, heavy rain was falling, and the wind was increasing. By 0200 h, 31 October, winds had reached gale force, blowing from the west. Between 0330 and 0430 h the wind gradually shifted from west to south, continuing to blow at hurricane force, and gradually moving to the southeast. Estimated windspeeds reached 150 mph, with gusts to 200 mph. At 0500 h the sea surge began, reaching its maximum height at 0900 h. Low-lying areas in Stann Creek Town carried 10-12 feet of water, and near the Police Station and in Front Street the water was 4-5 feet deep. Between 0900 and 1000 h the wind began to abate, the gusts became weaker and more sporadic, and the water began to recede. By 1100 h it was possible to walk through the streets.

The storm centre appears to have passed directly over Mullins River, 10 miles north of Stann Creek, where all but three houses out of 300 were destroyed. Here the storm surge is said to have risen as high as 20 feet above sea level.

Melinda Forest Station is situated 5 miles inland from Stann Creek Town, in the Stann Creek Valley; Mr. R. Langley gives the following account of conditions. The wind was blowing to a storm by midnight on 30-31 October. By 0200 h, 31 October, the wind was "strong" and westerly. Hurricane force winds blew from the west until 0715, when the wind dropped suddenly and there was a distinct lull until 0800 h. Immediately after the lull the wind returned with full hurricane force, but blowing from the east, and a little from the southeast. By 1100 h it had abated somewhat, and by mid-day approximated only to a "very heavy storm". It is significant to note that the three-quarter hour lull was not experienced at Stann Creek, only 5 miles away.

Mango Creek

Mr. I.A. Fadden, Belize Estate and Produce Company Manager at Mango Creek, a coastal inlet near Placencia, 28 miles south of Stann Creek, made barometer readings during the storm (Figure 4). At midnight, 30-31 October, pressure stood at 29.75 in; it fell steadily throughout the early hours of 31 October, reaching a minimum of 29.01 in at 0930 h. The first heavy gusts of wind came at 0430-0500 h from the south-south-west, and then increased to an estimated 100 mph by 0730 h. At 0930 h the wind shifted suddenly to the south, and the highest winds of the whole hurricane were experienced at about 1000 h. At 1110 h, the wind had shifted to south-south-east. After 0930 h the barometer rose very rapidly, and by 1300 h was almost back to the pre-storm level.

Punta Gorda

Punta Gorda is situated on the coast of the Gulf of Honduras, near the southern borders of British Honduras. The Acting District Commissioner made this report: "At about 3.00 a.m. (0300 h, 31 October) a strong wind of approximately 35 mph began blowing in Punta Gorda. The velocity of the wind increased to such an extent that at day-break, about 6.0 a.m., the people were informed to vacate their homes to make use of the approved shelters. By 7.00 a.m. the velocity of the wind had increased to 45-50 mph and became stronger still in the course of the day, reaching approximately 75-80 mph between 12 and 2.00 p.m. when it began to subside gradually. By 7.00 p.m. the wind had finally calmed down."

Other Areas

Two inland records may be added to complete the picture of Hurricane Hattie's passage across the country. At Cayo, 60 miles WSW from Belize, winds "a little above hurricane force" blew from 1200 to 1500 h on 31 October. "Shortly afterwards" the Mopan and Macal Rivers rose in places by over 40 feet, a response to torrential rains in the hilly country to the south. In El Cayo town itself the river rose to within 2-3 feet of the roadway on the Hawkesworth Bridge, 52 feet above the streambed. Similar floods occurred at several places along the northern edge of the Maya Mountains: at Barton Creek the road was submerged 8 feet deep and at Roaring Creek it carried 12 ft. water. This flooding lasted one day: in some villages a second flood occurred a day or two later. Near the sea, with impeded drainage, excess runnoff remained on the land for a considerable time. There are no estimates of the amount of rainfall during the storm, but the 11.5 in. in 24 hours at Grand Cayman Island gives some indication of magnitude. Winds were sufficient to fell trees along the whole of the Belize-Cayo road, at least as far as Benque Viejo, though the greatest numbers of fallen trees are seen between Belize and Roaring Creek and points south. Tree-fall was moderate in the Mountain Pine Ridge area. Direction of fall was generally east to north. Catastrophic forest destruction occurred in the Maya Mountains, especially in the Cockscomb Basin, and points southwest to Quartz Ridge, but any detailed report on these is outside the scope of this paper.

At Orange Walk, 42 miles NW of Belize, winds of 40-45 mph were experienced between midnight and 0830 h on 31 October. Gusts were estimated at 65-70 mph.

Changing Wind and Wave Conditions, 2100 h 30 October - 1200 h 31 October

The foregoing narrative of hurricane conditions at locations throughout the British Honduras reef area and inland gives a general, though patchy, picture of changing wind and sea conditions as Hurricane Hattie passed. This information is summarised in approximate fashion in a series of charts at hourly intervals from 0900 h on 30 October to 1200 h on 31 October (Figures 6-10). These diagrams are derived only from actual weather conditions, by plotting wind direction at hourly intervals for each reporting station, together with other relevant information, such as barometric records and radar fixes of the storm centre. Wind streamlines were then drawn to fit these observations and the approximate centre of the storm at each time. Each hourly chart was computed without reference to those immediately before and after; hence, if the charts are combined, the resulting hurricane track (Figure 11) looks somewhat erratic, though this may well have been the case. The outer edge of the streamlines delimits in a very approximate way the limit of hurricane force winds. Using these charts, the general sequence of wind directions at any one place, other than those for which we have eye-witness accounts, can be determined. For points north of the storm centre, the winds were generally, northwest, north, northeast, and east; and for points south, generally southwest, south, southeast and east.

Storm Surge

There is no precise information either on wave conditions during the hurricane or on the limits of the storm surge which accompanied it. The storm surge would seem to have been less severe on the outlying reefs and atolls than on the mainland coast, where a shallow offshore shelf presented optimum conditions for high surge development. Thus at Sandbore Cay, Lighthouse Reef, near the storm centre, the surge reached its greatest height of about 9 feet above normal sea level at 2230 h 30 October, $1\frac{1}{2}$ hours before the passage of the centre itself. No appreciable surge was recorded at Half Moon Cay, 20 miles to the south. Information for Turneffe is very sparse indeed: the surge at Mauger Cay reached its maximum during the early hours 31 October, with heights of perhaps 5-6 feet. There is no further information on points to the south, but most of the small eastern cays show signs of complete inundation. It is difficult on these more exposed cays to separate the effects of intense wave action from those of a true storm surge. On the barrier reef and mainland coast we have rather more data, though the accuracy of some reports is questionable. The most trustworthy record is that of Belize, where the surge began immediately after the passage of the storm centre 15-20 miles to the southeast. Between 0600 and 0800 h on 31 October water level rose to a maximum of 12 feet above normal (the astronomical tides on this coast rarely exceed one foot, and may be disregarded here); the fall in level from the peak of the surge was much slower than the rise, and at mid-day sea level was still 3-4 feet above normal. This is shown not only by the Belize records, but also by that of the Tactician at 1300 h in Belize harbour. There is no information on the extent of the surge along the uninhabited mainland coast north of Belize, and information from the barrier reef cays is sparse. Cay Caulker reports a high water mark of 15 feet, the water not receding until 0900 h; this probably refers to the highest water mark of wave action, and the true surge height was probably very much lower. On morphologic grounds it was probably less than 6 feet, and may only have been 2-3 feet. Cay Caulker lies 30 miles north of the storm track. At Ambergris Cay, 40 miles north, the surge probably did not exceed 2-3 feet.

South of the storm track, information is again limited. Stann Creek, 9 miles south of the storm centre, has well-attested reports of a surge beginning at 0500 h and lasting till about 1000 h, reaching 10-12 feet above normal. The times and extent of the surge are similar to those at Belize. However, no surge occurred at Tobacco or South Water Cay, 20 miles south of the storm track, on the edge of the coastal shelf. At Mullins River, where the storm centre crossed the coast, there is a rather dubious report of a maximum surge level of 20 feet; again, this probably refers to the maximum height of wave action. There is no information on surge levels on the mainland coast south of Stann Creek.

Figure 12 summarises this very sketchy data. The figures for Sandbore and Mauger Cays on the atolls are not really comparable to those on the mainland, since open-ocean levels must have been considerably lower than coastal figures on account of the shelf effect. Much information has accumulated on hurricane-induced surges (Redfield and Miller, 1957; Hubert and Clark, 1955), and empirical relationships have been found between height of storm surge, lowest central pressure, and distance north and south of the hurricane track (Hoover, 1957; Conner, Kraft and Harris, 1957; Harris, 1956, 1957, 1959). Using Conner, Kraft and Harris's formulae, with a lowest central pressure of 27.3 in, the maximum surge should have reached approximately 13 feet. Hoover's results give rather higher figures, of over 16 feet on the basis of Gulf Coast hurricanes, and over 15 feet on the basis of Atlantic coast storms. The order of magnitude is clear. Hoover (1957, 174) also shows that the highest surge generally occurs 10-15 miles to the right of the storm centre (facing the direction of movement) in Gulf Coast hurricanes, and 20-30 miles to the right in the case of those on the Atlantic coast. In any one storm the point of maximum surge, and the level of the peak surge, will clearly depend on bottom topography, shoreline orientation, angle of approach and other factors, in addition to the magnitude of the storm. It is reasonable to suppose that Hurricane Hattie's surge resembled previous surges. However, the angle of approach would tend to give unusually high levels in the lagoon segment between Stann Creek and Belize, so that the high report from Mullins River cannot altogether be excluded. Disregarding this channelling of the approaching surge, the Belize record of 12 feet 20 miles north of the storm centre may have approached close to the maximum surge level; up to 15 feet may have occurred in the Sibun River area. South of Mullins River one would have expected a rapid falling off in maximum level. The channelling effect of angle of approach on the shallow coastal shelf may have increased the ordinary surge by up to 4-5 feet at Stann Creek. The very rough curve in Figure 12 b gives an indication of the surge-spread on the mainland coast. It must be stressed that as a result of the advance of the surge over the 10-20 mile wide coastal shelf, the mainland coast surge was undoubtedly both higher and of greater lateral extent than on the barrier reef or on the atolls. It might be noted that the hurricane surge during Hattie was higher than most recent Gulf of Mexico hurricane surges (Dunn and Miller, 1960, 219), and was similar to the open coastline levels during Hurricane Carla of 1961 (Dunn and others, 1962, 113).

There are few records of the "forerunner" or gradual rise of sea-level over a period of up to several days preceding the storm, though a slight rise in sea level accompanied the heavy swells which struck the outer atolls during the two preceding days. The first distinct sea-level rise was generally noted only a few hours before the hurricane, i.e. during 30 October.

Wave Action

Superimposed on the general rise in sea-level, and even more difficult to consider, is the effect of wave action. Observational data on waves during Hurricane Hattie are completely lacking, except for the Cay Caulker report that most of the damage was caused by five distinct waves. Since hurricane waves are wind-generated, it is reasonable to suppose that highest waves will be produced in the northern (right-hand) sector of the storm, where winds are moving in the same direction as the storm itself (Pore, 1957). Wind speed may be estimated at 150 mph; these high winds acted in an E-W direction, toward the British Honduras coast, from the time when the storm began to turn westwards on 29-30 October, 350 nautical miles east of Belize. Empirical tables relating wave characteristics, fetch and wind speed (e.g. Bretschneider, 1952) indicate that with wind speeds and a fetch of this magnitude, waves will be over 60 feet in height, with periods of more than 16 seconds. Normal wave period observed on the outer reefs varies from 5 to 7 seconds. Alternatively, Cline's (1926) rough empirical method (wind speed divided by 2.05 gives wave height) gives even greater heights; Japanese experience in the Pacific would suggest heights of more than 40 feet (Dunn and Miller, 1960, 101). These are all open-ocean figures, and waves of this magnitude have occasionally been observed during hurricanes. However, it is questionable whether such waves were experienced in the British Honduras reef area. If such waves were generated, and formed recognisable wave trains, they were probably confined to the open sea north and east of Lighthouse Reef; they may have helped in the destruction of the Sandbore Cay Lighthouse. Between the atolls and in the barrier reef lagoon, however, local bottom relief, shallow water, and varying wind direction may all have limited wave development. South of the storm centre, while many accounts speak of even more violent winds immediately after the central calm, waves were unlikely to have been so great, because of restricted fetch as the winds blew counter to the direction of hurricane movement. Even so, considerable damage was caused near deep-water areas, as at Cay Bokel.

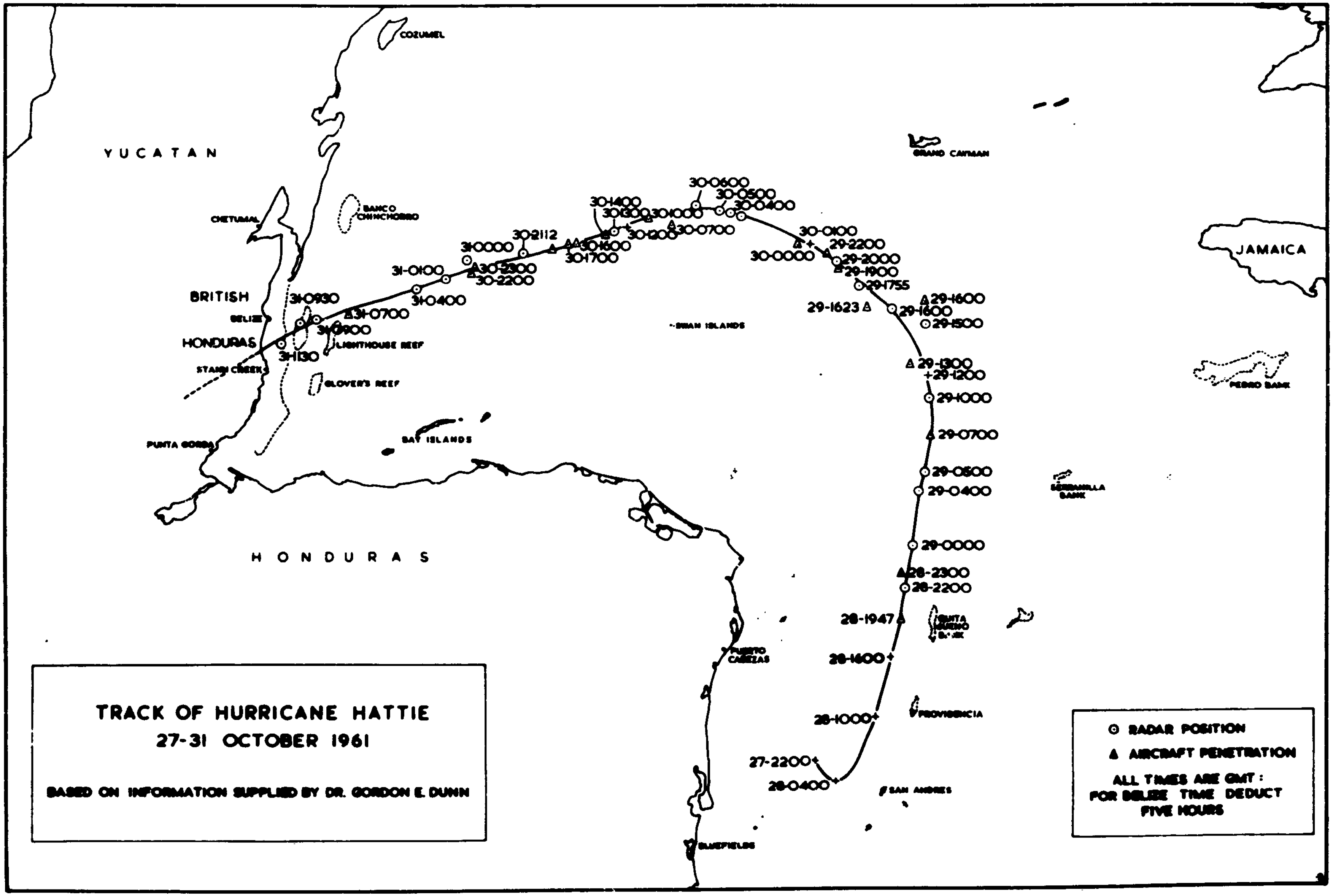
As will be apparent in succeeding chapters, damage due to waves, while considerable, hardly seems to indicate the truly monstrous waves suggested by wind speeds. Recognisable wave trains were probably not well developed near the storm centre itself. Windspeeds were so high that the air-water interface became indistinct: several accounts speak of the air being full of spray, and of salt water 'raining' in through open roofs. The sea surface was probably highly confused, with short, very steep, but only moderately high waves (perhaps 20 feet) from many directions, depending on local winds. This may have lessened the erosive potential of the waves (Arakawa, 1954).

Direction of Water Movement

Figure 13 attempts to show, in a general way, the dominant directions of water movement associated with the hurricane, and the approximate area affected by the storm surge. Seas ahead of the hurricane were easterly; it was these swells, running ahead of the storm, which caused the early damage at Lighthouse Reef. To the north of the storm track, as the storm passed, sea movement continued easterly and northerly. Channel-cutting and delta-deposition at St. George's Cay, together with reports from Belize, Stann Creek, and the Tactician, of W to NW winds immediately ahead of the storm, indicate major water movements from the northwest in the northern barrier reef lagoon in the few hours immediately preceding the passage of the storm centre. Northwesterly seas may have played some part in the Crickozeen Creek slumping (Chapter 6). South of the hurricane track, the first swells were again easterly, but the main seas associated with the passage of the hurricane were southeast, south and southwest. This is shown by sediment deposition on cays, direction of tree-fall in inundated areas, and such miscellaneous indicators as the direction of fall of the Cay Bokel Lighthouse. This map of water movement may be compared with that showing direction of tree fall due to wind during the hurricane (Figure 63); the two show a considerable correspondence.

Rainfall

No rainfall information is available from British Honduras during the storm, since instruments were destroyed. It is in any case questionable whether standard rain gauges could give even an approximation of a mainly horizontal rainfall. The 11.5 inches in one day at Grand Cayman Island may be recalled; many instances in other hurricanes of over 20 inches in 24 hours have been recorded, mainly in mountainous areas (Schoner and Molansky, 1956). Rainfall is generally concentrated near and a little ahead of the storm centre (Miller, 1958). Rainfall in the Maya Mountains may have been more than 20 inches, judging from the extensive high floods. This excess run-off probably reduced salinity temporarily in the shallow northern barrier reef lagoon (cf. Goodbody, 1961), but this would have little effect on the reefs of that area, which were by then already dead.



TRACK OF HURRICANE HATTIE
27-31 OCTOBER 1961
BASED ON INFORMATION SUPPLIED BY DR. GORDON E. DUNN
RADAR POSITION
AIRCRAFT PENETRATION
ALL TIMES ARE GMT : FOR BELIZE TIME DEDUCT FIVE HOURS
YUCATAN
BRITISH HONDURAS
HONDURAS
JAMAICA
COZUMEL
BANCO CHINCHORRO
CHETUMAL
BELIZE
STANN CREEK
PUNTA GORDA
LIGHTHOUSE REEF
GLOVER'S REEF
BAY ISLANDS
SWAN ISLANDS
GRAND CAYMAN
PEDRO BANK
SERRANILLA BANK
PUERTO CABEZAS
PROVIDENCIA
SAN ANDRES
BLUEFIELDS
27-2200
28-0400
28-1000
28-1600
28-1947
28-2200
28-2300
29-0000
29-0400
29-0500
29-0700
29-1000
29-1200
29-1300
29-1500
29-1600
29-1600
29-1623
29-1755
29-1900
29-2000
29-2200
30-0000
30-0100
30-0400
30-0500
30-0600
30-0700
30-1000
30-1200
30-1300
30-1400
30-1600
30-1700
30-2112
30-2200
30-2300
31-0000
31-0100
31-0400
31-0700
31-0900
31-0930
31-1130

FIG. 2

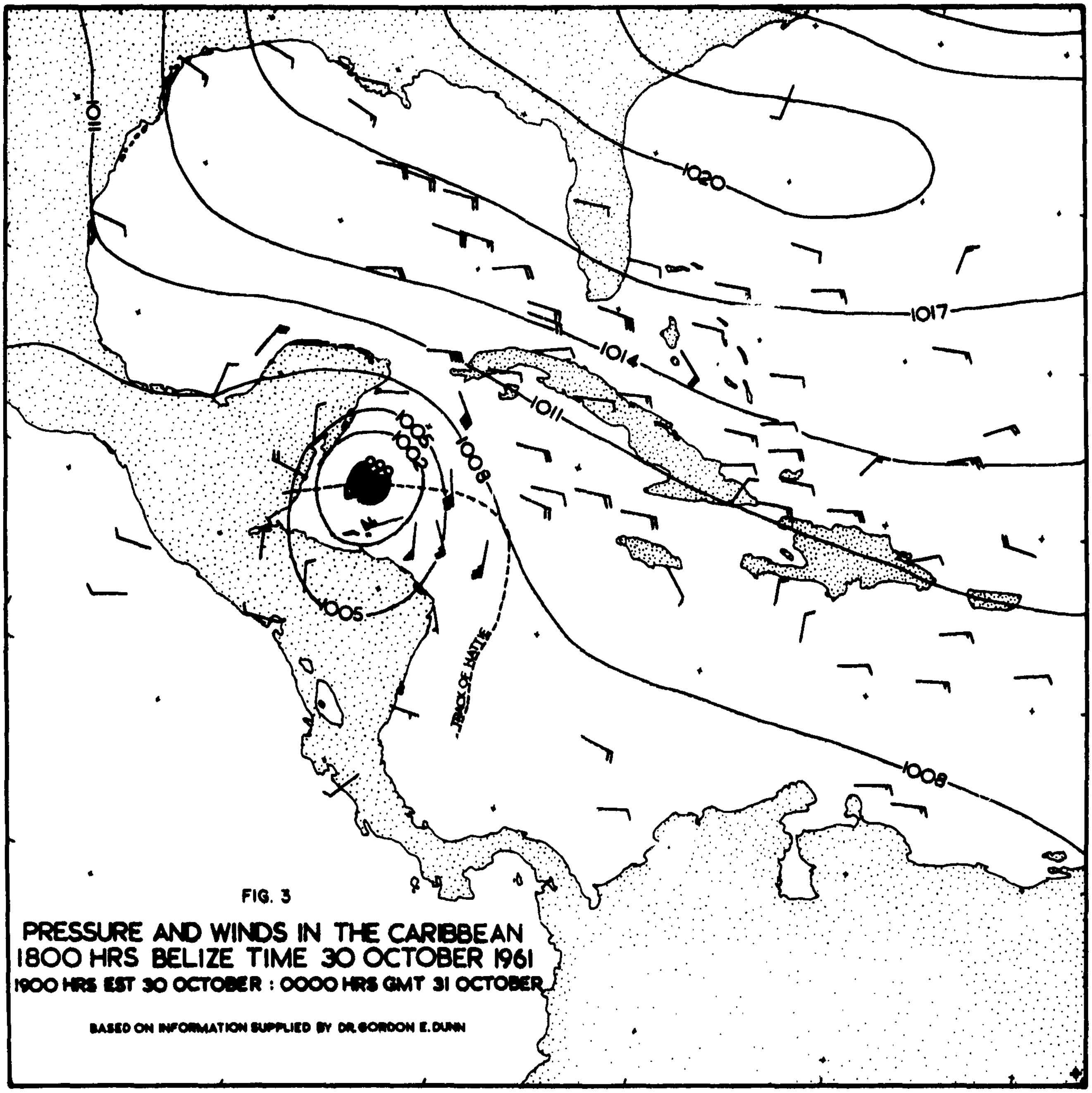


FIG. 3

PRESSURE AND WINDS IN THE CARIBBEAN
1800 HRS BELIZE TIME 30 OCTOBER 1961
1900 HRS EST 30 OCTOBER : 0000 HRS GMT 31 OCTOBER

BASED ON INFORMATION SUPPLIED BY DR. GORDON E. DUNN

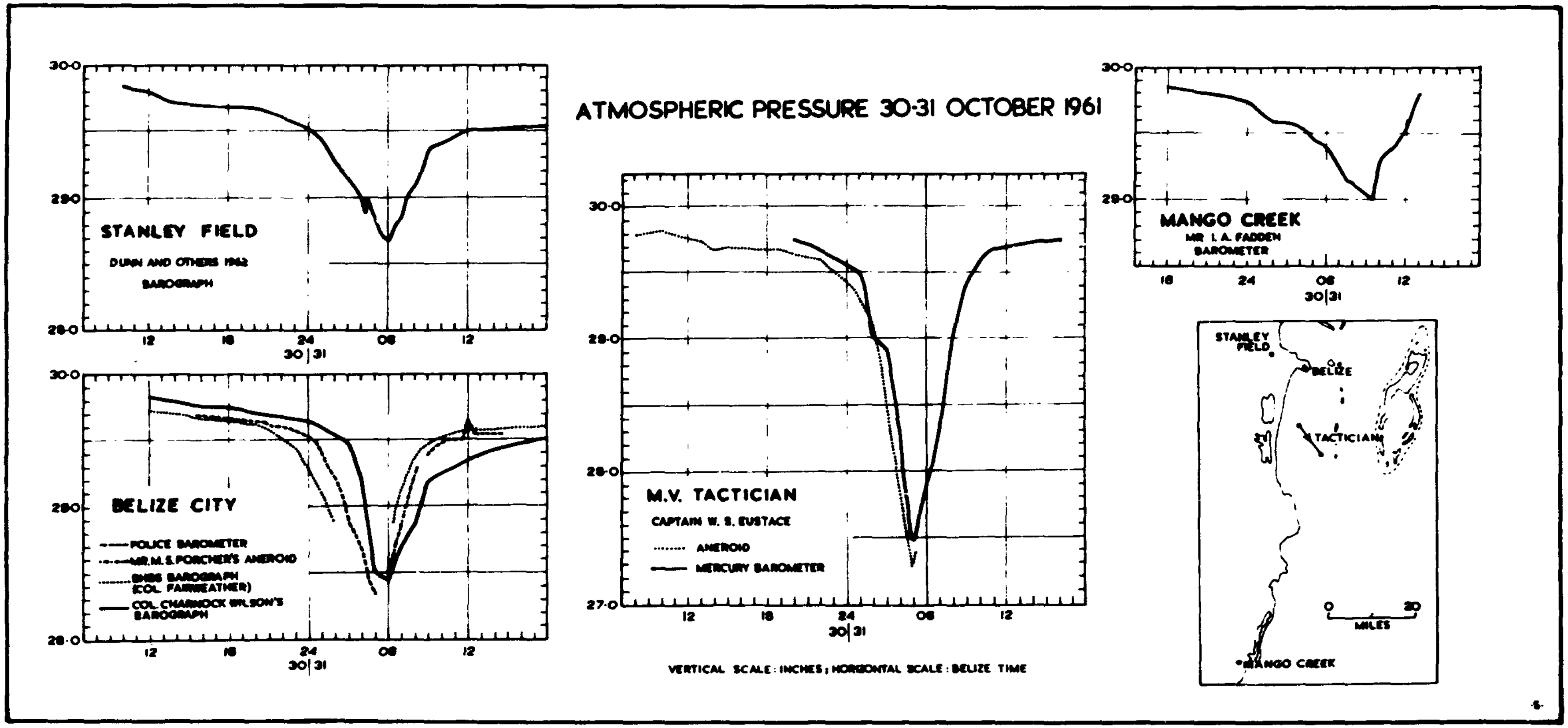

ATMOSPHERIC PRESSURE 30-31 OCTOBER 1961
STANLEY FIELD
DUNN AND OTHERS 1962
BAROGRAPH
BELIZE CITY
POLICE BAROMETER
MR. M. S. PORCHER'S ANEROID
BHBS BAROGRAPH (COL. FAIRWEATHER)
COL. CHARNOCK WILSON'S BAROGRAPH
M.V. TACTICIAN
CAPTAIN W. S. EUSTACE
ANEROID
MERCURY BAROMETER
MANGO CREEK
MR. I. A. FADDEN
BAROMETER
STANLEY FIELD
BELIZE
TACTICIAN
MANGO CREEK
MILES
30|31
VERTICAL SCALE: INCHES; HORIZONTAL SCALE: BELIZE TIME

FIG. 4

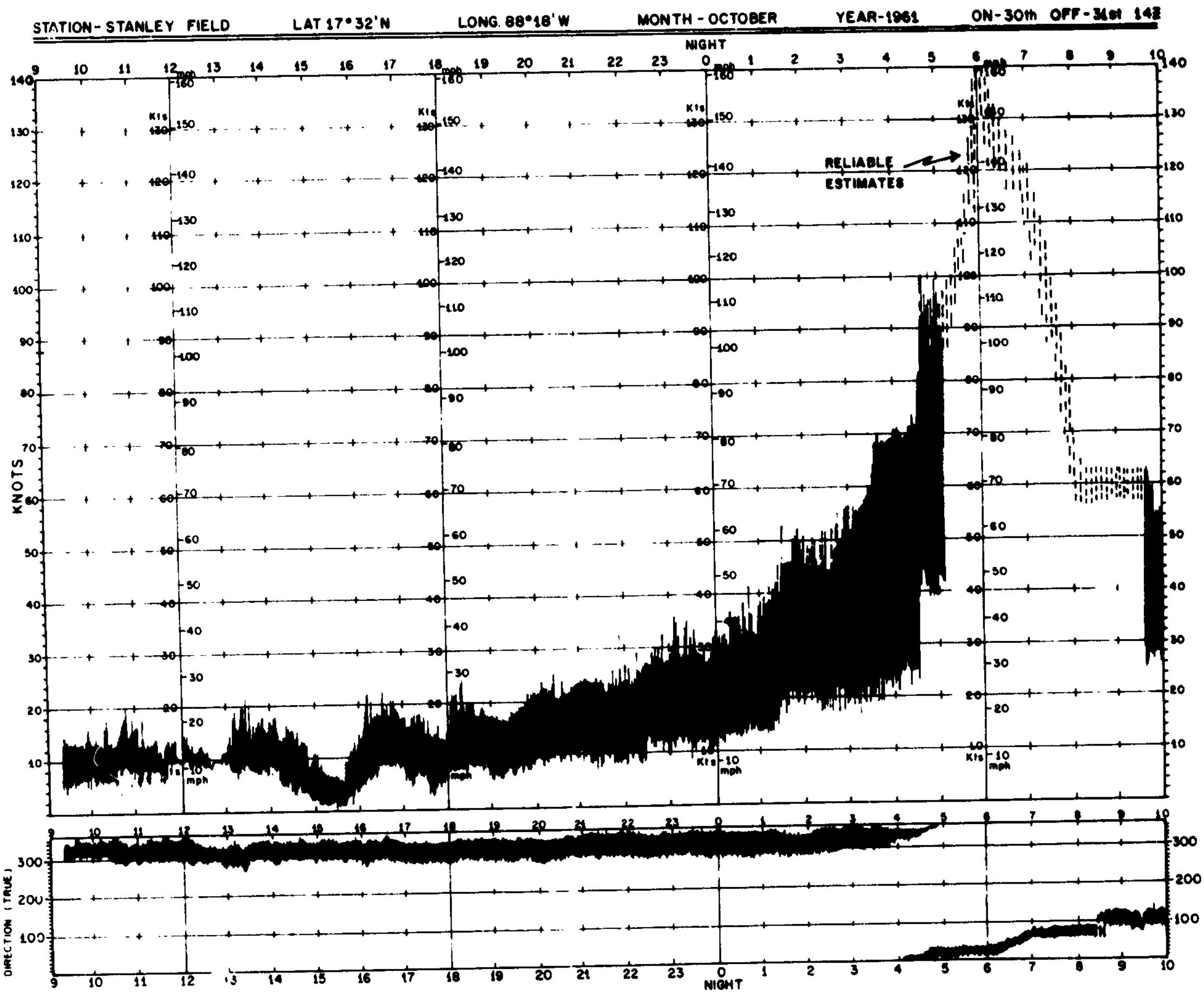
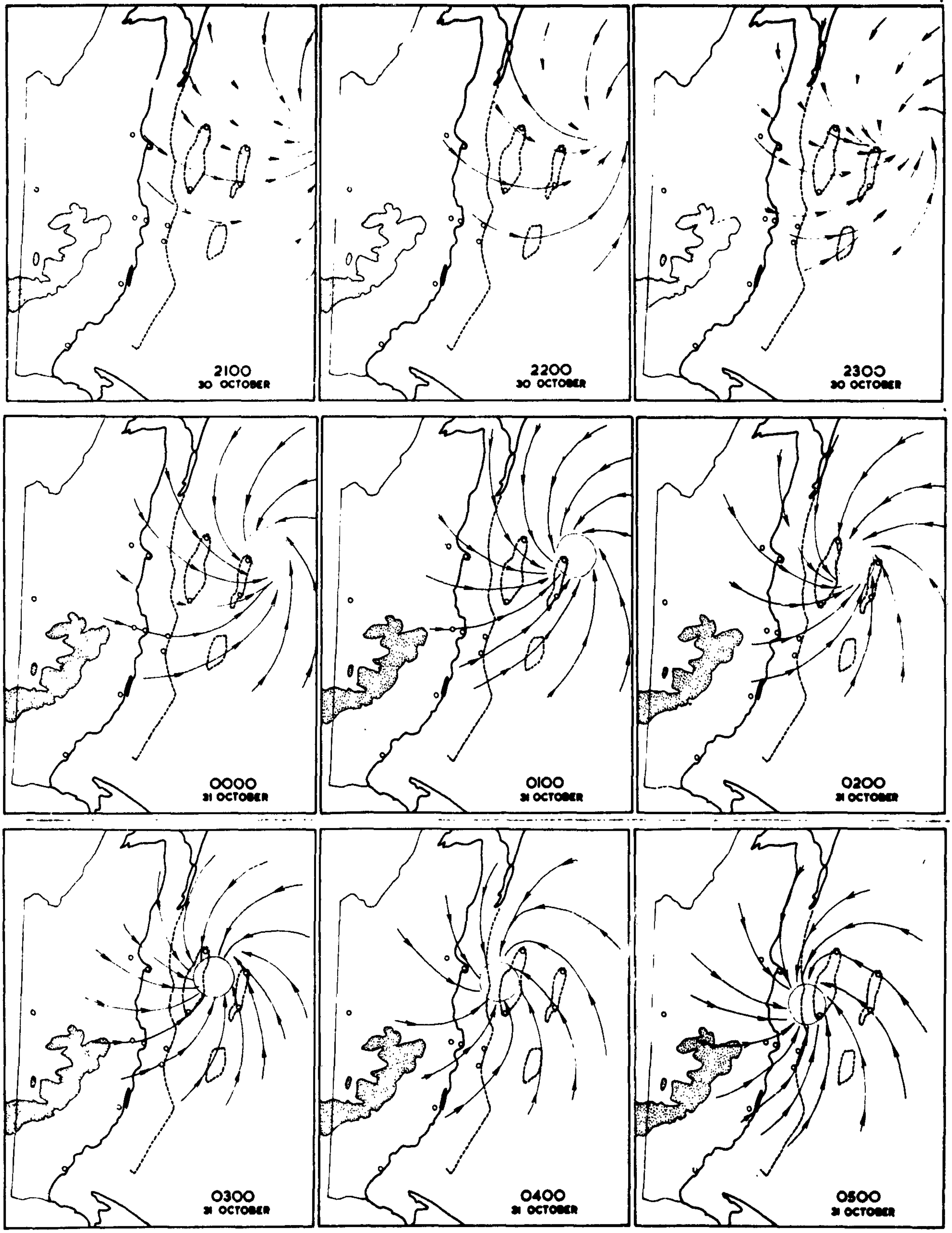
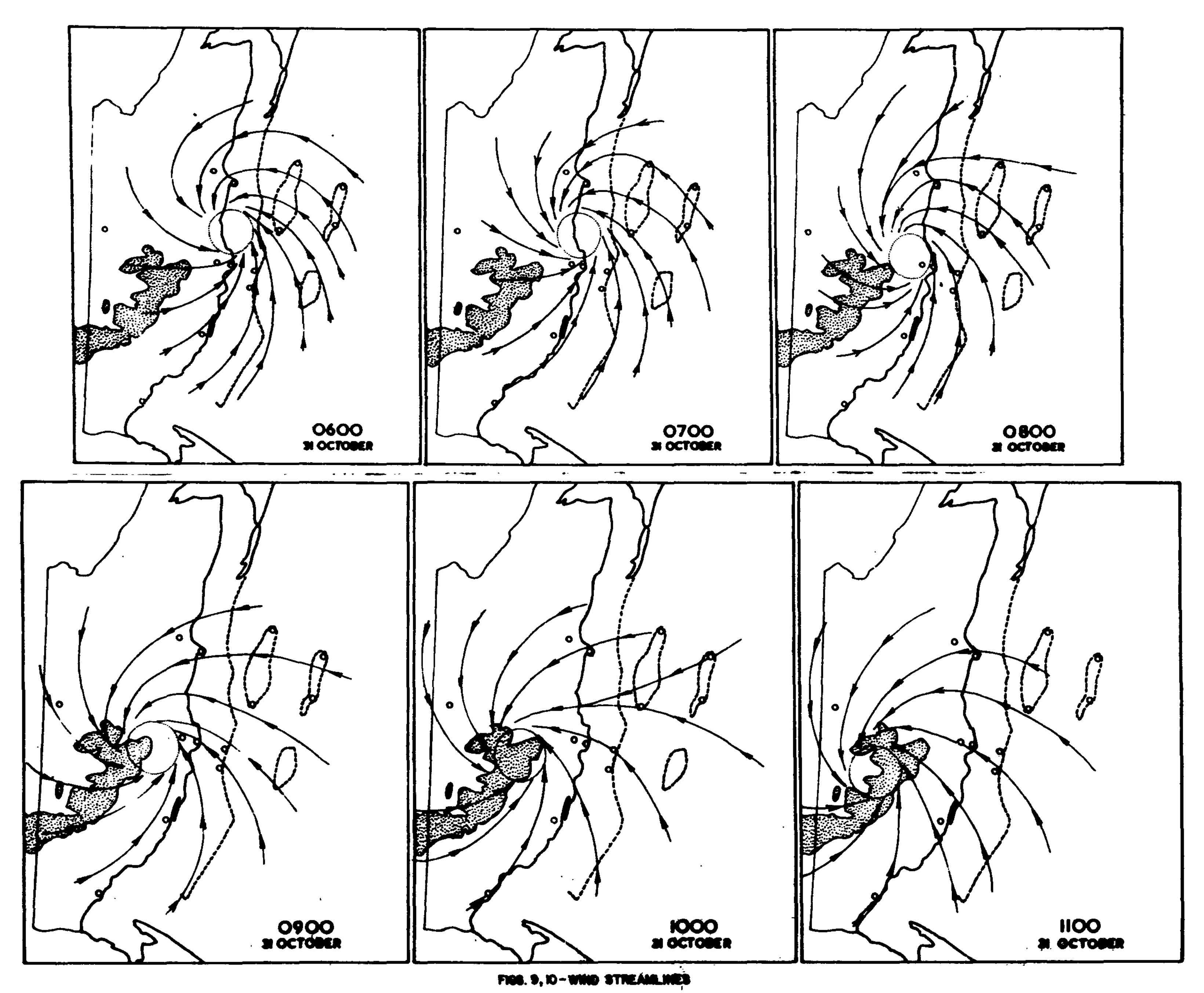


FIG. 5 - ANEMOMETER TRACE, STANLEY FIELD, BELIZE, 30-31 OCTOBER 1961. REPRODUCED FROM DUNN AND STAFF, 1962, COURTESY U. S. WEATHER BUREAU.



FIGS. 6, 7, 8 - WIND STREAMLINES



FIGS. 9, 10 - WIND STREAMLINES

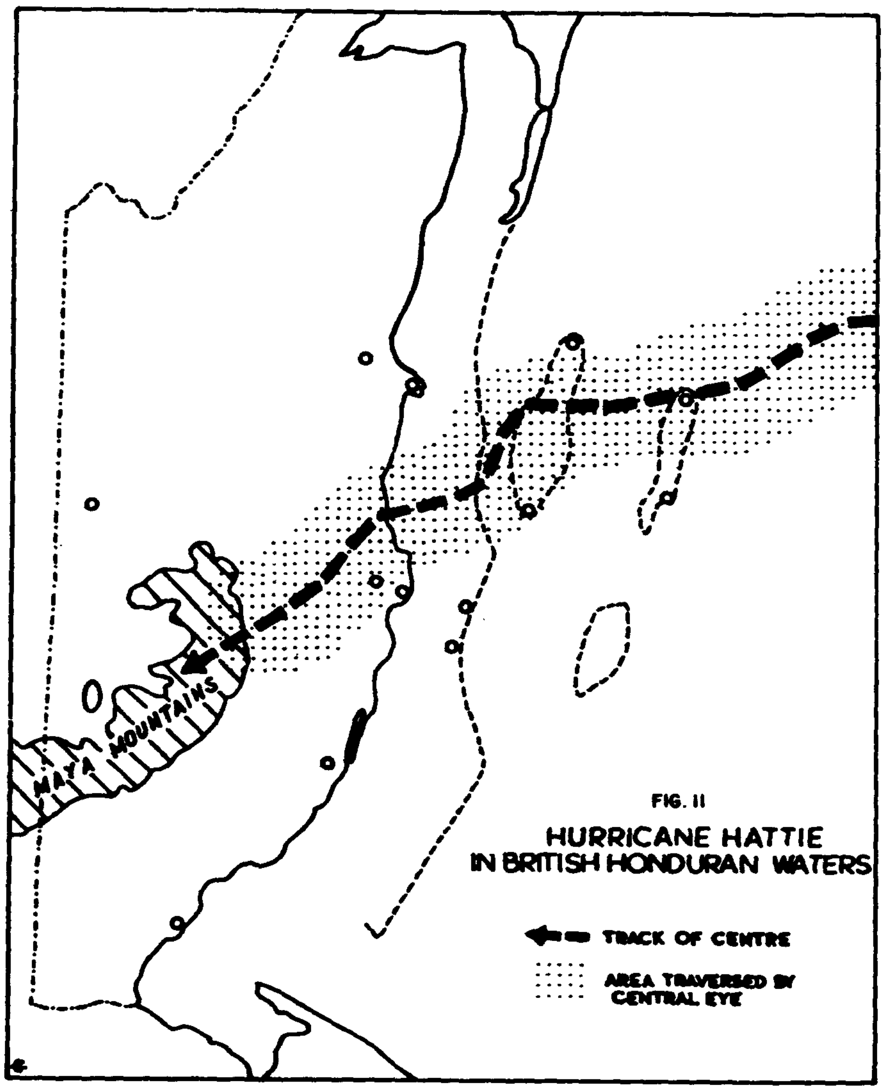
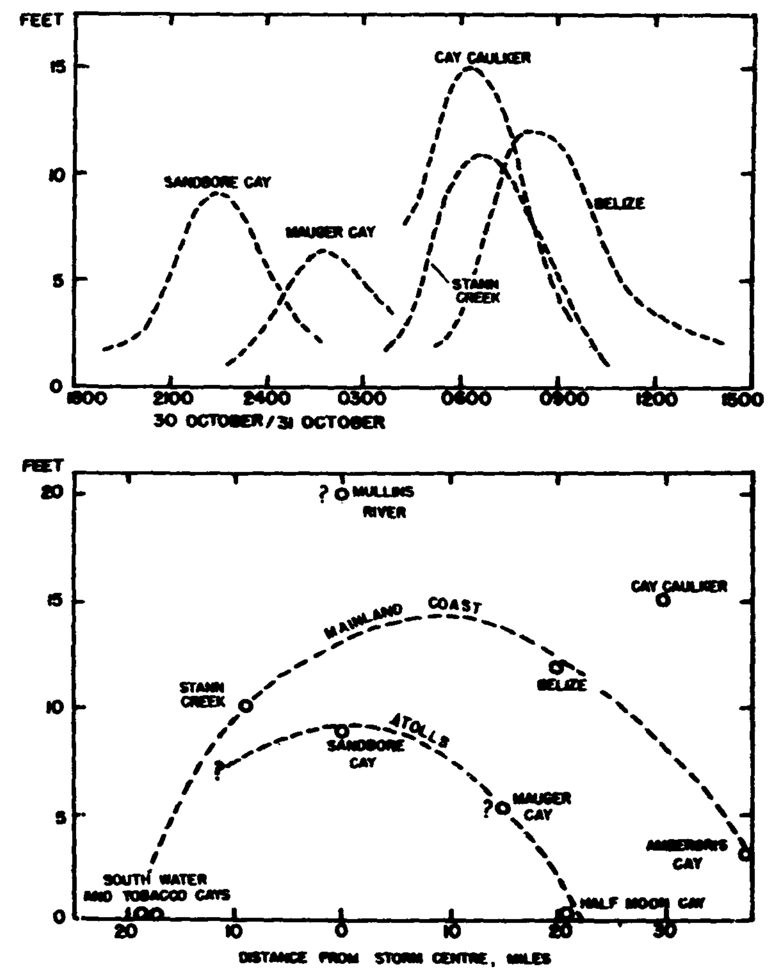


FIG. 11

HURRICANE HATTIE IN BRITISH HONDURAN WATERS

FIGURE 12, PROGRESS OF STORM SURGE



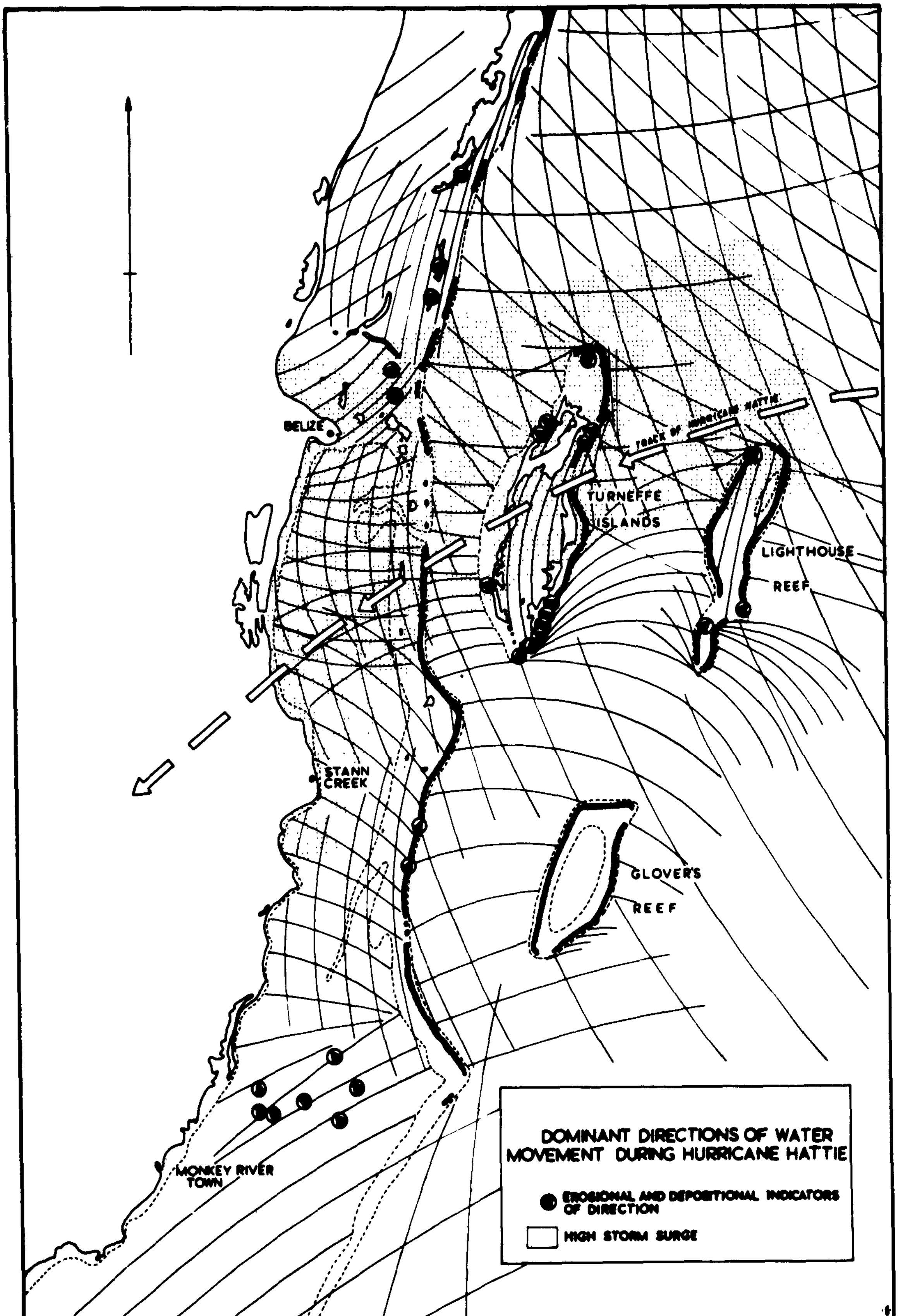

BELIZE
TRACK OF HURRICANE HATTIE
TURNEFFE ISLANDS
LIGHTHOUSE REEF
STANN CREEK
GLOVER'S REEF
MONKEY RIVER TOWN
DOMINANT DIRECTIONS OF WATER MOVEMENT DURING HURRICANE HATTIE
EROSIONAL AND DEPOSITIONAL INDICATORS OF DIRECTION
HIGH STORM SURGE

FIG. 13

III. REEF DAMAGE DURING HURRICANE HATTIE

Unfortunately only incidental observations could be made on living reefs during the 1962 expedition, and fresh seas prevented any underwater observation at all on the windward sides of both Turneffe and Lighthouse Reef. However, the whole length of reef round Turneffe, Lighthouse and Glover's Reefs, and along the barrier reef, was observed from the air and photographed at frequent intervals. These photographs could then be compared with a similar series made in 1961. Reefs were seen underwater at a number of places along the barrier reef itself. These observations are summarised in Figure 14. The main conclusion is the highly variable degree of reef damage, and the all-important role of the location and orientation of reefs in relation to hurricane winds and waves. Since the hurricane crossed the reefs almost at right angles, it is reasonable to assume that east facing reefs to the north of the storm track would suffer most severely from generally easterly and northeasterly winds and waves; and that reefs south of the storm track, facing away from the dominant winds or parallel to them, would suffer least damage. This did, in fact, occur, and hence there is no zonation of damage north and south of the storm track similar to that discernible on the cays.

Lighthouse Reef lay entirely to the south of the storm track, and its east reefs suffered remarkably little damage; groove-buttress systems seem unaltered for the length of the atoll. Minor damage is indicated at the north end of the east reef by shingle carpets on the reef crest; but greatest damage seems to have occurred on the east-west trending section of reef between Half Moon Cay and Long Cay. This is near the south end of the atoll, and aligned transverse to the southerly winds and waves dominant in this sector (Figure 13). The west reefs on this atoll were not well developed, and there is no means of assessing change. Lagoon reefs are unaltered, except in the northern lagoon, near Northern Two Cays, where some surface-breaking Acropora has been overturned.

Hurricane Hattie crossed Turneffe Islands near Pelican Cay. Northwards to Mauger Cay damage to the east reef has been heavy, especially on the reef crest and upper seaward slope. Fresh gravel carpets are spread across the reef crest, replacing living coral. Numerous corals have been thrown up at Cockroach Cays, including Diploria, Montastrea, Porites, Acropora, and Mussa angulosa (not previously recorded from this reef). Over the greater part of the seaward slope, however, the groove-buttress system is still preserved, and in some cases it is possible to identify particular reef-configurations on both pre- and post-hurricane photographs. South of Pelican Cay, degree of damage is very variable. Seas were mainly southerly, and either parallel to the reefs or nearly so. Damage is concentrated on reef segments oriented E-W or NE-SW, whereas immediately adjacent reefs, facing away from the southerly winds show little damage. A good example is found at Soldier Cay: north of the prominent Soldier Cay elbow the reef extends for several miles and seems little changed, but immediately south of this point damage increases and much debris is piled on the reef crest. Similarly, damage is considerable on the south facing reefs near Cay Bokel.

It is on the barrier reef itself, however, that reefs suffered damage to a heavy, even catastrophic degree. Hurricane Hattie crossed the barrier near Rendezvous Cay: on the barrier reef proper, and on numerous patch reefs immediately lagoonward of the barrier, between Rendezvous and English Cays, up to 80% of the reef corals have simply disappeared. Very heavy damage indeed has been caused as far north as Paunch Cay: but north of this point the reef is poorly developed and interrupted, and the degree of damage is uncertain. Between the Deep-water Channel and Rendezvous Cay the change is most dramatic: reefs which previously broke surface with distinctive assemblages of orange and yellow Acropora, now rise, greenish-white, ghost-like, and devoid of corals, from the surrounding blue water. No trace of any groove-buttress system can be seen along this reef, or indeed north of Cay Glory, 10 miles south of the hurricane track. Immediately north and south of the Cay Glory gap reef remnants on the seaward slope indicate the previous existence of a linear groove-buttress pattern, but this pattern does not become uninterruptedly apparent until south of South Water Cay. Changes on these barrier cays reefs can best be described by outlining underwater observations at a number of points.

Paunch Cay Reef

Dominant pre-hurricane species here were Montastrea annularis, Acropora palmata, A. cervicornis, and other assemblages similar to these of Rendezvous Cay, described below. From air photographs and underwater observation it seems probable that 90% of the living reef has been destroyed. The dominant surviving species is M. annularis, together with a few large overturned colonies, still living, of A. palmata, and patches of Porites astreoides, Dichocoenia stokesii, Siderastrea siderea, and especially Diploria labyrinthiformis, D. strigosa and D. clivosa. Millepora is particularly widespread at the present time. Only small specimens of Montastrea cavernosa were seen. and no A. cervicornis. Small corals such as Siderastrea radians and Manicina areolata are now absent. Cervicornis rubble is now accumulating on the reef flat as an embryonic cay (Chapter 4).

Sergeant's Cay Reef

The main species seen living here after the hurricane were M. annularis, Diploria, some Siderastrea siderea, and Porites astreoides. Round the seaward side there is a confused tangle of A. palmata with some still living. No A. cervicornis was seen, though the location of former patches is marked by well-defined rubble zones. There has been much destruction of Agaricia agaricites on the windward side, though a few patches remain alive. No "finger" Porites (P. porites, P. furcata, P. divaricata) was seen alive, but some dead and broken clumps were still recognisable. Other corals seen living in 1962 included Eusmilia, Isophyllia, and M. cavernosa.

Reef-patch south of English Cay

The reef patches between English and Rendezvous Cays attract attention because of their "bald" appearance. One was investigated about ½ mile south of English Cay. The coral fauna was previously comparable to that around English and Rendezvous Cay: a zone of A. palmata round the edges, especially on the windward side, A. cervicornis in the protected centre, and massive M. annularis on the outer slopes. Much dead A. cervicornis debris was seen, but none at all living. Conversely, A. palmata survived fairly well, though many large specimens were overturned, and some were dead. Most of the Agaricia was dead, together with nearly all the Porites porites. Scattered small colonies of Porites astreoides were fairly prominent in the general scene of confusion, together with much Millepora.

Rendezvous Reef

The centre of the hurricane passed almost directly over the Rendezvous Cay reef, a patch reef 450 yards long, elongated in a north-south direction, and 150-250 yards wide, rising steeply from water more than 50 feet deep. The edges of the patch, especially within 20 feet of the surface, were coated with coral before the hurricane, except on the west side, where a gap gave entrance to an anchorage near the cay carrying 4 feet of water. Otherwise the surface of the patch generally carried 1-2 feet of water. The pre-hurricane distribution of corals was investigated by diving and underwater mapping in 1959-60 by J.E. Thorpe; an outline map of the distribution of colonies has appeared (Thorpe, in Thorpe and Stoddart, 1962, Figure 4), together with a brief description (Thorpe and Bregazzi, 1960, 25-28). The main results are still in manuscript, and I am indebted to Mr. Thorpe for use of his unpublished charts. I also became familiar with this reef during residence in 1959-60, and a visit in 1961; many air and underwater photographs are available to supplement Thorpe's map. After the hurricane, a large number of air photographs were taken on two separate occasions, and two days were spent diving on the reef itself and taking underwater photographs. Figure 15 summarises the main changes in the distribution of reef corals: Part A is taken from Thorpe's published map; Part B is a compilation map from 25 air photographs, in colour, taken at heights of 100-300 feet in April and May, 1962. The second map is obviously much less reliable than the first, but there is no doubt that it reflects fairly accurately the magnitude of changes due to Hurricane Hattie.

Before the hurricane, the reefs could be described as falling into four divisions:

(a) the reefs on the west side, south of the anchorage gap; with a crest of massive M. annularis, and fairly extensive areas of A. cervicornis and Porites, and smaller amounts of Millepora and A. palmata. This zone continues round the south end of the reef patch, with scattered colonies of M. annularis.

(b) the reefs along the southern section of the east side: with massive A. palmata, and smaller amounts of Millepora, Diploria, Porites, Montastrea and Agaricia.

(c) the wide area of reef growth in fairly shallow water (less than 10 feet deep) across the northeast end of the reef patch: consisting of massive M. annularis, A. palmata and Millepora, with patches of A. cervicornis (especially in shoal water) and Agaricia agaricites.

(d) the deep-water spurs at the northeast end of the patch, extending down to depths of 20-40 feet, coated with massive M. annularis, together with A. palmata and Porites.

(e) the narrow reef rim on the northwest side of the patch: mainly massive M. annularis, with Mycetophyllia, Isophyllia, Mussa, and on the reef crest, A. cervicornis.

In addition, the centre of the patch, much of it covered with Thalassia, supported scattered small colonies of Manicina areolata, Cladocora arbuscula and Siderastrea radians. Many other species are present in the peripheral reefs (such as Siderastrea siderea, Colpophyllia natans, Dichocoenia stokesii and Dendrogyra cylindrus) but do not in themselves form distinct zones. Thorpe and Bregazzi's full list of species has been given in my previous paper (ARB 87, 17-18).

The changes resulting from the hurricane in these zones may be summarised as follows:

(a) Approximately 80% of the stony corals disappeared in this zone. One patch on the south side of the anchorage gap, consisting of M. annularis, A. palmata and Millepora disappeared entirely. Further south, M. annularis survived in isolated blocks, some of them split apart, together with a little Agaricia. The extensive area of A. cervicornis at the southwest corner has gone entirely, and only scattered Porites porites nestling in cervicornis rubble remain. Scattered colonies of M. annularis along the south side of the reef patch have largely disappeared.

(b) This narrow zone of A. palmata, Millepora, and scattered massive corals (M. annularis, Diploria) suffered very heavy damage, perhaps 90% being destroyed. The chief coral surviving is M. annularis, often with scour holes to leeward of the colonies. Associated with the large surviving coral colonies are a number of smaller corals, including Favia fragum, Mycetophyllia, and Agaricia agaricites. All the A. cervicornis has been destroyed, except for occasional straggling branches rising from blankets of cervicornis debris. Damage to the dominant A. palmata is also great: colonies were broken and overturned, and generally killed, often by smothering with debris, though occasional colonies remained alive even though completely inverted. While previously one could cross this reef at only a few points, it is now possible to swim across almost at will. On the reef flat to leeward, between the reef crest and the beachrock, there are scattered specimens of D. clivosa and

Siderastrea siderea still living, though in some cases overturned. No Porites was seen.

(c) Survival in this zone is much greater, the successful species again being chiefly M. annularis, with the more massive A. palmata, and Diploria. There is much cervicornis rubble, but no living colonies; and no species of Porites were seen except Porites astreoides.

(d) This zone was not examined in detail; from the photographs it is apparent that more coral survived here, possibly because of its greater depth and the dominance of the more resistant species, particularly M. annularis.

(e) Towards the north end nearly all the coral has been destroyed, but elsewhere small colonies of M. annularis have survived. A. cervicornis is not to be seen.

To sum up the reef changes at Rendezvous Reef: Montastrea annularis has survived all round the reef patch with moderate success, together with Millepora, which may, at least in part, have grown since the storm. More massive specimens of A. palmata have also survived in places. On the surface of the patch, Siderastrea radians can still be found in the turtle grass, but not Cladocora or Manicina. The deeper slopes round the whole patch seem to be bare. No large blocks have accumulated in the centre of the patch though the turtle grass is littered with much small debris. As rough estimates of the amount of damage, the total reef damage may be placed at 75-80%; destruction of A. cervicornis 100%; A. palmata 80%; and M. annularis 50%. The extensive rubble banks along the eastern reef crest are now thickly coated with purple algae.

Cay Glory

Damage was also considerable at Cay Glory, 10 miles south of Rendezvous Cay. On the reef flat itself, very little living coral remains, apart from scattered fragments of living Acropora palmata and A. cervicornis. The most widespread corals are now small scattered colonies of M. annularis, P. astreoides, S. siderea, and D. strigosa. Two specimens only of Porites porites were seen, and one of Dichocoenia. The reef crest itself is covered with a fresh rubble carpet 30-40 yards wide, carrying 12 inches of water, with a steep inner margin 2-3 feet high.

Carrie Bow Cay

At Carrie Bow Cay the degree of reef damage has markedly decreased. On the reef flat the reef is healthy but sparse; it includes M. annularis, A. palmata, rather broken A. cervicornis, Agaricia agaricites, Porites porites, Diploria and Siderastrea. The reef crest consists of a rubble carpet 10-15 yards wide, of tightly packed debris, partly rising above sea level, derived from the heavier destruction of corals on the outer slope. Only the upper section of the outer slope could be investigated, where apart from scattered Porites astreoides it is simply a desolate carpet of rubble. Air observation showed that more coral survived at greater depths, below about 4 fathoms. Furthermore, the massive corals (Montastrea, Diploria, Siderastrea) of the northern and southern horns of the reef survived with little damage.

Peter Douglas Cay

Finally, we may note reef conditions in the central barrier reef lagoon, where destructive hurricane effects on cays were slight, apart from mangrove defoliation. The reef at Peter Douglas Cay consists only of Montastrea annularis, Porites astreoides and Siderastrea siderea, with lesser amounts of Acropora cervicornis and A. prolifera, and very little A. palmata. The only species markedly affected by the hurricane was A. cervicornis, the colonies being much broken, but generally still living. No under-water observations were made south of this point, but air observation showed virtually unchanged conditions, both along the southern barrier reef, and on Glover's Reef. A major exception is the reefs round the southernmost islands of the central barrier reef lagoon, where widespread deposition indicates considerable reef damage.

Comment

This catastrophic degree of reef damage over several miles of the barrier reef is of considerable interest. Mortality of corals during storms has previously been described by Moorhouse (1936) following the 1934 cyclone at Low Isles, Great Barrier Reef of Australia, where many branching corals on the reef flat disappeared. Similar, more detailed observations were made at the same place, again on shallow water corals, by Stephenson, Endean and Bennett (1958) following the minor 1954 cyclone. Most observations have been confined to shallow reef-flat and lagoonal waters because of the practical difficulties of investigating the reef-front, resulting from wave action and surf; yet it is on the more exposed reef-front that damage may be expected to be greatest. Thus, following Typhoon Ophelia at Jaluit, Banner reported that "on the bottom of the lagoon below low tide there was no evidence of disturbed conditions. Even delicate corals were not broken. In contrast it seems likely that the outer reef front suffered profound changes", as shown by the amount of fresh coral shingle in bars and shingle carpets (in Blumenstock, 1958, 1269; also Banner, in Blumenstock, editor, 1961, 75-78). Banner's deduction of "rather extensive" hurricane damage on the reef front is born out by the observed changes on the British Honduras reefs, though the evidence of such damage in British Honduras, in the shape of rubble and shingle constructions above sea level, is very much less extensive than on Jaluit.

In general terms, the observation made by Stephenson, Endean and Bennett, and other earlier workers, that the more rapidly-growing, branching, fragile species are more susceptible to damage than the slower-growing, massive, often globular and hemispherical species, is confirmed by the British Honduras data. The most successful coral in resisting damage was everywhere Montastrea annularis; the least successful

Acropora cervicornis, Porites other than P. astreoides, and the small unattached corals, such as Manicina areolata, Siderastrea radians, and Cladocora arbuscula. Table 2 lists the more common coral species of the British Honduras reefs in approximate order of resistance to destruction by storms.

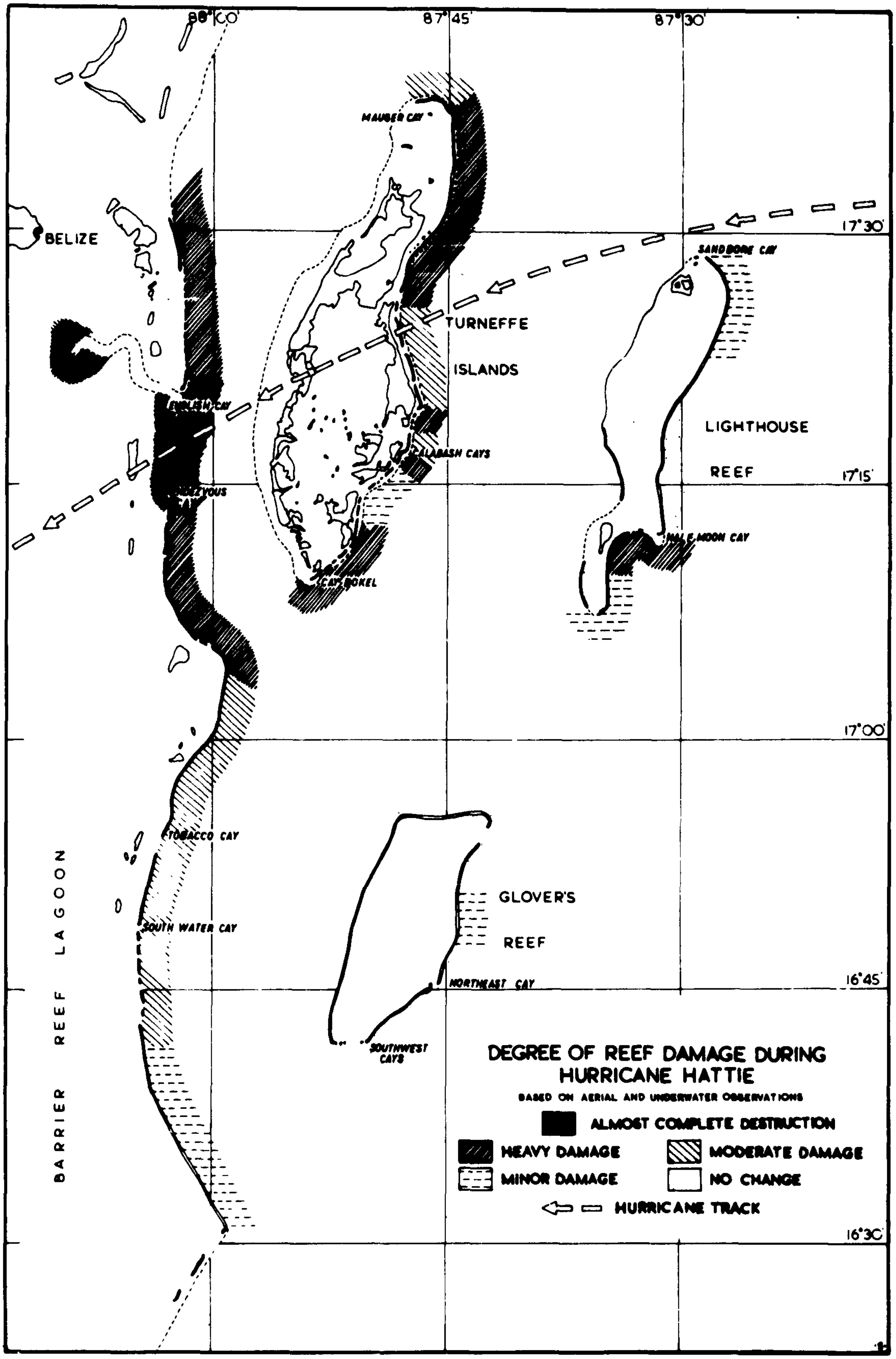
Table 2. Relative resistance of species to hurricane damage.

Least resistant	Acropora cervicornis
	Porites porites
	Porites divaricata
	Porites furcata
	Siderastrea radians
	Favia fragum
	Manicina areolata
	Cladocora arbuscula
	Isophyllastrea rigida
	Colpophyllia natans
	Agaricia agaricites
	Mycetophyllia lamarckana
	Acropora palmata
	Siderastrea siderea
	Montastrea cavernosa
	Porites astreoides
	Solenastrea bournoni
	Dichocoenia stokesii
	Dendrogyra cylindrus
	Diploria clivosa
	Diploria labyrinthiformis
	Diploria strigosa
Most resistant	Montastrea annularis

The nature of damage to colonies varies considerably, and some of the more common types of damage may be noted. Acropora palmata is often overturned and even completely inverted, without breakage, and the colony may survive and continue to grow in this way. Examples were seen where new vertical branches were growing upwards from the former undersides of now inverted colonies. Direction of fall of the tree-like colonies is generally from sea to land. Dead Acropora branches are often almost submerged in other debris, which may have been mainly responsible for their deaths. No extensive colonies of A. cervicornis were seen over a 30-40 mile lone reef tract on the barrier reef. The location of former colonies is often marked by piles of broken cervicornis sticks, often tightly packed, with an admixture of other small species. Occasional branches, sometimes broken, may be seen rising from the debris, still with living polyps, but these are uncommon. The most resistant colonies of Montastrea annularis may be rather complex, consisting not of a single hemispherical mass but of numerous smaller sub-hemispherical colonies grouped together in larger colonies with a total height and diameter of several feet, or of a series of overlapping plates also grouped together to form a large colony (Lewis, 1960). Frequently the larger colony has been fractured along the lines of contact between the smaller colonies, and the whole mass has fallen apart. This type of damage is usually peripheral. Other more purely hemispherical colonies of the genera Diploria, Montastrea, Porites, Siderastrea, Solenastrea, etc., were subject to rolling across the reef flat, some being left inverted but not dead, in the manner envisaged by Kornicker and Boyd for the formation of micro-atolls (Kornicker and Boyd, 1962, 668). These colonies were also subject to wave scour round their margins. Porites porites was several times seen, apparently undisturbed, though no longer living; on examination, however, the colonies proved to be thoroughly shattered and about to disintegrate.

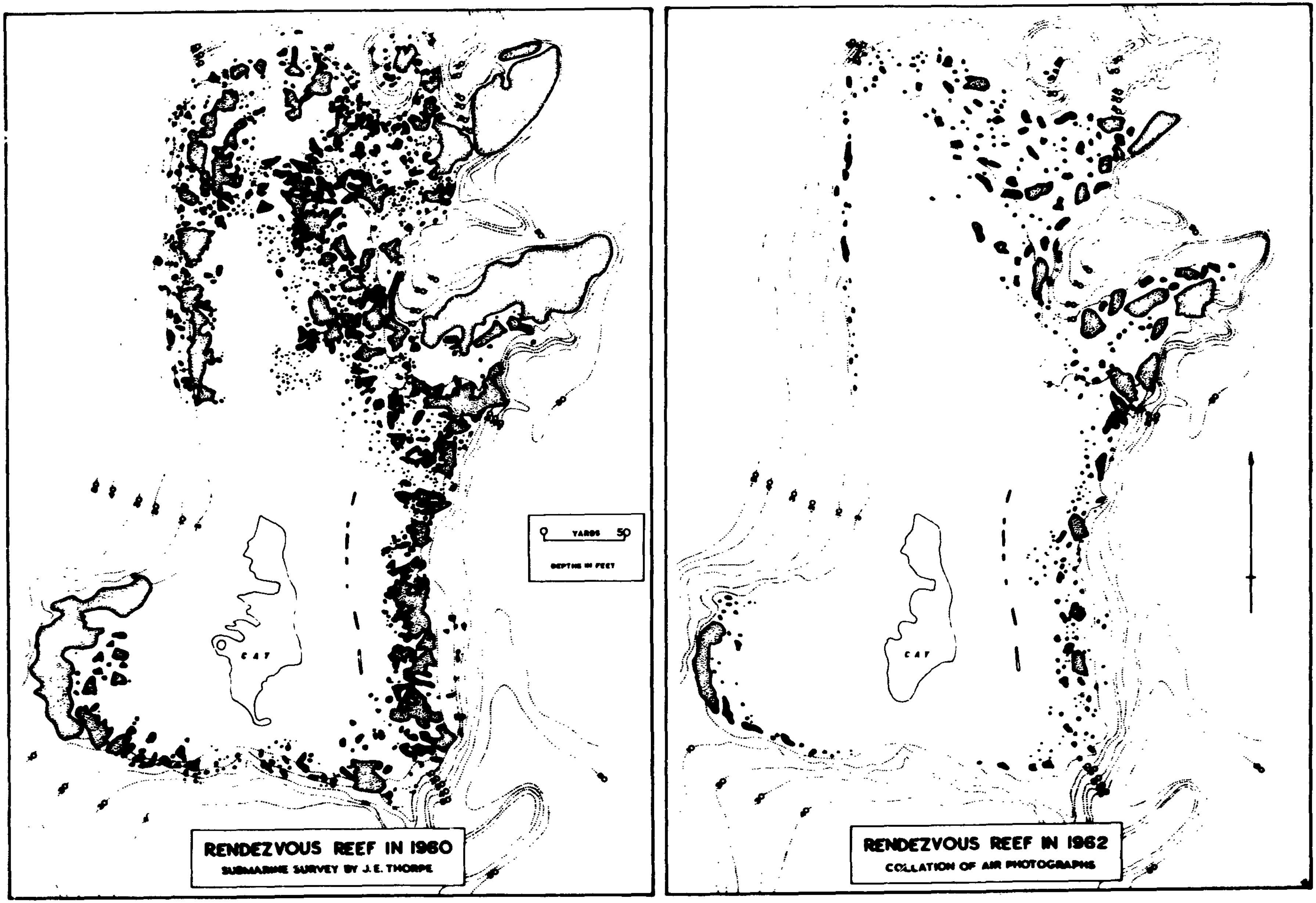
Stephenson and others arrived at similar results in Australia. At Low Isles the more massive and resistant species include Porites lutea, Goniastrea pectinata and Platygyra landlina; the less resistant fragile species included Montipora divaricata and Pocillopora damicornis. While accepting the dominant mechanical effects of hurricane waves, they also draw attention to the effect of increased amounts of debris in the water following the storm; "There is the possibility that destruction of coral may have continued after the cyclone had passed. Moderate and possibly local destruction of Acropora would produce coral rubble whose subsequent movements could damage a much larger area, and would probably hamper recolonization by corals of areas already devastated. Further degradation into grit would accelerate this process, particularly in a bared area where this grit could be agitated by waves. In 1954 much of the lower seaward slopes of the eastern side of the island was characterised by a substratum of grit and rubble, and the grit was in fact kept in continual motion during moderate seas at low water ... It is not impossible that a really severe cyclone would clear the area more completely of broken coral, and have less prolonged effects" (Stephenson, Endean and Bennett, 1958, 304). The suggestions that increased amounts of mobile debris may help smother still living corals, and that the same debris may also prevent recolonization, both seem highly probable; on the other hand, even so severe a storm as Hurricane Hattie was insufficient to sweep the debris away, and in this case the effects would seem likely to be more, rather than less prolonged.

Finally, there is the problem of the much greater degree of reef destruction on the barrier than on the outlying reefs. To some extent this is explained by the relative location of reefs and the hurricane track, but there is still a considerable difference between the northern barrier reef and the northern Turneffe reefs. The constriction of the channel between Turneffe and the barrier reef between English and Rendezvous cays, may have led to the piling up of surge water and increased wave action under the influence of northerly winds. On the east reefs of Turneffe there is no such constriction, and adequate drainage to north and south. It is also interesting to note that very little material has accumulated above water level in the area of maximum reef damage. Thus in the case of Rendezvous Cay virtually none of the reef material is now visible above sea level: most of the reef constituents must have been swept into deeper water round the reef patch. On the other hand, where damage was less extreme, as in the southern barrier reef lagoon and in places on Turneffe and Lighthouse Reefs, considerable shingle ridges and carpets have been deposited above sea level. All these extensive depositional features above sea-level, however, lie outside the storm surge zone. Presumably in areas affected by the surge all cay land was submerged and presented no barrier to the waves, once vegetation had been stripped, whereas outside the surge area, islands acted as barriers to wave movement throughout the storm. To a small extent also the absence of debris above sea level in the surge areas is illusory, as I am informed that much more material was visible immediately after the storm, and has since disappeared through wave action. Nevertheless, it is certain that no features comparable to the great shingle ridges at Jaluit, up to 8 feet high and 20 yards wide, with coral boulders 1-5 feet in diameter, were built anywhere in British Honduras. This comparatively meagre development of ridges on reef flats may perhaps result from poorer reef development in the Caribbean, compared with the Pacific, and the more sheltered sea conditions. At this stage, it might be unwise to attach too great significance to these differences. The subject of sediment deposition is raised again in Chapter 8.



88°00'
87°45'
87°30'
17°30'
17°15'
17°00'
16°45'
16°30'
BELIZE
MAUGER CAY
TURNEFFE
ISLANDS
ENGLISH CAY
RENDEZVOUS CAY
CALABASH CAYS
CAY BOKEL
SANDBORE CAY
LIGHTHOUSE
REEF
HALF MOON CAY
TOBACCO CAY
SOUTH WATER CAY
GLOVER'S
REEF
NORTHEAST CAY
SOUTHWEST CAYS
BARRIER REEF LAGOON
DEGREE OF REEF DAMAGE DURING
HURRICANE HATTIE
BASED ON AERIAL AND UNDERWATER OBSERVATIONS
ALMOST COMPLETE DESTRUCTION
HEAVY DAMAGE
MODERATE DAMAGE
MINOR DAMAGE
NO CHANGE
HURRICANE TRACK

FIG. 14



YARDS 50
DEPTHS IN FEET
CAY
RENDEZVOUS REEF IN 1960
SUBMARINE SURVEY BY J.E. THORPE
CAY
RENDEZVOUS REEF IN 1962
COLLATION OF AIR PHOTOGRAPHS

FIG. 15

IV. HURRICANE DAMAGE TO NORTHERN BARRIER REEF CAYS

Hurricane Hattie crossed the northern barrier reef near Rendezvous Cay (Chapter 2, Figure 2), latitude 17°15'N. Damage extended northwards from this point as far as Ambergris Cay and the northern boundary of British Honduras at Boca Bacalar Chico; in this area dominant winds and waves were northwest, north, northeast and east. South of Rendezvous Cay, damage extended almost to Gladden Spit on the barrier reef edge, and almost to Punta Ycacos on the mainland coast; winds and waves were here southwest, south and southeast. Because of this change in wind and wave conditions on either side of the storm track, and because of the number of cays involved, it is convenient to describe those to the north of Rendezvous in the present chapter, and those to the south in Chapter 5. The cays of the southern barrier reef, not affected by Hurricane Hattie, are not considered here and will be described in a later paper. In both chapters the cays are described from north to south.

The general disposition of the cays on the northern barrier reef and in the lagoon has been described by Vermeer (1959, 41-47, 58-65) and will only be broadly outlined here. North of Belize the coastal shelf averages 15 miles in width, and between Belize and the Bulkhead Reef (extending from the mainland to Ambergris Cay) is $1\frac{1}{2}$-$2\frac{1}{2}$ fathoms deep. The Bulkhead itself is a shoal area carrying $\frac{1}{4}$-$\frac{3}{4}$ fathoms, and encloses the 55-mile long Bahia de Chetumal, a drowned portion of Yucatan lowlands carrying 1-3 fathoms, with which we are not here concerned. The cays of the northern barrier are mostly mangrove cays with seaward sand ridges: they include Ambergris Cay, Cangrejo Cay, Cay Caulker and Long Cay. The Hicks Cays are the only extensive group of cays within the lagoon proper north of Belize. Immediately south of Belize the lagoon deepens rapidly to 3-4 fathoms, reaching 10 fathoms in the latitude of Rendezvous Cay. The seaward edge of the coastal shelf is formed by a low platform, 2-4 fathoms deep, 3-4 miles wide, from the outer edge of which the present barrier reef rises to sea level. Several mangrove islands are located on this low platform, including the Drowned Cays, Middle Long Cay and Colson Cays; while a number of small sand cays are found on the barrier reef proper. These include St. George's East Cay, Paunch, Sergeant's, Goff's, English and Rendezvous Cays. South of Belize there are no cays within the lagoon, except for a cluster of mangrove islands with a little dry land at the inner edge of the Deepwater (Grennel's, Eastern) Channel, which intersects the barrier reef and low platform in latitude 17°20'N.

Ambergris Cay

Ambergris Cay is the largest island on the British Honduras coastal shelf, though its description as such is somewhat artificial (Figure 16). It extends for some 25 miles southwards from the Boca Bacalar Chico, a largely artificial channel only 6 feet wide, which gives access from the sea to the Bahia de Chetumal, and serves as the Mexico-British Honduras boundary. The cay varies in width from over 4 miles to less than 100 yards. According to Bird Allen (1841, 80) the cay was named "from the produce of its shores", and Captain Henderson (1811, 24) described it as "of considerable size, abounding with extensive fresh water lakes, and at most seasons ... plentifully stocked with many kinds of game. This Key is likewise said to produce Logwood, and the more valuable kind of dye-wood, named Brasiletto". Jeffreys noted in his 1775 chart that there were "plenty of deer in it and Ambergrease often found on its Beach".

The seaward shore generally lies ¼ mile from the barrier reef, from which it is separated by a channel 1-2 fathoms deep; but at the rocky Reef Point, 4½ miles south of Boca Bacalar Chico, the shore swings out to the edge of the coastal shelf and the reef itself is interrupted (air photograph in Stoddart, 1960). This is probably controlled by the faulting which has shaped the rectilinear east coast of Yucatan. North of Boca Bacalar Chico the coast consists of uplifted Tertiary Limestones extending to Cabo Chatoche; in the Xcalak area, immediately north of the Boca, the limestones belong to the Carrillo-Puerto Formation of Upper Miocene-Pliocene age (Butterlin and Bonet, 1960). South of the Boca, Ambergris Cay falls into three main divisions: (a) a three-mile long zone of mangrove swamp, lagoon, and tidally-exposed sand; (b) the Basil Jones area, 5 miles long and 2-3 miles wide; and (c) the rest of the cay. The Basil Jones area was briefly visited in March 1960; it consist of a seaward beach ridge and leeward mangrove swamp, with a broad intervening area of palm thicket, distinguished in Figure 16 as high and low woodland with mangrove. Surface bedrock, a creamy limestone, was seen exposed along the track leading to Basil Jones. This is presumably comparable in age to that north of the Boca, and its presence shows that the cay is more properly a long sand and mangrove spit built southwards from a solid rock core, probably continuous at very shallow depths with the main peninsular limestones. "Basil Jones" is the name given to a test drill for oil made in the late 1950's by a Shell-Gulf Oil consortium, which reached 7322 feet without show of oil. No information is available on the well log (Keller and Wories, 1959).

South of Basil Jones is the main part of the cay, extending for about 14 miles. In structure it consists of a seaward sand ridge from 100 to 500 yards wide, backed by a wide zone of <u>Rhizophora</u>. The mangrove often falls into two sections: one immediately adjoining the sand ridge on its lee side, and one two miles to the east, forming the eastern shore of the cay. The intervening area is filled with shoal sand only intermittently colonised by mangrove, and often forming innumerable circular depressions 1-200 yards across, separated by intricate, narrow intertidal sand rims, occasionally colonised by vegetation. These are well developed behind San Pedro, and also near Reef Point; no detailed work has been done on these features, which bear a superficial resemblance to drying patterns in the savanna country near Belize, as seen from the air. The sand ridge is the only dry part of the cay, and is of variable height and width. For most of its length it is only 3-5 feet above sea level, and often lower; but at San Pedro and for about 1 mile to the north it is considerably higher. In 1959 Vermeer described a raised beach on the seaward face of this ridge, 6 feet high and 10-20 yards wide, 2 miles north of San Pedro (1959, 51-52, Figure 6). Levelling in 1961 along this ridge showed variable heights with ridge crests at 5 and 8 feet, and a surface much disturbed by wind erosion and deposition. The tops of the ridges in this area might in fact best be termed dunes under palm thicket. Any such seaward-facing ledge as that described by Vermeer is probably a hurricane construction (Stoddart, 1962a, 167), and it is in fact doubtful whether any traces of high stands of the sea can be traced anywhere on the British Honduras reefs (ARB 87, 109-110, 123-125). Immediately north of San Pedro village the ridge crest reaches 8 feet above sea level, and the water table, shown by a well, is 7.5 feet deep. The ridge here is about 80 yards wide; on its west side it passes under dense palmetto thicket or Avicennia-Rhizophora bush, depending on altitude. Along the broadly arcuate seaward shore, traces of eroded cemented sands can be found up to 6 inches above sea-level at the promontories separating the bays; these are probably exposures of old cay sandstone, similar to those on the east side of Turneffe. San Pedro village, population about 300 is built on the highest part of the sand ridge, which rises here to nearly 20 feet above sea level. The water table lies at depths of 15-17 feet in wells, and supplies excellent drinking water, which was not contaminated during Hurricane Hattie. Water between the cay and the reef is not less than 1 fathom deep, and the reef itself is poorly developed. In spite of the distance from the storm track, there was considerable erosion of the seaward shore near the village. A number of houses near the sea were undermined by waves and collapsed; the cemetery on lower ground was partly washed into the sea; and a newly-built assemblage of holiday huts south of the village was very badly damaged. Actual retreat of the shore and sand-stripping was, however, minor, and few trees were knocked down. Terminalia catappa was seen living close to the beach, and only the near-shore coconuts were affected by waves. Away from the village, the main effect was deposition of a thin sand carpet a few yards wide. Even at the south end of Ambergris Cay few coconuts have been felled. The limited damage seems to have resulted solely from the work of waves in exposed situations; the wind evidently lacked the force to knock down coconut trees. There is no evidence that the sea crossed the island at any point. Nor is there any evidence of a high storm surge.

The southern tip of Ambergris is formed by a number of small mangrove islands, and between these and the main cay, and also Cay Cangrejo, there are a number of deep submarine channels heading in the shoal reef area and debouching into the main coastal shelf lagoon. Similar channels are to be found between Cay Cangrejo and Cay Caulker. These were photographed before and after the hurricane, and there seems to be no significant change in their form. None of the mangrove on Ambergris is seriously defoliated, except to a limited extent near the south end, and even here Rhizophora on the lee side retains its leaves. The limit of serious defoliation must, therefore, lie between Ambergris Cay and Cay Caulker, about 40 miles north of the storm centre.

The effect of the hurricane on mangrove cays in the lee of Ambergris Cay (Deer Cay, Swab Cay, Blackadore Cay, Mosquito Cay) was negligible.

Cay Caulker

Cay Caulker (Corker of Jeffreys, 1775, and Owen, 1830) is a large mangrove-sand cay situated 5 miles south of Ambergris Cay and 1-1½ miles from the edge of the coastal shelf. It has been briefly described by Vermeer (1959, 55-58). The island, which parallels the shelf edge, is about 4½ miles long, but varies considerably in width. The northern section, some 2½ miles long, is 350-550 yards wide; then follows a mile-long section, fronting a great leeward indentation, with a maximum width of only some 70 yards; while the broad southern end of the cay widens out to about ¾ mile in width (Figure 17).

The island is still very inadequately known; it was visited in 1961 and again in 1962, and photographed from the air in 1959, 1961 and 1962. The seaward side is formed by a sand ridge of variable height. Along the northern half of the cay it is everywhere low, and fronted on the seaward side by now defoliated Rhizophora. Along much of the narrow sector of the cay it is also less than 3 feet high, but near Cay Caulker village it rises to 6-7 feet (Vermeer quotes a maximum of 12 feet). Along the southern section the ridge again declines and is fronted by mangrove. About the interior of the cay very little is known: the southern lobe contains much mangrove and some standing water (Vermeer, 1959, 56-7), and mangrove forms a discontinuous rim round the shore of the main west bay, and also towards the northern end of the west side of the cay. Much of the lee shore, however, consists of a low, often cliffed sand beach without mangrove. The interior of the northern sector is covered with palm thicket rather than with mangrove. The seaward sand ridge is generally planted with coconuts, especially near Cay Caulker village, on the narrow section of the cay.

The village is favourably situated on the highest part of the sand ridge, with an excellent small-boat anchorage in the west bay. It has a population of about 300 and before the hurricane was a boat-building and fishing centre with a largely Spanish-speaking population, a police station and shops. Reyes, Alamina, Young and Bevans were common surnames here. In addition to coconuts a number of other trees were planted near the village, some ornamental (including large specimens of Pinus), some fruit, including mango (Mangifera indica), plantain (Musa paradisiaca), and 'almond' (Terminalia catappa), plus many exotic flowering shrubs.

During the hurricane damage was concentrated near the village itself, where the land, though highest, was narrowest and most cleared of native vegetation. Two streets of wooden houses nearest the sea were destroyed by wave action, together with the main boat-building sites, and the sea completely crossed over the land area at its narrowest point. The schoolhouse, standing in the track of the waves, collapsed, with 14 deaths. At this point, north of the village, the land is low-lying and presented little obstacle. Coconut trees were uprooted, and the holes left by their roots formed the nucleus of scour holes cut into the cay surface. The deepest of these holes is about 6 feet deep and most are about 6 yards long, elongated in the direction of water movement. Further scour holes have been cut in the shallow floor of the west bay close to the shoreline. In the village itself, where the land is higher, east-west trending streets, at right-angles to the shore, channelled storm waters across the cay, and were scoured out to depths of 1-2 feet. The walls of these channels are nearly vertical, and reveal layers of cemented sand, dipping seaward parallel to the cay surface. Elsewhere along the seaward shore there has been stripping of the surface sands within 10 yards of the shore, removing up to 2-3 feet of sand in vertical cross-section, as indicated by the roots of still-standing coconut palms.

The survival of coconut palms, especially away from the narrow area where the sea crossed the island, is remarkable; young trees are still standing within a few feet of the seaward shore itself. Rhizophora has been completely defoliated along the whole of the east shore and along the margins of the west bay; but in March 1962 Rhizophora with leaves was to be seen along the rest of the west shore. Coccoloba survived even near the seaward beach, and Terminalia within 50 yards of it, though both were much broken. One or two large pines were overturned in the village, and there was complete destruction of plantains. Generally, physiographic effects away from the village were negligible, and vegetation damage was moderate, except near the village and along the seaward shore.

Cay Chapel

Cay Chapel (Figure 17) is a mangrove-sand cay lying 1 mile south of Cay Caulker and 1½ miles from the edge of the coastal shelf, here only sparsely fringed with reef. The island is elongate, aligned parallel to the shelf edge; it is 2¼ miles long, with a greatest width of about 500 yards. The greater part of the cay is built of parallel sand ridges, aligned north-south rising to a maximum height of 6 feet above sea level. The structure of the ridges and intervening swales has been largely destroyed by bulldozing operations connected with land clearing. At the northern and southern ends of the cay there is a slight growth of Rhizophora, but otherwise mangrove is restricted to the margins of a leeside swamp area near the middle of the cay. The vegetation of the sand area formerly consisted of a dense palm thicket of coconuts and Thrinax, with Coccoloba, Tournefortia, Suriana, Euphorbia and grasses; it has clearly changed much since Jeffreys noted a single "large cocoa tree" in 1775. Since 1961, however, the island has been in the hands of land developers, who before the hurricane had almost completely cleared the vegetation from the whole of the northern end of the cay, leaving only coconuts standing, with no ground vegetation at all. Previously the island had been exploited for coconuts, yielding 60-70,000 nuts per month. Of the coconuts standing at the time of the storm, residents estimate that 60% were felled; but at the time of my visit most of these had been bulldozed away. In the northern cleared sector there was some undercutting and root-exposure along the east shore, and sand-stripping and root-exposure across a zone about 10-15 yards wide near the shore, and patchy sand deposition across a zone 12-25 yards wide immediately inland from it. The sea is said to have risen to a height of 10-12 feet above normal and to have submerged the northern end of the cay; however, this height is very much greater than that reported for Cay Caulker, and the true rise may have been much less than 10 feet. Since the hurricane, the bare sand surface has been colonised by Tournefortia seedlings, a little Euphorbia and 'burr-burr', Cenchrus.

The southern section of the island is still densely vegetated, and since the hurricane has been almost impenetrable except along bulldozed trails. Wind damage to vegetation has been considerable, acting from the northeast, but maximum damage occurred along the seaward shore, where the vegetation, mostly Coccoloba, has been pushed back for several yards. Immediately south of the easternmost point on the seaward shore, this retreat of the vegetation hedge and the stripping of surface sand has exposed a wide area of cay sandstone. The exposure is about 15 yards square, and dips seaward. At its outer edge it is 1 foot thick, with its lower edge 18 inches above sea level, at about the limit of normal wave swash. The top of the inner edge rises to about 3 feet above sea level. It is bounded on all sides by steep and overhanging margins, and the surface is deeply pitted and eroded; the surface is also much better cemented than the interior. The constituent sand is very fine, and does not contain the large Halimeda plates and red foraminifera characteristic of intertidal beachrock. Similar cementation can be traced at intervals along the shore beneath the Coccoloba fringe. The exposure seems similar to, though better developed than, that at Cay Caulker village.

Cays between Cay Chapel and Belize

Apart from St. George's Cay and St. George's East Cay, discussed below, there is little to remark about the numerous mangrove islands on the coastal shelf between 17°30'N and 17°45'N. These cays include Long Cay (the northernmost of that name), Hicks Cays, Montego and Frenchman's Cays, Hen and Chicken Cays, Rider's Cays, and the northernmost Drowned Cays. Apart from a narrow seaward fringe of sand and coconuts on Long Cay and on the Drowned Cays north of Gallows Point, these islands consist wholly of mangrove, and are often discontinuous. The Hicks Cays, for example, consist of a dozen islands, four of them large, the intervening passages being shallow and colonised by Rhizophora seedlings, but with deep meandering channels, through which tidal currents set with great rapidity. All these mangrove cays suffered complete defoliation, and most were probably inundated by the storm surge. Flying over them after the storm, the area of bare mud and shallow water within many of the cays seemed greatly increased, probably largely as a result of the breakup of the mangrove canopy; seen in this condition the name of 'drowned cays' seemed particularly appropriate. On the sparse dry areas even coconuts were still standing, but gaps showed that at least 75% had been destroyed. At Montego, Frenchman's, St. George's and Hick's Cays leaf growth on Rhizophora in April, 1962, was limited to young plants on the west sides, indicating protection from easterly hurricane waves.

The form of the Drowned Cays proper is well shown on the new Admiralty chart of Belize Harbour, No. 522 of 1960, based on surveys of 1957-8. These mangrove islands are intersected by a number of narrow east-west channels or 'bogues', namely Shag Cay Bogue, Bannister Bogue, Farls Bogue and Goring Bogue. These are similar to the un-named bogues between Frenchman's, Montego and St. George's Cays further north. Most of these bogues carry 3-4 fathoms water, and they must have acted as major drainage channels for the east-west passage of water during the storm surge. The northernmost bogues show signs of scouring, with prominent sand deltas at their western end (e.g. north of St. George's Cay) but there is no means of estimating the amount of deepening either here or at Drowned Cays.

Stake Bank, midway between Drowned Cays and Belize, is worthy of mention. According to Anthony de Mayne's MS survey of Belize Harbour, 1828, this was at that time a shoal bank with one or two mangrove seedlings. There is a widespread tradition that the shoal is built from ballast deposited by ships in the harbour (Anderson, 1958, 95). In 1765 Speer described it as a "long Bank, ... called Stake Bank, ... dry in some parts";

it was not then visible until close by, as Speer gives course directions when it may be seen "if you look out well" (1765, 20). Jeffreys marked it on his 1775 chart. Since 1828 the few mangrove seedlings have expanded to form a mangrove cay 500 yards long, resting on a shoal measuring approximately 2000 x 1000 yards.

A further point of interest concerns the coastline near Belize. Immediately south of the Belize River peninsula, in Sibun Bight, vertical air photographs flown by the R.A.F. after the hurricane (V2/543/RAFI565/0071-72, 17 December, 1961) compared with the U.S. Navy cover 1945, reveal scour and bottom deepening between the coast and the three-fathom line. The scour hole, which follows the curvature of the coast, is 2000 yards long and averages 1100 yards in width. Unfortunately it was not seen while in British Honduras, and was not investigated in the field.

For further notes on the Drowned Cays, see Vermeer (1959, 58-59).

St. George's Cay

St. George's Cay deserves fairly detailed treatment, not only because of the extent of the hurricane damage, but because of the island's importance in the history of the Colony. According to Romney and others (1959 , Figure 10) there is a Maya shell-midden on the cay; but its importance really dates from the European occupation. The Spanish knew it as Cayo Casino, but the name changed after the English took it over in the late seventeenth century. Captain Henderson spoke of it as

> "a most agreeable and healthful spot, ... which contains a number of good houses. This is much resorted to as a place of convenient retirement by the inhabitants of the settlement during the hot months. The purity of the air and other advantages connected with it render it likewise a desirable retreat for the sick and convalescent. Some years past, St. George's Kay was the chief place of trade in this part of the world, on which the merchants almost wholly resided; and where the vessels engaged in it deposited their cargoes and again took in their lading." (1811, 22-23).

The Honduras Almanack for 1829 gave a fuller description (13-14):

> "St. George's Kay, is very narrow in some parts, and about one mile in length, in the shape of a crescent, at the northern extremity. It is now chiefly used as a place of retirement from the bustle of business, and the peculiar salubrity of the air renders it highly beneficial to invalids, and convalescents, particularly in the hot months. Here is a Government House, for the Superintendant, besides many other good and substantial buildings. On the western side there is a commodious situation, called Irish Bay, where Droggers and smaller crafts are built, and repaired. Off the Eastern side of

> the island, vessels of large burden are still loaded for the European markets, with mahogany from the New River, and its vicinity. ... The soil is naturally sterile, though at some labour, and expense, small gardens have been successfully cultivated upon it."

In the later eighteenth century, however, the focus of government was already moving to Belize. In 1798 all the houses on the cay were destroyed by the settlers a short time before an attack by the Spanish. In the ensuing "Battle of St. George's Cay" of 10 September, 1798 the Spanish were repulsed, and this has been held, incorrectly, to give the English title to the whole of British Honduras by right of conquest (Anderson, 1958, 36-39; Carr and Thorpe, 1961, 46-47, 169-170; Humphreys, 1961). In the early part of the nineteenth century a Government House, Cathedral and Barracks were all built in Belize, and the island became simply a holiday resort, a function it continues to fulfill.

The cay is situated (Figure 18) a little more than 1½ miles from the edge of the coastal shelf, to the north of a broad shelf-edge embayment carrying 4-6 fathoms of water. It lies to the south of an extensive group of small mangrove islands, extending from Hicks Cays to Frenchman's Cay, which have increased considerably in area since Owen's survey in 1830; and about 2½ miles to the north of Drowned Cays. The island itself is crescentic, convex to the southeast, with a total length, measured along its seaward shore, of nearly two miles. It falls naturally into two parts: the southwest section, which is fairly straight, about a mile long and 100-200 yards wide, and consists entirely of mangrove, with little if any dry land; and the northeast section, recurving at its north end, also about a mile long measured along its seaward shore, low, sandy, and inhabited. The Rhizophora section will not be further discussed, except to say that with the exception of defoliation it suffered no considerable changes during Hurricane Hattie.

The sandy section was visited in February, 1960, and photographed from the air in 1961. It then consisted of an arcuate strip of sand varying from 100 to less than 50 yards in width, generally about 1 foot above sea level, rising a little higher in a few places, falling rather lower in others. About one half of the seaward shore was protected by a low masonry wall. The leeward shore, facing what used to be known as Irish Bay, had much mangrove towards its north end, with a few isolated islands of mangrove in the bay itself. The vegetation of the sandy area was highly artificial; houses had been built along its whole length, and coconuts had been planted for shade. The ground vegetation consisted chiefly of grasses, Sesuvium, Euphorbia, Ipomoea, Wedelia and similar plants. There were a few Coccoloba trees, and numbers of cultivated plants, including fruiting plants, in the house gardens. Because of the amount of human interference, however, no collections were made.

Damage during the hurricane was intense (Figure 19). All the 27 jetties, most with enclosed swimming pools or "crawls" at the end, were destroyed, though their positions can still be clearly seen in bottom weed patterns, and only some half dozen houses remained standing, all of them badly damaged. The damage may be described in two parts, occurring north and south of Channel A. North of this point the cay is generally 100 yards wide, with extensive mangrove on its lee shore; the seawardshore, facing north, northwest and northeast, is protected for nearly all its length by a masonry wall. On the north and particularly northwest-facing sections, damage was not catastrophic. Some houses and many coconuts stood, and the original ground vegetation of Paspalum, Euphorbia, Wedelia and Hymenocallis survived. Apart from the few houses which remained standing in the northwest-facing section, buildings disappeared entirely, except for concrete foundations, and such things as concrete vats. All crawls disappeared. Direction of tree fall varied from 225-250^{o}, and may reflect wave action as well as northeasterly winds. The number of fallen trees increases southwards, until near Channel A almost all trees have disappeared. The masonry wall protected the shore to some extent, but it is now separated from the shore by 2-3 yards of water along most of its length. In places the wall itself has been broken up and has disappeared.

The second section, about 750 yards long, is much narrower, from 45 to 70 yards wide, and lacks any mangrove on its lee shore. It is very low-lying, protected by a wall for only part of its length, with a number of Rhizophora bushes between the crawls on the seaward shore. The vegetation had been almost entirely removed for large, closely spaced houses, with crawls, and the vegetation was restricted to a few coconuts and a sparse ground cover. Of the houses, only the remains of three can now be seen, but of these one is strangely almost undamaged; many people sheltered in it during the storm. The whole of this section of the cay must have been submerged during the hurricane. The most distinctive features of damage are the five channels cut across the island, four of which are deeply scoured. Channel A is the most northerly and largest; it bifurcates seawards, and passes seawards into a large submerged sand delta on the seaward side. On its north flank there is a very deep circular scour hole cut by the side of a concrete tank. The channels and scour hole are both more than 20 feet deep. Between Channels A and B the cay surface lies only a few inches above sea level, and has been cut into a number of irregular sections, separated by water at high tide: the intact house stands on one of these. Channel B is smaller, with no delta, but deepens and widens seawards. Patches of grass have survived in places between the two channels. Between Channel B and C the cay segments are larger, also with some grass, but all the houses and nearly all the trees have disappeared. Channel C is narrow (about 10 yards wide) but at least 3 fathoms deep; it too has a large delta on its seaward side. Between Channels C and D the sand surface is higher, with a number of coconuts and some Coccoloba standing, a surviving ground cover of grasses, Wedelia and Hymenocallis, and some dead Rhizophora on the seaward shore. At its southern end is the cemetery dating from the earliest days of the colony; it has been much broken and only two or three stones are now decipherable, one dating from 1836. Fortunately the inscriptions have been published (Usher, 1907). Channel D, 20 yards wide, and Channel E, 25 yards wide, also contain fairly deep scour holes, both probably more than 2 fathoms deep, with large sand deltas at their eastern mouths. South of Channel E there is but a small sandy area before the cay passes into the main mangrove sector. Fallen coconuts on this sand area are aligned 225-260^{o}, apparently in response to northeasterly winds, but the presence of scour holes filled with water, often at the base of fallen trees, and a thin, discontinuous fresh sand carpet, show that the surface was submerged. Patterns in the sand carpet also indicate northeasterly waves. Much wreckage has been piled against the mangrove itself. The ground vegetation has survived fairly well in this section, and consists of grasses, Ageratum, Cakile, Euphorbia and Cyperus. The fresh sand is now being colonised by Sporobolus. All the Rhizophora along the west shores of the sandy area is completely defoliated, and in March, 1962 had not begun to regain leaves.

The two main conclusions from this account of St. George's Cay are, first, that destructive winds and waves, shown by coconut trees, accumulations of wreckage, and sand patterns, came from the northeast; and second, that the channels which intersect the cay, as shown by their deltas, were cut from Irish Bay toward the sea, that is, from the northwest. In Chapter 2 it was shown that west and northwest winds immediately preceded the arrival of the storm centre, so that the channels may have been cut before the other features ascribed to northeasterly winds and waves. The freshness of the sand deltas, however, argues against this.

In early 1962, parties were continuing to visit the island for recreational purposes, generally making day trips from Belize, even though whatever advantages the island previously enjoyed (cf. Carr and Thorpe, 1961, 47) had been completely destroyed.

St. George's East Cay

St. George's East Cay (Figure 20) was, before the hurricane, a small island on the northern side of the major reef gap between Gallows Point Reef and St. George's Cay. It was situated on a small patch reef, 1¼ miles due east of St. George's Cay itself. Owen did not chart it in 1830, and it does not appear on any subsequent Admiralty charts. In 1960 it was the most northerly of the true sand cays on the barrier reef; it was photographed from the air in 1961.

In 1960 the island was crescent-shaped and convex to the northwest, with a greatest length along its main axis of 120 yards. The island was formed by a ridge of medium shingle along its northwest shore, rising steeply to 3 feet above sea level. From the crest line the surface sloped gradually to the southeast. At each end of the cay the shingle formed flat-topped lobes, enclosing a sandy beach along the southeast shore. The shingle consisted largely of Acropora fragments 3-6 inches long; but on the island surface recognisable coral fragments were fewer, and coarse sand predominated. Water more than 1 fathom deep approached within 2 yards of the northwest shore, and the bottom near the island was cobble covered.

No trees grew on the cay, which was consequently inconspicuous. Much of the ground surface was covered with a discontinuous mat of Sesuvium portulacastrum, interspersed with patches of Euphorbia mesembryanthemifolia and clumps of Tournefortia gnaphalodes. Over the southwest two thirds of the cay these were virtually the only plants to be found, together with a single Rhizophora seedling. At the northeast end the vegetation was more luxuriant: a ground cover of Sesuvium, Canavalia and Ipomoea, with bushes of Tournefortia, Conocarpus and Borrichia up to 4 feet high. The cay was not inhabited, and did not appear to be often visited, which probably accounted for the unusual development of vegetation on a sand cay so near to Belize.

During Hurricane Hattie the cay was completely washed away, and no sandbore or shoal could be seen on the site of the old island in April, 1962. St. George's East Cay was the largest sand cay to disappear entirely during the storm.

Paunch Cay

Paunch Cay, the Punchgut Kay of Speer (1771) and Paunchgut of Jeffreys (1775), was located in 1960 on a small reef patch on the coastal shelf edge, near the southern end of Drowned Cays. It was then 50 yards long and 10-20 yards wide, and consisted of a strip of coarse white sand with a little shingle, elongated north-south. The island was asymmetrical, with a pronounced ridge rising to 3 feet above sea level along the west shore (Figure 21). Three parallel and slightly submerged lines of beachrock were seen off this side of the cay, trending slightly west of north. The longest extended for 50 yards, passing southwards under cay sands; all the lines were broken and interrupted, but clearly dipped to the west. The surface of the rock was thickly covered with algae and some small living corals, including Favia, Siderastrea and Porites. The surface was irregular and eroded, and the rock was cavernous underneath, sheltering many crayfish.

The island was then unvegetated: it had a plant cover during Owen's 1830 survey, and in 1896-7 the Rambler noted huts and palm trees 35 feet tall. This vegetated island was destroyed in the hurricane of 10 September, 1931; the relict beachrock now visible may date from the pre-hurricane cay. Between 1931 and 1961 Paunch Cay was simply a shifting unvegetated sandbore, on the site of the older island. During Hurricane Hattie the sandbore itself was washed away, and much of the living reef destroyed. After the storm the beachrock remained in place but seemed more broken. All larger algae and small corals had been swept from its surface; only one Halimeda plant was seen, no crayfish and few sea urchins. In the area of the old cay to the east of the beachrock, the floor now carried 2½-3 feet of water. A few yards east of the beachrock a steep-sided rubble patch rises to within 12-15 inches of the surface, and consists mainly of cervicornis debris, tightly packed. It seems likely that a new sandbore based on this post-hurricane shingle foundation will shortly emerge, forming a fresh sandbore comparable to that existing between 1931 and 1961.

Sergeant's Cay

Sergeant's Cay (sometimes spelt "Serjeant's")(Figure 22) is situated on a reef patch at the edge of the coastal shelf, one mile south of Paunch Cay; it was charted by Speer (1771) and Jeffreys (1775). At the time of the Rambler survey in 1896-7 it had "huts and palm trees" with "tops of trees about fifty feet"; and this description appeared on charts until the Vidal survey of 1957-8. Until the 1961 hurricane it remained a tolerable description of the cay.

Before the storm the island was roughly triangular, with a greatest length of 110 yards along the south side, and a greatest width of 50 yards. There was little variation in surface level, which reached 2-3 feet above sea-level, but the western shore was cliffed and undercut. In February 1960 there was an accumulation of fresh sand along this side of the cay, forming promontories to northwest and southwest. This undercutting and subsequent accumulation was noted in mid-1957 by Vermeer (1959, 73); but his estimated height of 5 feet on the windward shore is much exaggerated (Vermeer, 1959, 71-74). The total area of the cay in 1960 was approximately 4500 sq. yards, of which the fresh sand area on the west side accounted for 11%. The cay stands on a small reef patch, with a shallow reef flat along its seaward shore. The southern shore shelved steeply to depths of 1-1½ fathoms, giving anchorage to small boats and access to a substantial wooden pier 60 yards long. About 10 yards from the shore itself there was a submerged barrier of conch shells which did not quite reach the surface. The vegetation of the island was completely artificial. With the exception of a large Avicennia on the south shore, the only trees were some three dozen coconuts, with no undergrowth. The island was privately owned by an American fishing syndicate, and had a large clubhouse, two smaller houses, and three water tanks. No beachrock was exposed round the cay.

During Hurricane Hattie Sergeant's Cay was almost completely destroyed though fortunately the inhabitants had taken refuge on the larger Water Cay and no-one was killed. Pilots from English Cay who sailed past Sergeant's on 4 November, 1961 report that the cay was then completely awash, with waves overtopping a low sand shoal. In March 1962, when the re-survey was made, however, a sizeable island had again grown up, and plant colonisation was beginning. The only traces of the former cay were a tilted concrete water tank on the east shore; house posts and concrete rubble some yards to seaward; posts from the demolished jetty on the south shore; and a small area of coconut roots near the centre of the island. These traces permit the fairly precise location of the present cay with reference to the old on Figure 22. The new island has an area of 2600 sq. yards, a decrease in total area of rather more than two-fifths. The highest point on the cay is about 3 feet above sea level on the north point, where sand and shingle forms a crescentic ridge. There is some undercutting near the west point, forming a steep sand cliff 2½ feet high. The main plant coloniser is Portulaca oleracea, in scattered patches 1-2 feet in diameter, with thick succulent leaves and stems and yellow flowers. Two other species were present in small patches: Sesuvium portulacastrum and Euphorbia mesembrianthemifolia; near the centre of the cay there is a single small Rhizophora seedling. It is unlikely that the cay will again be settled in the near future, and it will be interesting to follow the evolution of the island and its vegetation. North of the island the shallow sea floor is covered with Thalassia turf dating from before the storm; this is almost undamaged, except for a number of shallow round scour holes cut through to the underlying sand.

Goff's Cay

Goff's Cay (Figure 23) is located on the northern side of the entrance to the Deepwater Channel, at the south end of a strip of surface reef, trending N-S and about 800 yards long. Bottom topography near the cay is intricate as a result of former karst erosion at the edge of the coastal shelf; the shelf itself near the cay carries 1-2 fathoms of water, but immediately east and south there are deeper channels and holes with up to 24 fathoms. The edge of the shelf (50 fathom isobath) lies about 1100 yards east of the cay. Before the storm the island itself was triangular with sides 70-80 yards long, and straight shorelines. The whole cay was built of rather gray sand, with no shingle. In February, 1960, and on later occasions, there was an extensive spit, 20-25 yards long, of fresh white sand, unvegetated, at the north end of the cay. A smaller, similar spit was mapped at the southeast corner. The shore of the cay behind both spits was undercut. No beachrock could be seen round the shores. The reef flat to the east of the island was narrow, about 25 yards wide, and scattered with algae-blackened boulders and fragments of coral. Coconuts dominated the vegetation and formed a canopy over the central island-core. There were several trees of Coccoloba uvifera, and several small Avicennia trees on the southeast side. At the northeast end of the cay, beginning to extend across the fresh sand accumulation, was a crescentic mat of Sesuvium, with some Ipomoea and Canavalia, giving way inland to a narrow patchy zone of Euphorbia mesembrianthemifolia. Most of the surface under the coconuts was bare sand, with only long straggling vines of Ipomoea and Canavalia and some Euphorbia.

Speer (1765, 19) referred to it as a "small round Kay ... not so big as English Kay", and Jeffreys (1775) charted it as 'Gough's Cay'. In 1896-7 the Rambler noted "huts and palm trees", with "tops of trees about 45 feet high". Since that time there was little apparent change until the 1961 hurricane.

During the storm the core-island suffered severe marginal erosion, decreasing in area by nearly 60%, from 2100 sq. yards to 950 sq. yards. The two sand spits mapped in 1960, covering 1100 sq. yards were completely washed away. Immediately after the hurricane it is clear that the cay had decreased to two-sevenths of its former size. In March 1962, however, at the time of the re-survey a considerable amount of fresh sand had accumulated round the old eroded core, adding some 1700 sq. yards to the 950 sq. yards left by the storm. The total area had thus increased to 80% of that before the storm, though a much greater proportion consisted of fresh loose sand rather than root-bound core.

The remnant of the core-island has been stripped of surface sand, and coconut roots are exposed. Its margins are undercut, steep, and formed of roots from which most of the sand has been flushed. Rocks and rubble are piled against the southeast shore. The reef flat to the east is covered with rubble and shingle, forming in places a continuous carpet of imbricated slabs. Rubble forms a broad zone along the reef crest, breaking surface at several places to form exposed shingle ridges less than 2 feet high. Some 400 yards north of the cay a circular sandbore of variable diameter was seen several times where no sandbore had previously existed. Two new exposures of beachrock were uncovered off the south and east shores, to seaward of the old cay site, dating from a period when the cay stood farther southeast than now. The exposures are flat-lying and show no clear dip. Before the hurricane they were presumably covered with sand.

Some broken vegetation survives on the island, nearly all of it dead. There are two or three coconuts, and a few much broken but still recognisable Coccoloba. The foundation posts of the hut can be seen near the southeast shore. The only new plant coloniser at the time of my visit was Portulaca oleracea, in a few scattered patches.

One point of interest, which shows that the cay has not materially shifted its position in the last century, is of a somewhat macabre nature. At the time of the first Admiralty survey of this coast, yellow fever carried off an officer and eleven men on the survey ship, and they were buried on Goff's Cay, a fact recorded on a plaque in St. John's Cathedral, Belize. In March, 1961, a number of skeletons, presumably of these unfortunate persons, began to wash out of the cay on its south side. Mr. A.H. Anderson, Archaeological Commissioner, collected the remains and took them to Belize, where they were found to include both male and female bones.

English Cay

English Cay (Figure 24) is located on one of a number of patch reefs on the south side of the entrance to the Deepwater Channel, three miles southwest of Goff's Cay. It was charted by Speer in 1771 and Jeffreys in 1775, and has played some part in the history of the Belize settlement. Speer (1765, 19) termed it "a short, round, bluff Kay", and the description still holds. Before the hurricane the island was triangular, with sides 80-100 yards long. Both the northwest and south shores were slightly undercut, and marked by leaning and fallen coconut trees. The third shore, facing east, was largely artificial, being formed in the north by a masonry wall and farther south by a rampart of conch shells. The island was low and sandy, rising to 2-3 feet above sea level on its east shore, and to approximately 4½ feet above sea level in the cay centre, near the lighthouse base. The cliffed shores to northwest and south were 12-18 inches high. The cay was composed entirely of fine sand with no shingle. In January 1960 there was a large fresh sand lobe at the southwest corner, projecting some 30 yards from the island core. This was seen on several other occasions, and was clearly a temporary and fluctuating, perhaps seasonal, accumulation. Vermeer, in a brief description of English Cay, says of it: "A sand spit which curves round toward the east, extends from the southeast part of the cay. Observed on my first visit to the cay, the spit had been washed away and was nothing more than a shoal bank of sand on a return visit some two months later" (1959, 75); this was in 1957. No beachrock was visible round the island.

The cay is a pilot station, and has a lighthouse 60 feet high, built in 1935, together with the remains of an older fixed light. There was a considerable semi-permanent population, and nine houses. The natural vegetation had been almost entirely removed, and the cay supported only coconut palms, particularly on the east side, where they were planted in regular rows. On the east shore near the conch shell rampart there were also two old and moribund specimens of Rhizophora, standing some yards inland from the shore, toward which they had apparently grown in step-by-step fashion. There was a single specimen of Coccoloba uvifera on the south shore. Coral was awash on the east and south sides of the reef patch only 40-50 yards from the cay, across a reef flat 1-2 feet deep. On the west side, however, there was an anchorage in 1-2 fathoms water over a sandy Thalassia-covered bottom, giving access to a 60 yard long jetty.

English Cay was severely damaged by Hurricane Hattie. All the houses, and all except 8 of the 98 coconut trees disappeared from the cay. Most of the remaining coconuts lost their crowns. The lighthouse stood, as did a steel water tank; a water mark on the side of the tank showed that the sea had risen during the storm to a level approximately 12 feet above normal. The remains of the original lighthouse had been dismantled in mid-1961, before the hurricane struck. The concrete wall and conch shell rampart were unable to protect the seaward shore: the conch shells disappeared, and only fragments of the wall remain. The east beach retreated 5-10 yards along its whole extent; at the north end of the cay a triangular segment of land of some 575 sq. yards was eroded away; the fresh sand lobe at the southwest corner disappeared; and the south and northwest shores also retreated from 2-10 yards. Rough calculations show that of an original area of 5750 sq. yards, 3150 sq. yards remain; one-third of the original land area has disappeared. However, most of this lost area is accounted for by the disappearance of the large fresh sand lobe, so that the erosion of the island core was nearer to one-sixth than one-third. Coconut roots were exposed along the whole of the east shore, but over the cay surface there has been surprisingly little sand-stripping and root-exposure. Residents informed me that immediately after the storm there was much rubble and coral debris strewn over the cay surface, together with fallen tree-trunks and other material, but in March 1962 nearly all this had been cleared, in some places forming a bank round the shore. It is interesting to note that the straggling Rhizophora seen before the storm survived, but now stands several feet seaward of the shore. Only the broken trunk of the Coccoloba remains. Houses are already being re-erected on the cay, which because of the pilot station and lighthouse had to be re-occupied within a few days of the storm. Water supply proved the greatest difficulty, as there is no fresh water lens and the vats were full of seawater, but this is only a temporary difficulty. It was also interesting to note the reappearance of a fresh leeward sand spit; when the cay was remapped in March this was not to be seen, but a few days later a long sinuous spit 50 yards long extended westwards from the western point.

The Southern Triangles

The Southern Triangles is a convenient name to apply to the two clusters of islands at the inner end of the Deepwater Channel (Figure 25). The name has of late fallen into disuse, though the cays on the south side of the channel are still named "The Triangles" on charts, those on the north side being given no specific name. In the eighteenth century, however, the whole group was referred to as the Southern Triangles, both in the Anglo-Spanish treaties of 1753 and 1783, and on the charts of Jeffreys (1775) and Speer (1765, 1771). The group contains some two dozen islands, mostly mangrove, situated on the flat tops of steep-sided shoals rising abruptly from 5-6 fathoms. The Deepwater Channel (Southern Grennels Channel) between the two clusters of cays has depths of 10-13 fathoms and very steep sides.

The northern group includes seven large islands including Ramsays Cay, One Man Cay, Robinson Island, Grennels Cay, and Robinson Point. Robinson Point Cay is the largest after Robinson Island, and the only one inhabited before the storm; it has a lighthouse erected at its westernmost point in 1939 (Figure 26). Vermeer discusses this island (1959, 75-79) and gives a fine air photograph (his Figure 16) which shows very well the general form of these cays. Robinson Point Cay is about ¾ mile long, and consists of a low, narrow sand ridge on its west and southwest sides. The easternmost part of the cay, and most of the area lying to the north of the sand ridge, is covered with Rhizophora and shallow open water. The sand ridge is nowhere more than 50 yards wide, and is generally much narrower; before the hurricane it carried a dense vegetation of coconuts, palmetto, exotic ornamental plants, and such typical strand species as Coccoloba uvifera, Cordia sebestena, Suriana maritima, Conocarpus erectus, Hymenocallis littoralis, Euphorbia sp., Stachytarpheta jamaicensis, Cyperus planifolius and grasses. In places, clumps of Rhizophora are found growing on the exposed south and southwest shores. Vermeer made much of the fact that the dryland area consisted mainly of shingle rather than sand, in contrast to other sand-mangrove cays such as Cays Caulker and Chapel. He noted the dominance of cervicornis debris, but his deduction that Acropora "is restricted to deeper water and does not usually live in more exposed parts of the reef" (1959, 77) is not acceptable. Cervicornis shingle ridges associated with mangrove are in fact fairly widespread in the barrier reef lagoon, the cervicornis flourishing in fairly sheltered water, and such ridges are not restricted, as Vermeer supposed, to deep water areas such as the margins of the Deepwater Channel. The shingle ridge at Robinson Point Cay does not rise more than 3 feet above the sea and is generally lower.

The sketch map of the cay (Figure 26) is not based on ground survey, but on an enlargement of the 1957-8 Vidal survey fair copy chart (Admiralty MS K2254), with detail added from my own air photographs and ground observations in 1961. The shingle-sand area with palm thicket is arcuate, with the lighthouse at its western point, and is about 1000 yards long. Immediately to the lee is an enclosed area of shoal water and bare mud, scattered with Rhizophora seedlings and enclosed by mature Rhizophora. The eastern 800 yards of the island consists of mature Rhizophora and Avicennia, and the ground surface here is generally above high tide level. In 1961 the cay was inhabited: three of the four dwelling houses were occupied, and there was a boat-building shed and slipway still in working order. Few boats had been built there for many years, however, in contrast with the thriving business at Cay Caulker and in Belize; though the island has a history of boat-building dating back at least to the early eighteenth century. The inhabitants were of interest: they were white settlers of English descent, whose ancestors had emigrated from Bath to the Mosquito Shore in the nineteenth century. They still spoke fine English, though with accent and expressions characteristic of the old English colonies of the Western Caribbean.

During Hurricane Hattie the island suffered great damage, and was completely submerged by the storm surge. All the houses and the boat shed disappeared, but the lighthouse survived. The inhabitants, all in Belize at the time of the storm, have now emigrated to the United States, and the cay is deserted. The lighthouse is automatic and is serviced from Belize, and thus requires no resident staff. All the dense vegetation was stripped from the shingle area, except for a few still-standing coconuts. Rhizophora round the cay margins was completely defoliated, and the more exposed trees were also broken up, losing their branches. In May 1962 the mangrove was again bearing leaves in the sheltered centre of the eastern mangrove area. The sand ridge immediately south of the lighthouse was almost breached, but otherwise there was little alteration to the cay outline.

Precisely similar damage was suffered at Robinson Island. The palm thicket was largely stripped, and the exposed Rhizophora was defoliated and broken. In the interior, however, and along the northwest-facing shore, the leaves are beginning to grow again. The implication is that heaviest waves came from the direction of deepwater east and southeast of the cay in the Deepwater Channel. The other islands in the northern group are all mangrove, and damage was comparable to that in the mangrove sections of Robinson and Robinson Point Cays.

The southern group of cays are all mangrove, with the exception of the easternmost, Spanish Cay. One can say little about the mangrove cays (Simmonds, Crayfish, Long and other cays), except that they consist of now defoliated Rhizophora on small shoals. Spanish Cay (Figure 27) is of more interest; when mapped in 1961 it was about 110 yards long and varied from 10-20 yards in width. The surface was low-lying and in places marshy, and consisted of a coarse sand with much Halimeda, scattered coral fragments and conch shells. The southern end of the cay was fringed with tall Rhizophora - remnants of a probably once more extensive cover - and there were numbers of tall Avicennia trees in several places. The vegetation had mostly been replaced by scattered coconuts, with Conocarpus bushes, grasses and sedges, and some ornamental plants. The island was used largely as a holiday resort: it had two very substantial houses, a number of huts and water tanks, a tomb, and two decrepit jetties; and it was divided across the middle by a fence. After the hurricane Spanish Cay was photographed from the air, but not visited. The jetties, huts, and all but one house had disappeared, together with most of the coconuts and nearly all the Rhizophora and Avicennia. The cover of grasses and sedges remained, however, at the north end, where old paths could be clearly traced. There had been slight shore erosion on the east side and signs of deposition along the west shore. The fact that any vegetation survived contrasts with other cays of similar size on the barrier reef itself in the same latitude.

Rendezvous Cay

Damage on Rendezvous Reef has already been outlined (Chapter 3); damage on Rendezvous Cay was less catastrophic, but still severe. The cay (Figure 28) is situated near the south end of the reef patch, and is also oriented N-S (cf. Figure 15). In plan it is rather intricate, but may be described in a generalised way as a very slightly arcuate strip of sand, convex to the east, with a total length of some 100 yards, and a width varying from 10 to 25 yards. Before the hurricane the western bay was partly filled in with a number of conch shell projections, built over a number of years in the 1920's and 1930's by a fisherman who made the cay his home; the cay was at this time known as "Brown's Cay", after this gentleman, and the name is still used among the older fishermen of the area. In 1960 the cay extended southwards by a narrow, tombolo-like sandspit to another island of conch shells 10 yards long; but this link did not exist in 1959. The cay itself was entirely composed of sand with much Halimeda. On the west side before the storm a beach ridge running the length of the cay rose to a maximum height of nearly 3 feet above sea level, but the greater part of the cay surface maintained a uniform elevation 1½-2 feet above the sea. There were scarcely perceptible ridges round the north shore of the cay. Northwards the cay was extended by a submerged shoal along the centre of the reef patch; the shoal consisted of sand, calcareous mud and such smaller debris as shells, small corals and branching calcareous algae. This spit was occasionally exposed at exceptionally low tides for a distance of about 50 yards. No beachrock was seen round the present shores, but there is a single arcuate line on the reef flat east of the cay, at distances of 30-40 yards from the shore. The rock is cavernous, and the exposure is fragmentary; only the southern section shows any seaward dip. It rises from water 12-15 inches deep, and before the hurricane was thickly covered with larger algae. The exposure has a maximum width of 2 feet at the south end; towards the north it is seen only as a bare strip in the thick Thalassia, though rock is revealed by auger probes.

Speer and Jeffreys both charted the cay in 1771 and 1775 respectively, and Speer described it (1765, 19) as "a low sand Kay, with only one bush on it". Owen charted it in 1830 without comment, but by the time of the Mutine survey in 1921-2 it had huts and palm trees 45 feet high, and was conspicuous. Since that time much of the conch shell area has been added, and in recent years the island was purchased by the Governor of the Colony, who built a house and jetty there. Before the hurricane the vegetation was extremely restricted. At the north end and on the east shore were one or two rather gnarled mature Avicennia trees, and scattered over the cay were a number of rather low and stunted Coccoloba trees. Apart from these the vegetation was limited to coconuts, varying in height from 15 to 60 feet; numerous Rhizophora seedlings, especially on the west shore; and very sparse patches of Sesuvium, Euphorbia, and Sporobolus, all frequently cleared.

The island suffered considerable damage during the storm. The house completely disappeared, except for the foundation stones; one of the concrete foundation stones was subsequently found on the eastern reef-crest, 100 yards northeast of its original location, others were found in shallow water off the southeast shore. All the coconut trees were destroyed, and only a few stumps remain near the centre of the cay. The two jetties (one of conch shells, the other timber) were destroyed, though the conch shell one can still be traced for some yards underwater. The seaward shore suffered remarkably little erosion, and roots are exposed only at one point. Much sand was deposited on the west side, however, especially on the conch shell areas, which were much disturbed. The spit between the cay and the small conch shell island to the south was destroyed. There was some surface stripping of sand, particularly at the northern end, where the surface now sinks to an enclosed, ill-drained hollow. No fresh beachrock was exposed, nor was the old relict beachrock damaged, apart from the stripping of large algae. Much sand has accumulated on the submerged northern spit, which now almost breaks surface in several places, even in normal tides. The total area of the cay has changed little: before the storm it totalled 2800 sq. yards, of which nearly 400 sq. yards was composed of conch shells, many much rotted and rising only 6-12 inches above sea level. The present area of sand is 2400 sq. yards, the same as before, but the conch shell area has been decreased by nearly half to 220 sq. yards, largely as a result of redistribution by waves and burial by fresh sand. The fresh sand coating is very thin, and the conch shells protrude through it in places.

The vegetation has changed considerably; the coconuts have gone, the Avicennia is broken and dead, and only one or two of the Coccoloba, much broken, survive. By contrast, in March and April 1962 the cay surface supported a variegated array of strand plants, many of them not present before the hurricane. Portulaca oleracea is most widespread, in characteristic circular patches, together with the sedge Cyperus planifolius and grasses such as Sporobolus. Small areas are covered with Sesuvium portulacastrum, Euphorbia mesembrianthemifolia and Ipomoea pes-caprae. Other plants represented and collected were Cakile lanceolata, Fimbristylis cymosa, Philoxerus vermicularis and Solanum lycopersicum. Nearly all the Rhizophora seedlings were destroyed, but a number of new ones were growing in the northern depression and near the old house foundations. Two seedlings of Tournefortia gnaphalodes were noted but not collected. There is little chance, however, of a natural succession being observed; a caretaker is to live on the island, and in April 1962 he and I planted over 40 young coconuts on the cay, which should begin to bear by 1970.

There were two casualties during the Hurricane: Jack and Viola Reyes, who lived on the cay when it was the headquarters of the Cambridge Expedition to British Honduras 1959-60, disappeared there during Hurricane Hattie.

Other sand cays of the Northern Barrier Reef

Mention must be made of the former existence of other coral islands on the northern barrier reef:

Curlew Cay is described by Speer (1765, 19) as "very low" with "only a few bushes" and comparable to Paunch Cay. In 1830 it was charted by Owen 1 mile south of Sergeant's Cay and due east of Water Cay. It was again charted by the Rambler in 1896-7, but disappeared some time after that date, possibly in the 1931 hurricane. In 1960 it existed as a small sand-bore 20 yards long and 2 feet high, lacking vegetation; and it is so marked on the 1960 edition of Admiralty chart 522. It was not seen after Hurricane Hattie.

Seal Cay was also noted by Speer (1765, 19) as "a very low, small, sandy Kay, called Seal Kay", located "about 3 quarters of a mile, E.S.E. from Goff's Kay". It was not charted by Owen, but the Rambler survey noted a sandbore at this point. It was not seen during our own surveys, nor by the 1957-8 Vidal survey.

Sandbore south of English Cay. The Vidal charted a sandbore 650 yards SSW of English Cay. When visited in 1960 this was a strip of sand 60 yards long and 10 yards wide, rising to a maximum height of 3 feet above sea level, and unvegetated. It was not charted by either Speer or Owen; nor was it seen after the hurricane. It was probably never been a true vegetated island, at least in recent centuries.

Samphire Spot is located midway between English and Rendezvous Cays; it was charted as "Saphire Kay" by Jeffreys in 1775 but omitted by him in 1792 and 1800. It was not noted by Speer or Owen, but appears as "Samphire Spot" on charts following the 1896-7 Rambler survey. In 1959-61 it was a small unvegetated sandbore, barely awash, and apparently stabilised by a large stranded log; presumably it disappeared during Hurricane Hattie, but in 1962, though the log had disappeared, the island was larger than formerly, with a diameter of 25 yards, but still unvegetated.

Jack's Cays. This name has been given to sandbores south and east of Rendezvous Cay, one on the end of a linear segment of the barrier reef, one on a patch reef to leeward. Only the former was seen in 1959-60, and then only intermittently, depending on the weather. It was generally 30-40 yards long and 2-3 feet high. The second was seen in 1962, where no sandbore had previously existed; it was 20 yards in diameter, though later it became smaller. At this time the first sandbore was also larger than usual, probably as a result of increased amounts of debris provided by the hurricane.

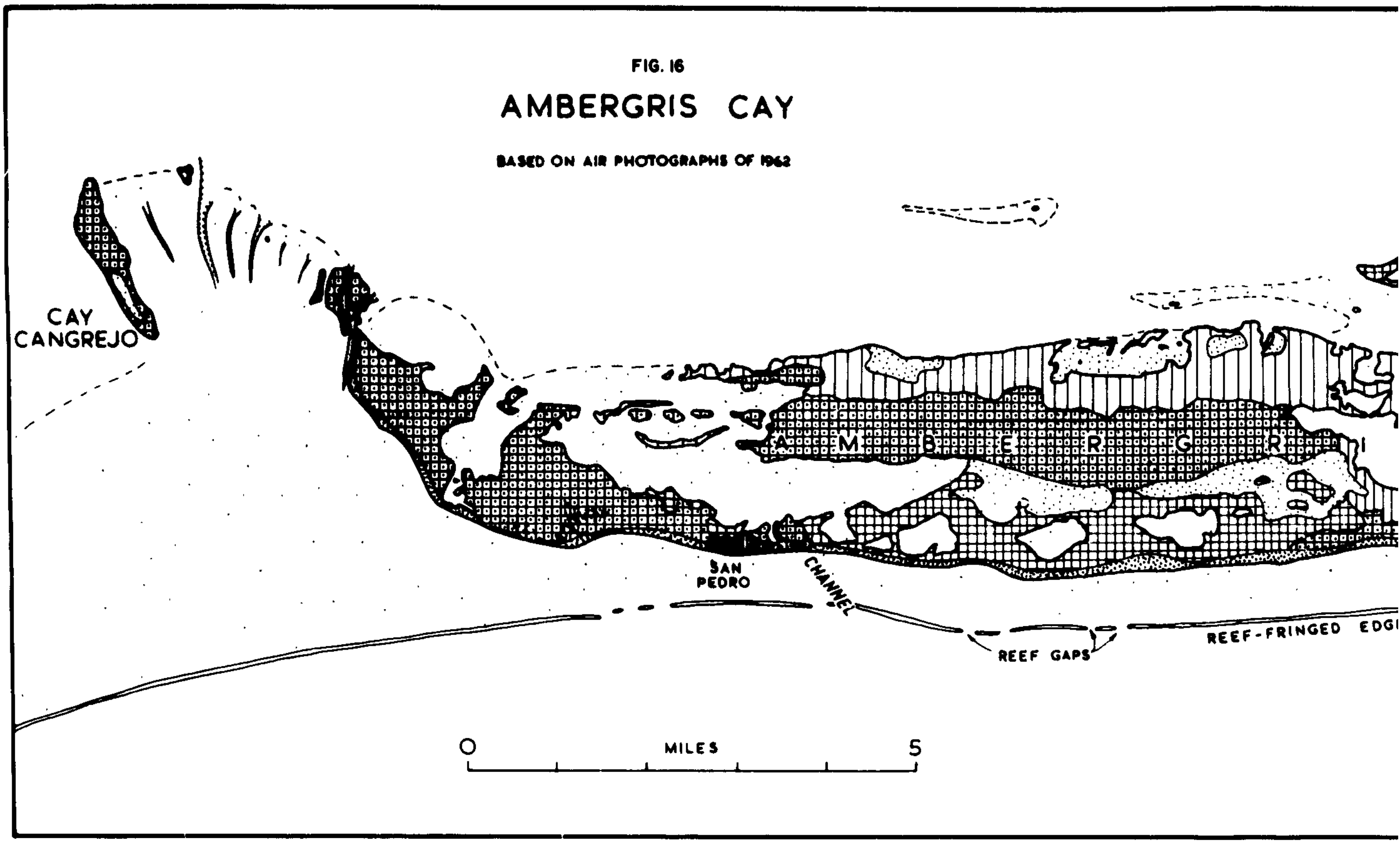
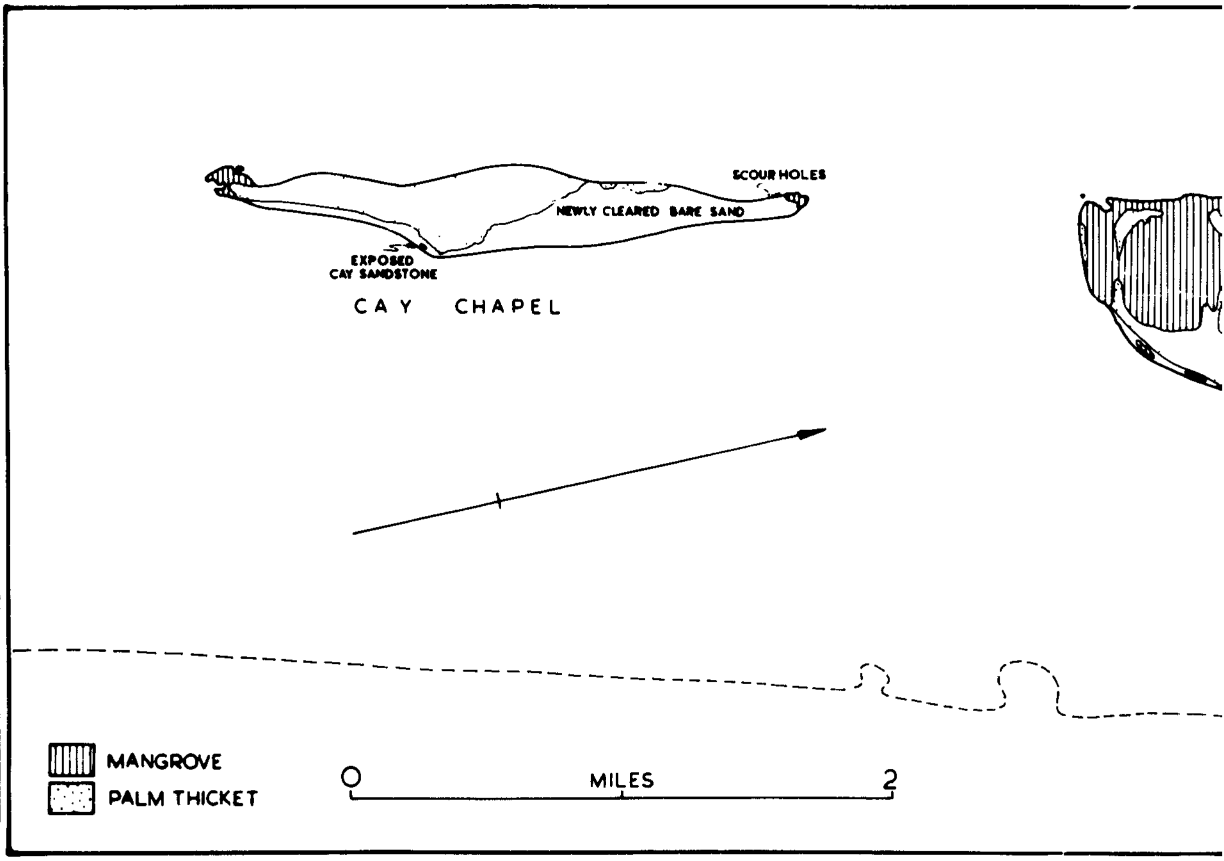


FIG. 16
AMBERGRIS CAY
BASED ON AIR PHOTOGRAPHS OF 1962
CAY CANGREJO
SAN PEDRO
CHANNEL
REEF GAPS
REEF-FRINGED EDG
MILES
0
5


SCOUR HOLES
NEWLY CLEARED BARE SAND
EXPOSED CAY SANDSTONE
CAY CHAPEL
MANGROVE
PALM THICKET
MILES
0
2

1

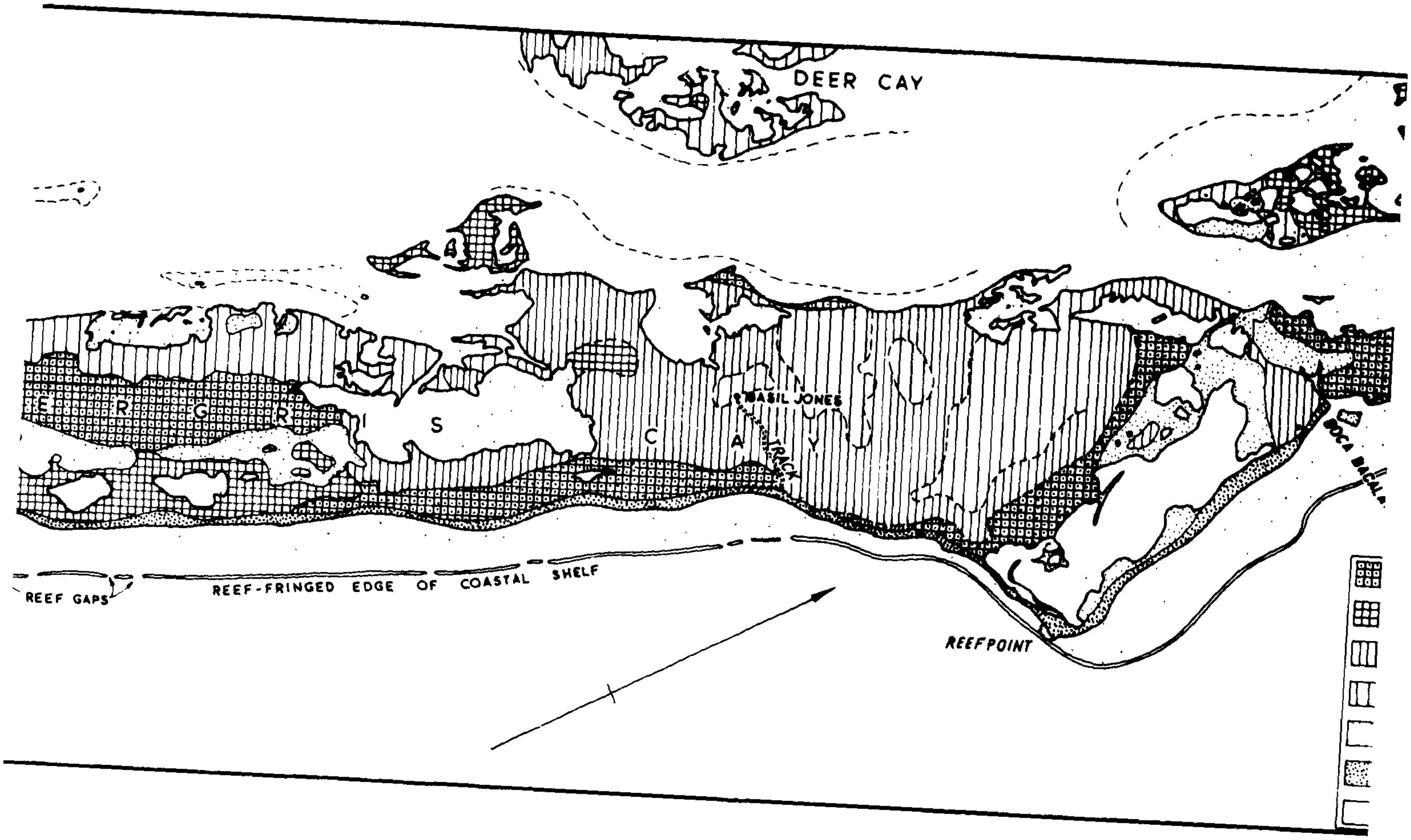
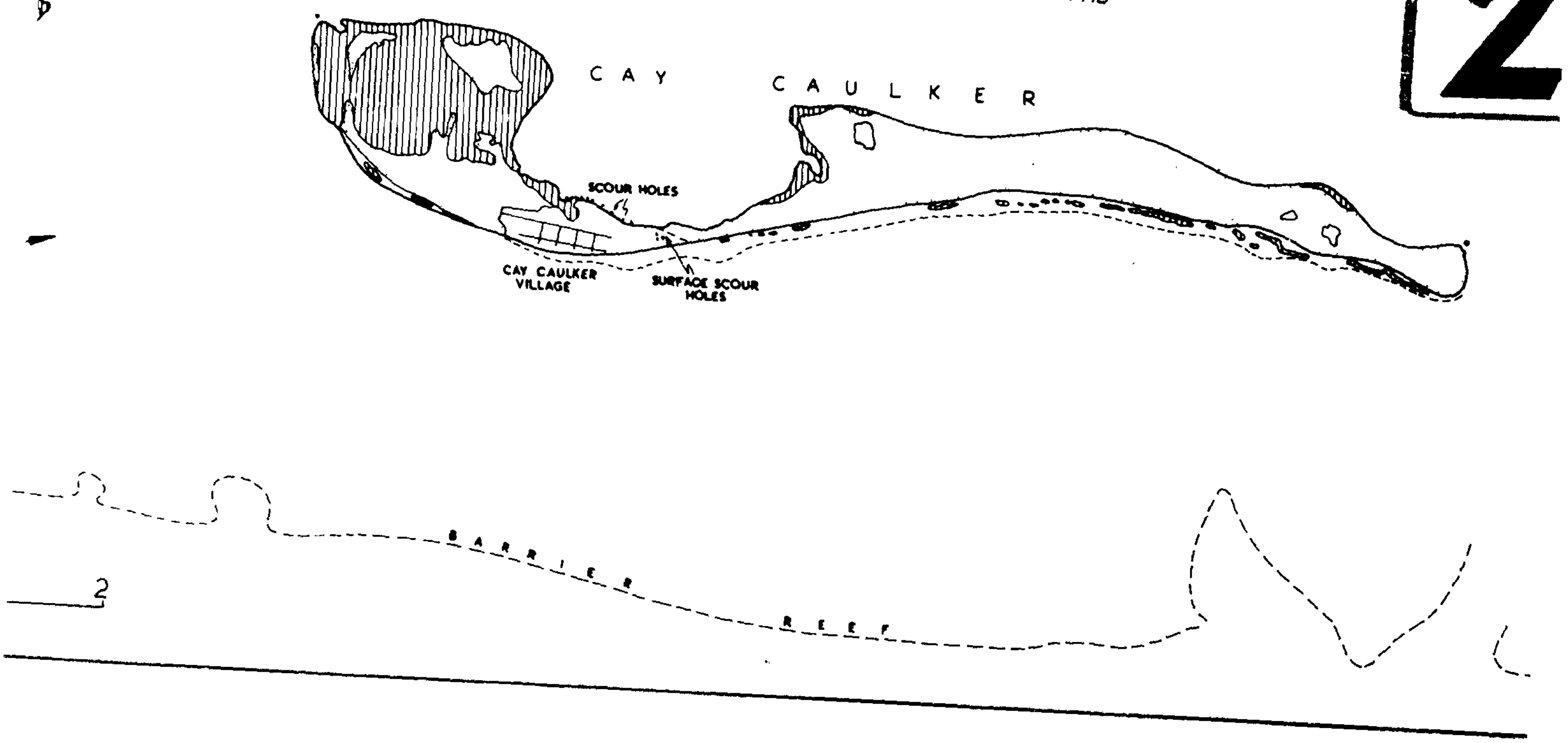


FIG. 17

CAY CAULKER AND CAY CHAPEL

BASED ON AIR PHOTOGRAPHS

2



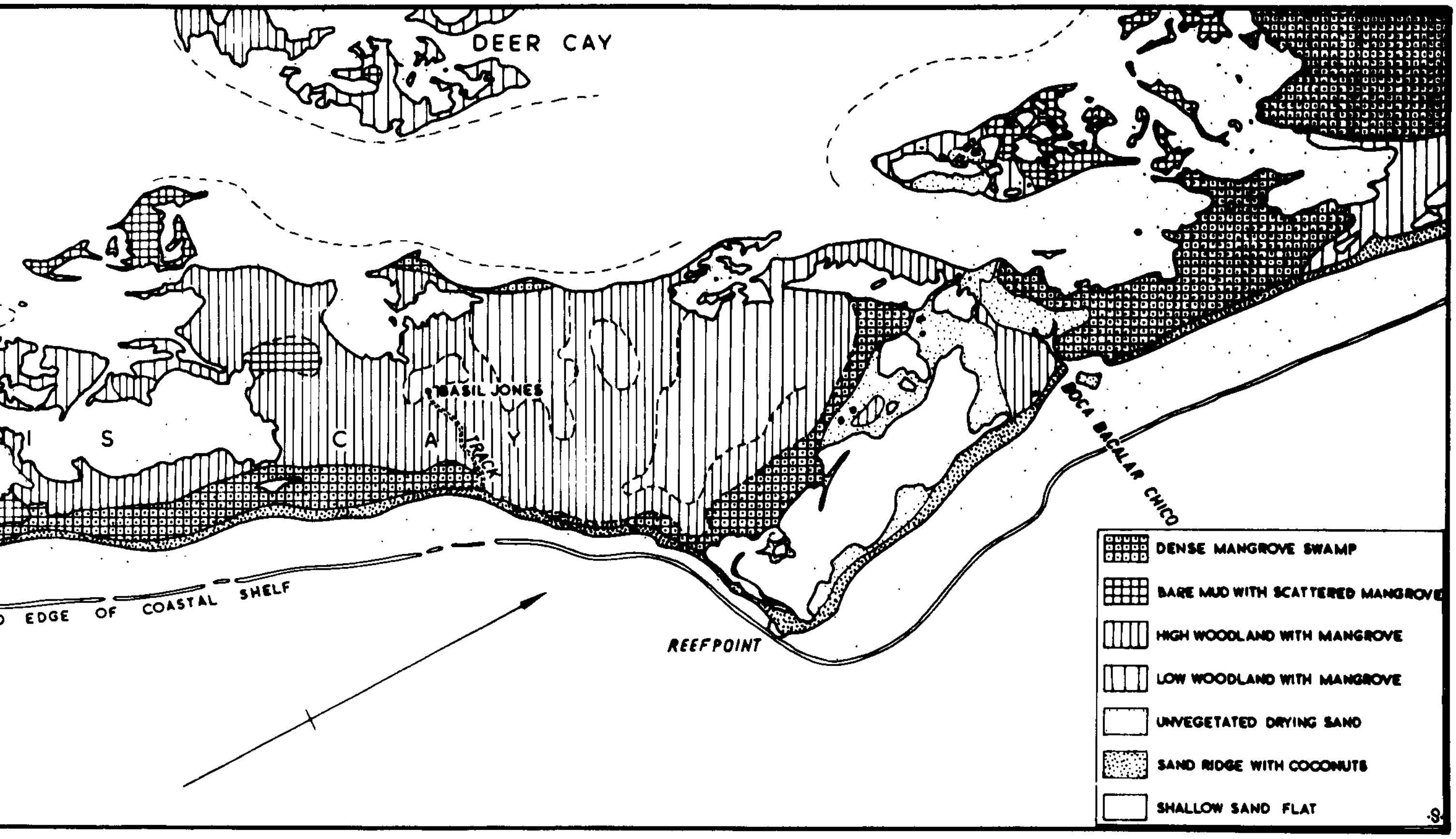
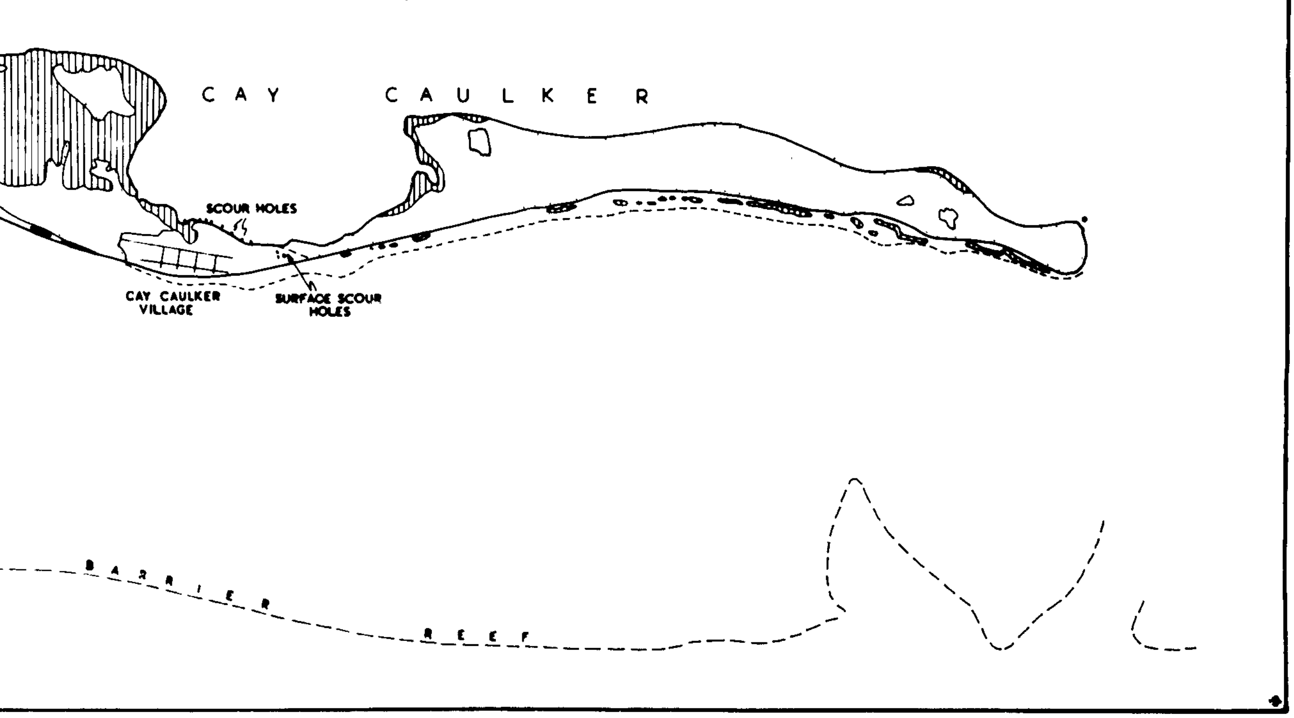


FIG. 17

CAY CAULKER AND CAY CHAPEL

BASED ON AIR PHOTOGRAPHS



3

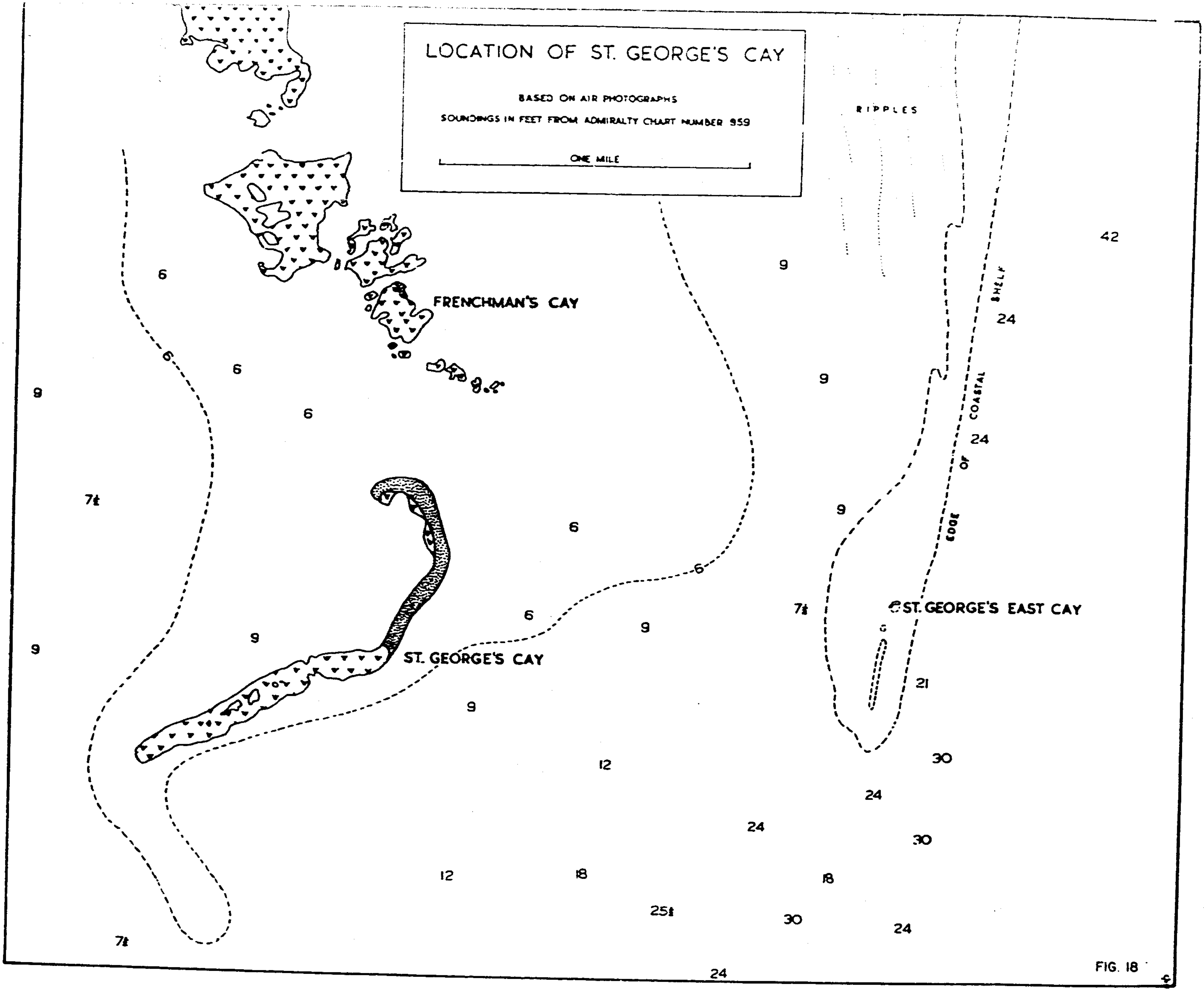

LOCATION OF ST. GEORGE'S CAY
BASED ON AIR PHOTOGRAPHS
SOUNDINGS IN FEET FROM ADMIRALTY CHART NUMBER 959
ONE MILE
RIPPLES
FRENCHMAN'S CAY
ST. GEORGE'S CAY
ST. GEORGE'S EAST CAY
EDGE OF COASTAL SHELF
42
24
24
9
9
9
6
6
6
6
6
6
6
9
9
9
9
9
7½
7½
7½
21
30
30
30
24
24
24
24
24
12
12
18
18
25½

FIG. 18

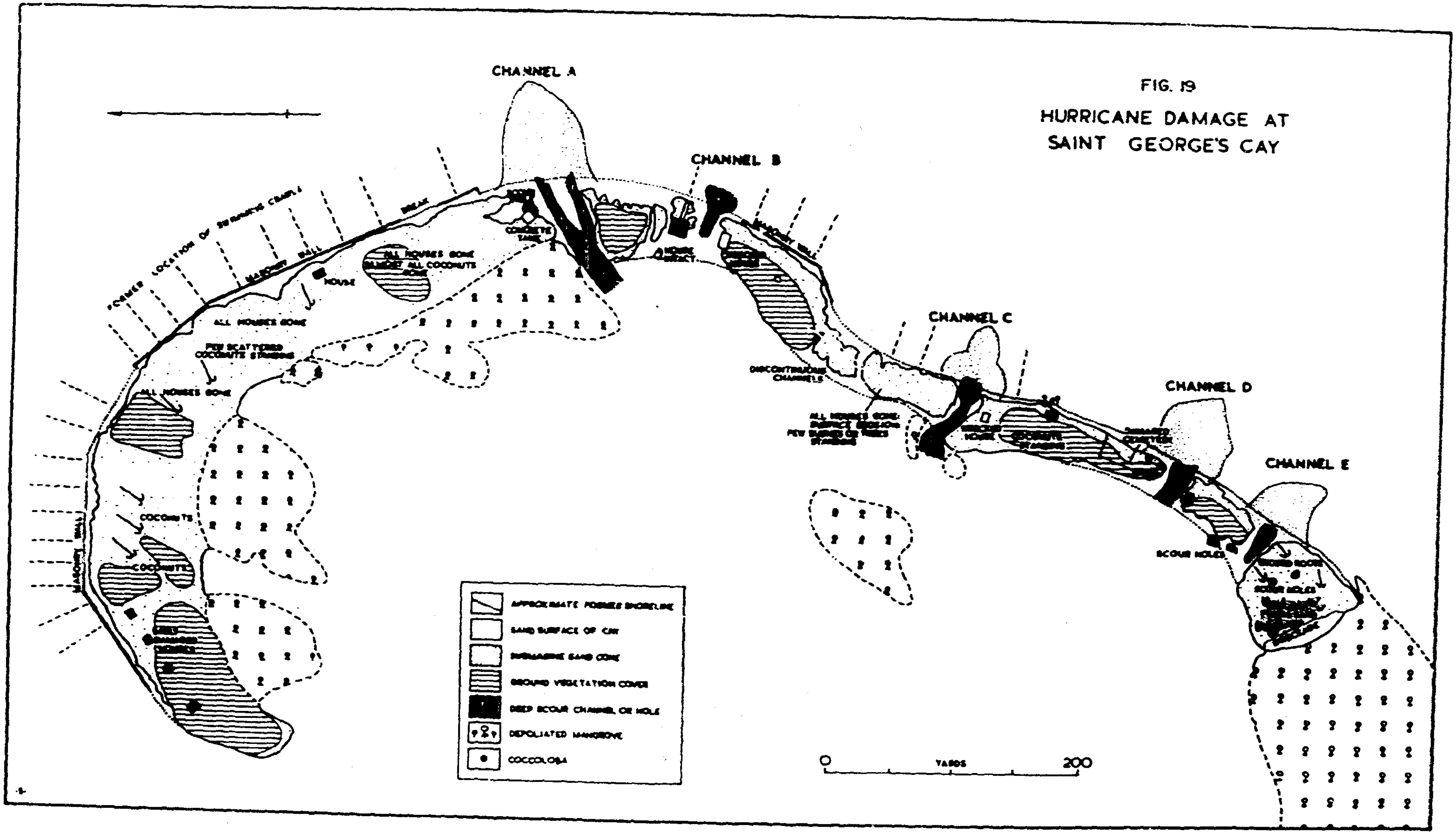


FIG. 19

HURRICANE DAMAGE AT SAINT GEORGE'S CAY

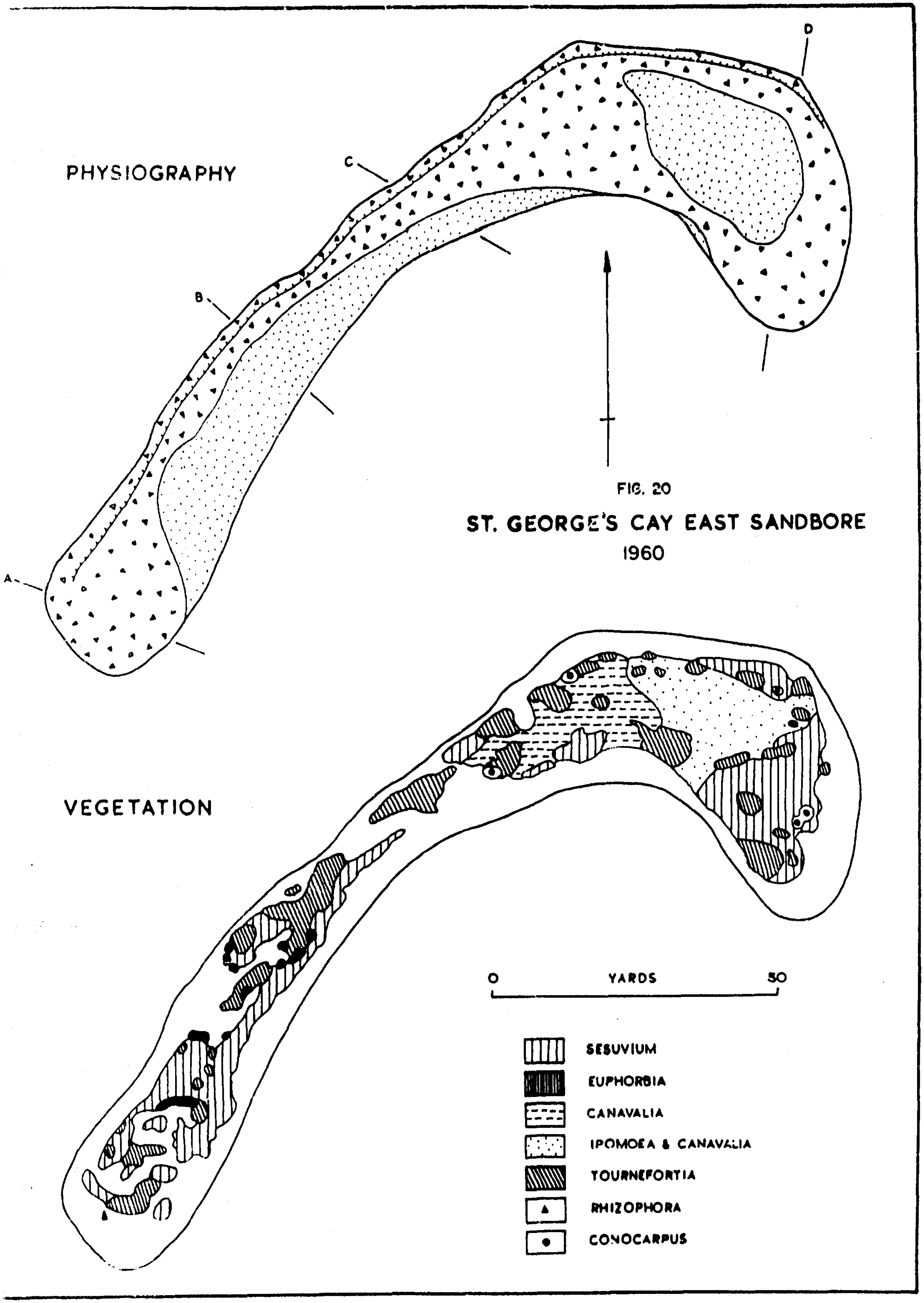
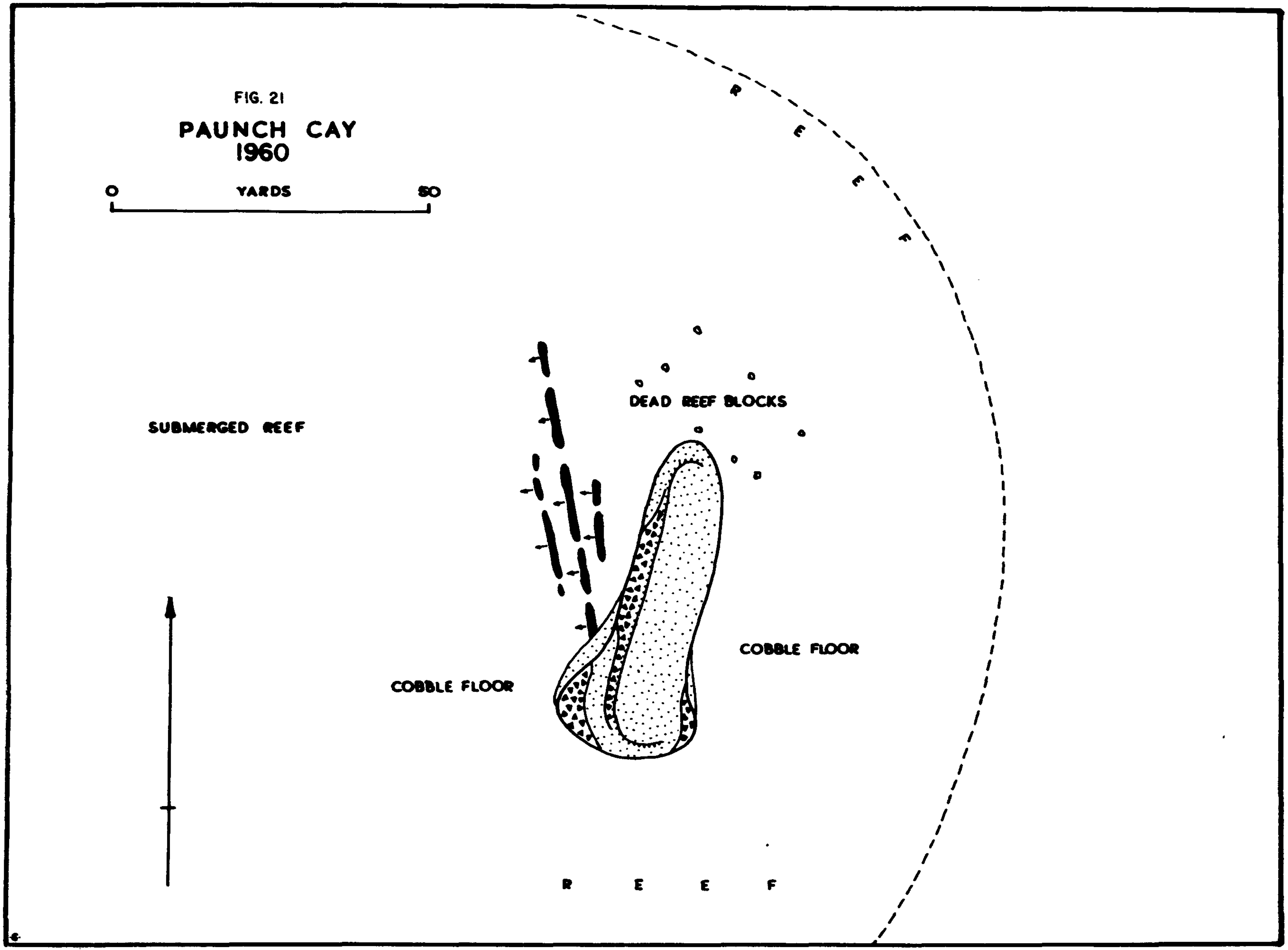


FIG. 20

ST. GEORGE'S CAY EAST SANDBORE
1960

FIG. 21

PAUNCH CAY
1960



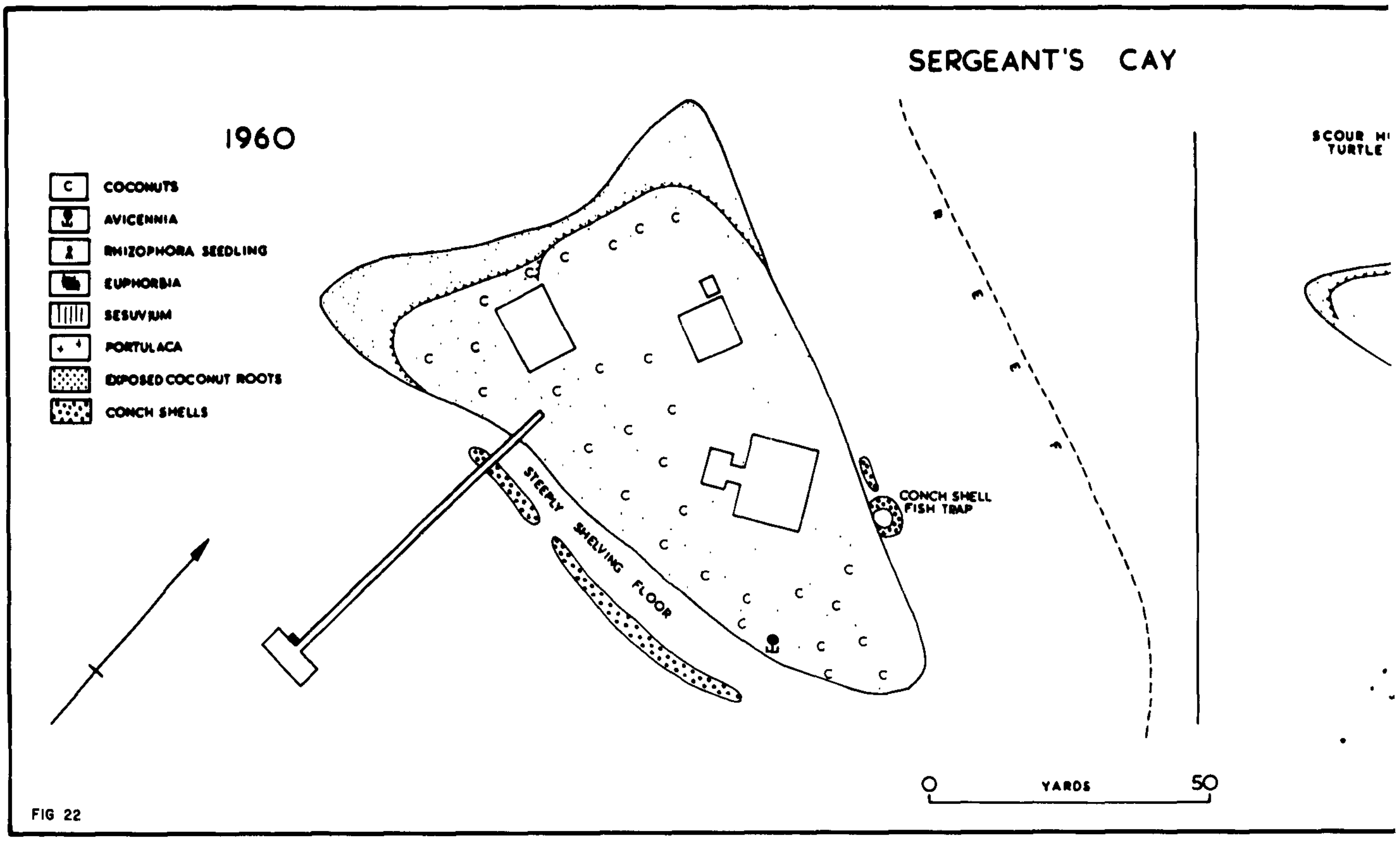

SERGEANT'S CAY
1960
COCONUTS
AVICENNIA
RHIZOPHORA SEEDLING
EUPHORBIA
SESUVIUM
PORTULACA
EXPOSED COCONUT ROOTS
CONCH SHELLS
REEF
STEEPLY SHELVING FLOOR
CONCH SHELL FISH TRAP
TURTLE
0 YARDS 50

FIG 22

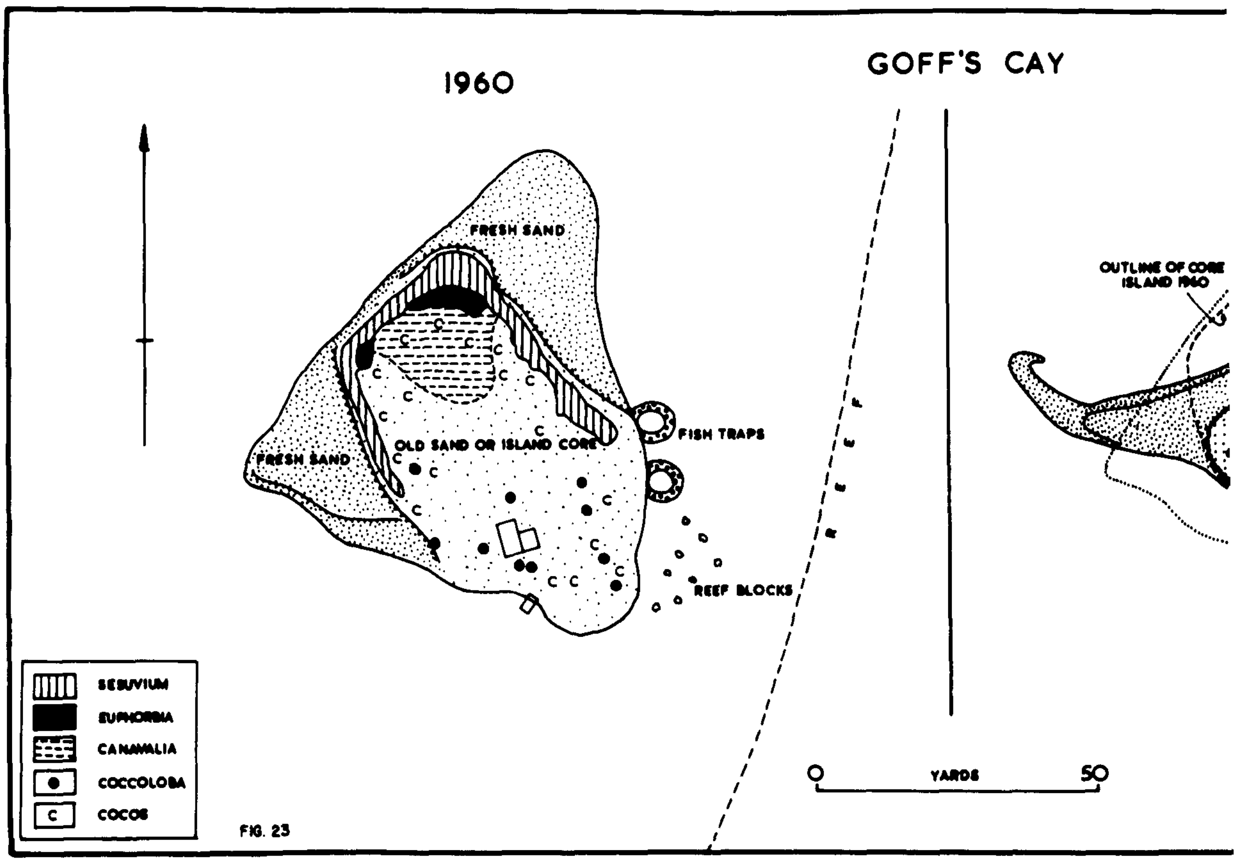
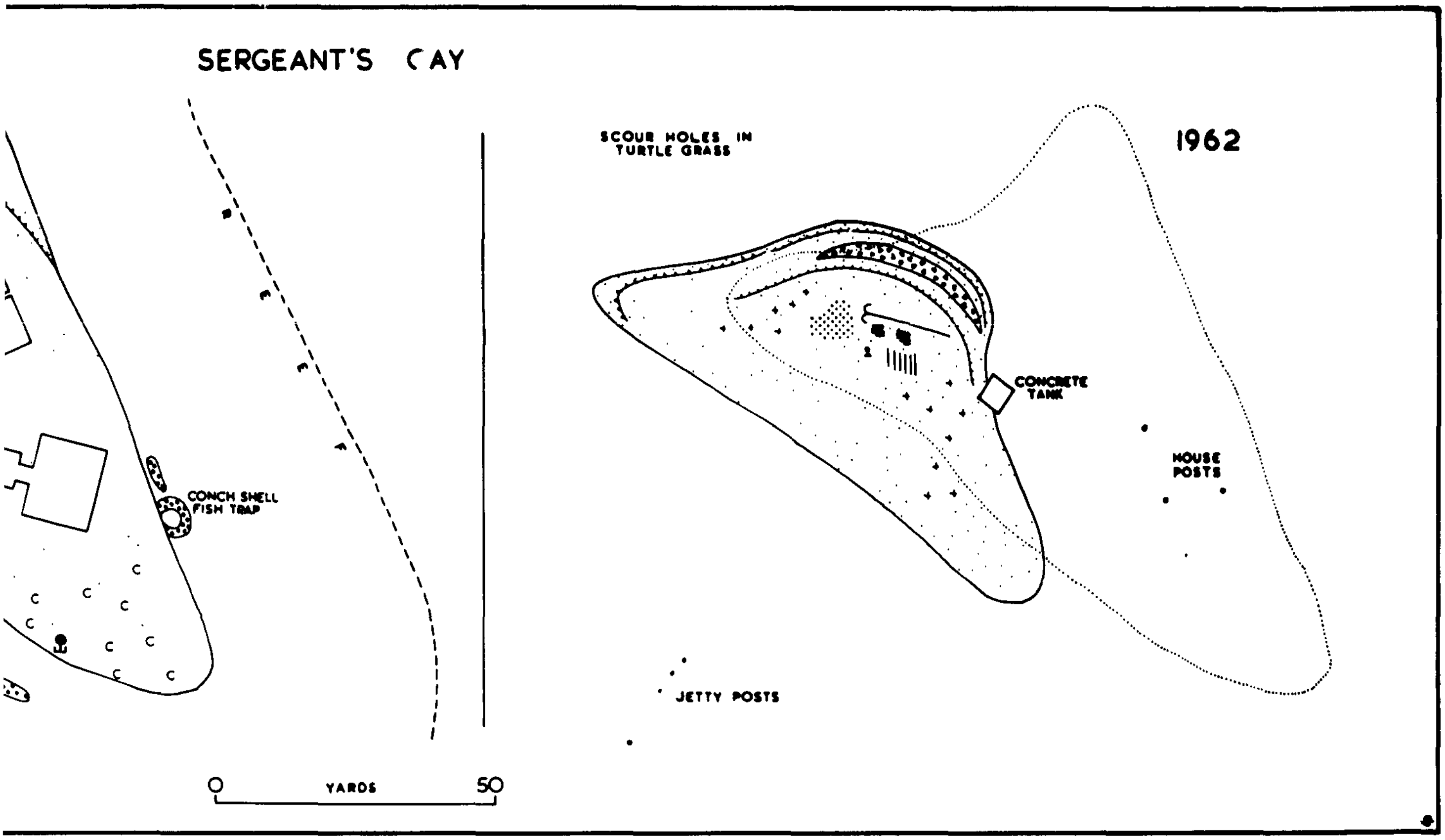
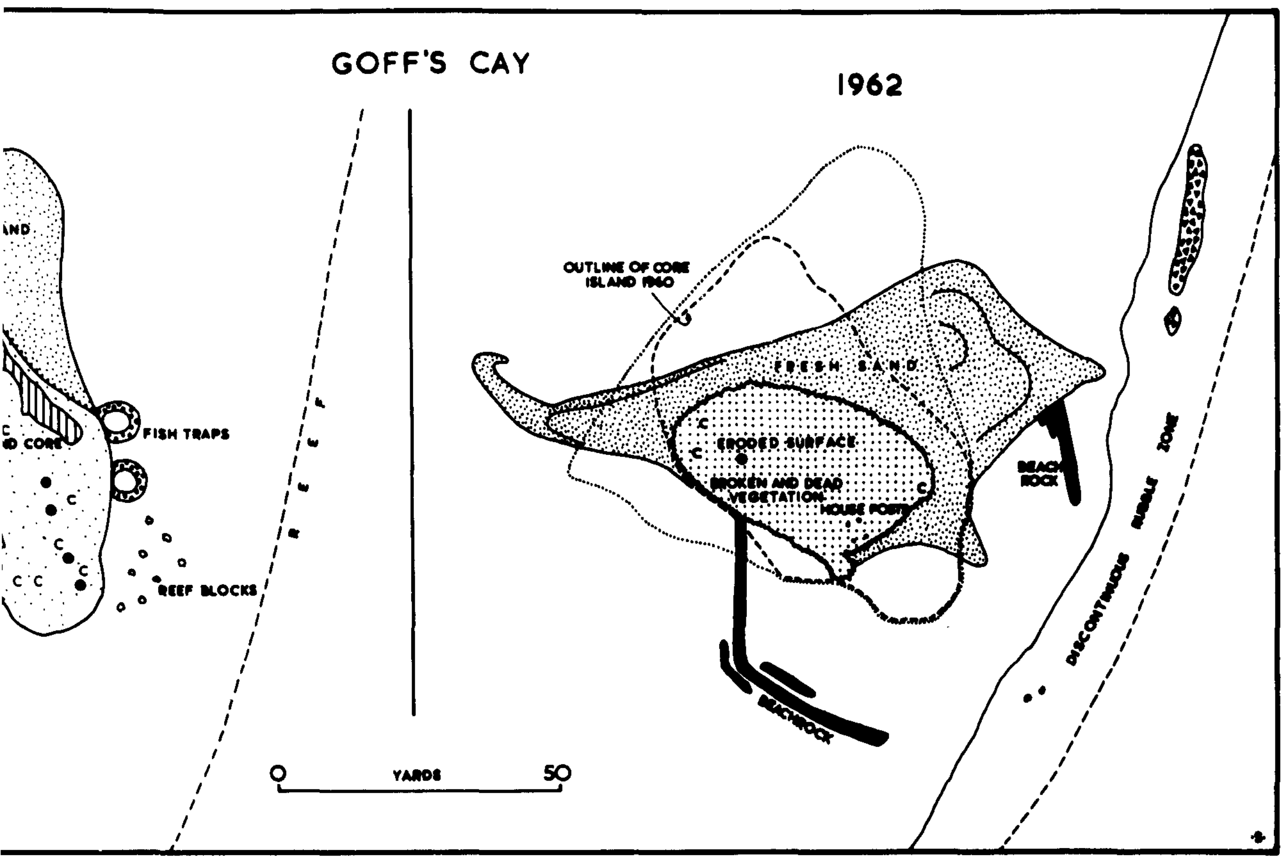

GOFF'S CAY
1960
FRESH SAND
OLD SAND OR ISLAND CORE
FISH TRAPS
REEF
REEF BLOCKS
OUTLINE OF CORE ISLAND 1960
SESUVIUM
EUPHORBIA
CANAVALIA
COCCOLOBA
COCOS
0 YARDS 50

FIG. 23


SERGEANT'S CAY
1962
SCOUR HOLES IN TURTLE GRASS
CONCRETE TANK
HOUSE POSTS
CONCH SHELL FISH TRAP
JETTY POSTS
R
E
E
F
0 YARDS 50


GOFF'S CAY
1962
OUTLINE OF CORE ISLAND 1960
FRESH SAND
ERODED SURFACE
BROKEN AND DEAD VEGETATION
HOUSE POST
BEACH ROCK
BEACHROCK
DISCONTINUOUS RUBBLE ZONE
FISH TRAPS
REEF BLOCKS
R E E F
0 YARDS 50

2

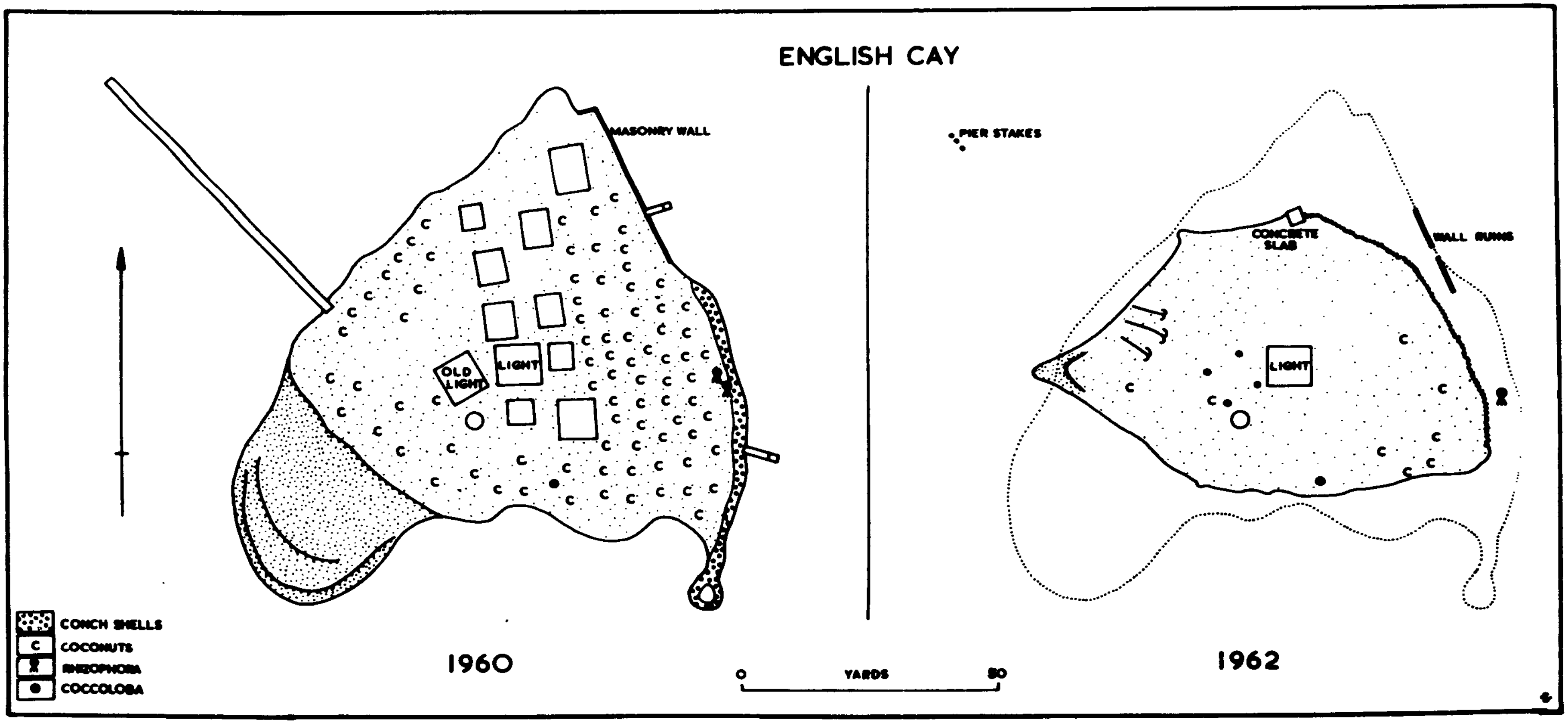

ENGLISH CAY
MASONRY WALL
OLD LIGHT
LIGHT
PIER STAKES
CONCRETE SLAB
WALL RUINS
LIGHT
CONCH SHELLS
C
COCONUTS
RHIZOPHORA
COCCOLOBA
1960
0
YARDS
50
1962

FIG. 24

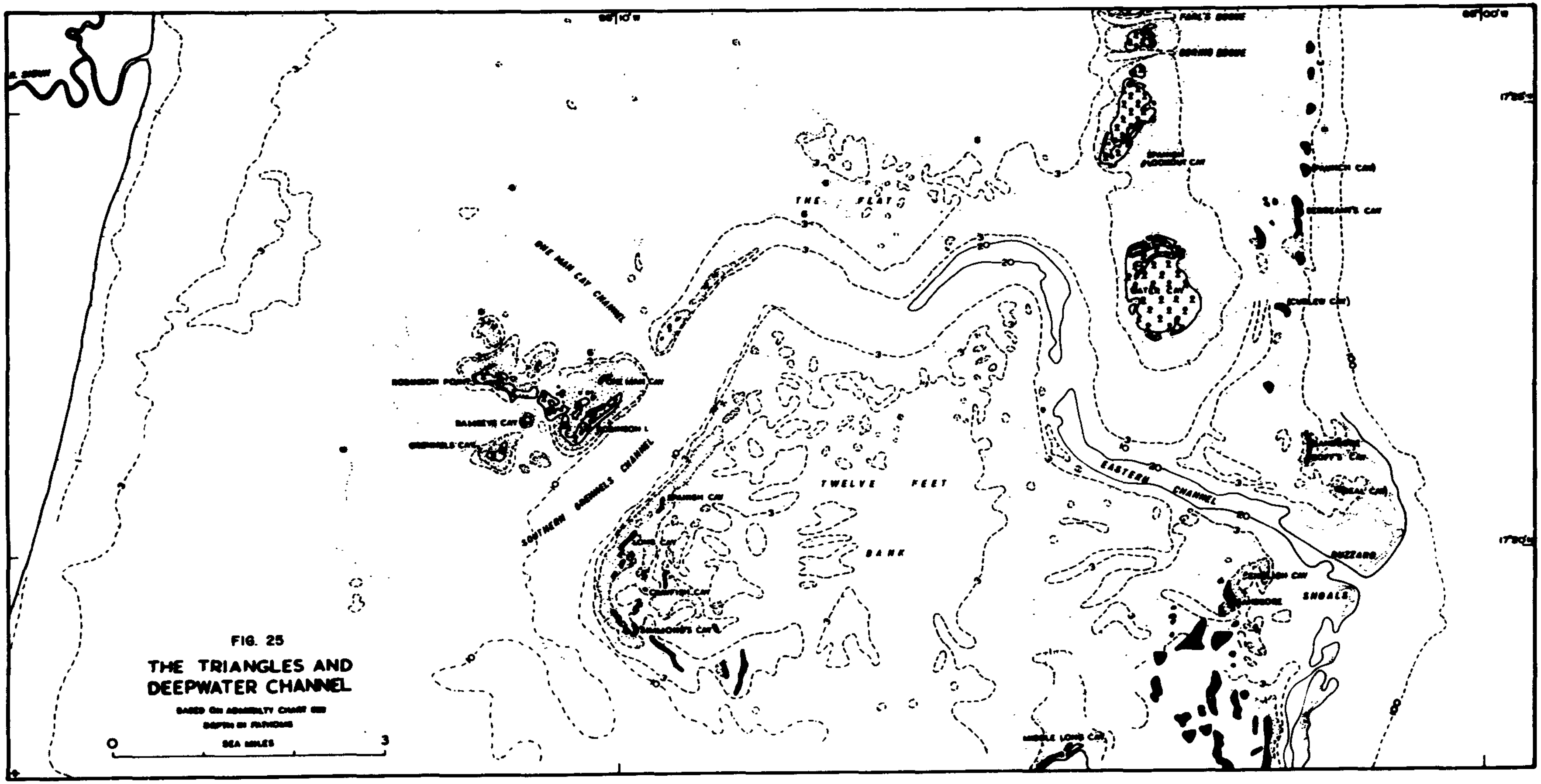


FIG. 25

THE TRIANGLES AND DEEPWATER CHANNEL

BASED ON ADMIRALTY CHART

DEPTH IN FATHOMS

0 — 3

SEA MILES

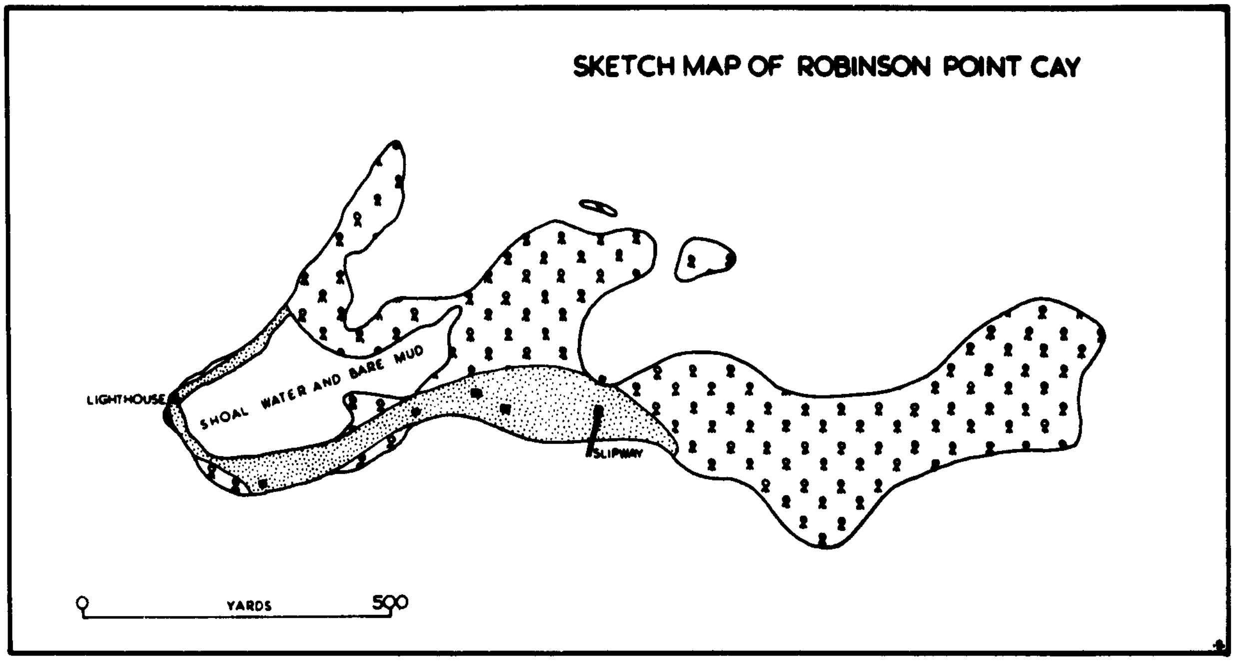

SKETCH MAP OF ROBINSON POINT CAY
LIGHTHOUSE
SHOAL WATER AND BARE MUD
SLIPWAY
0
YARDS
500

FIG. 26

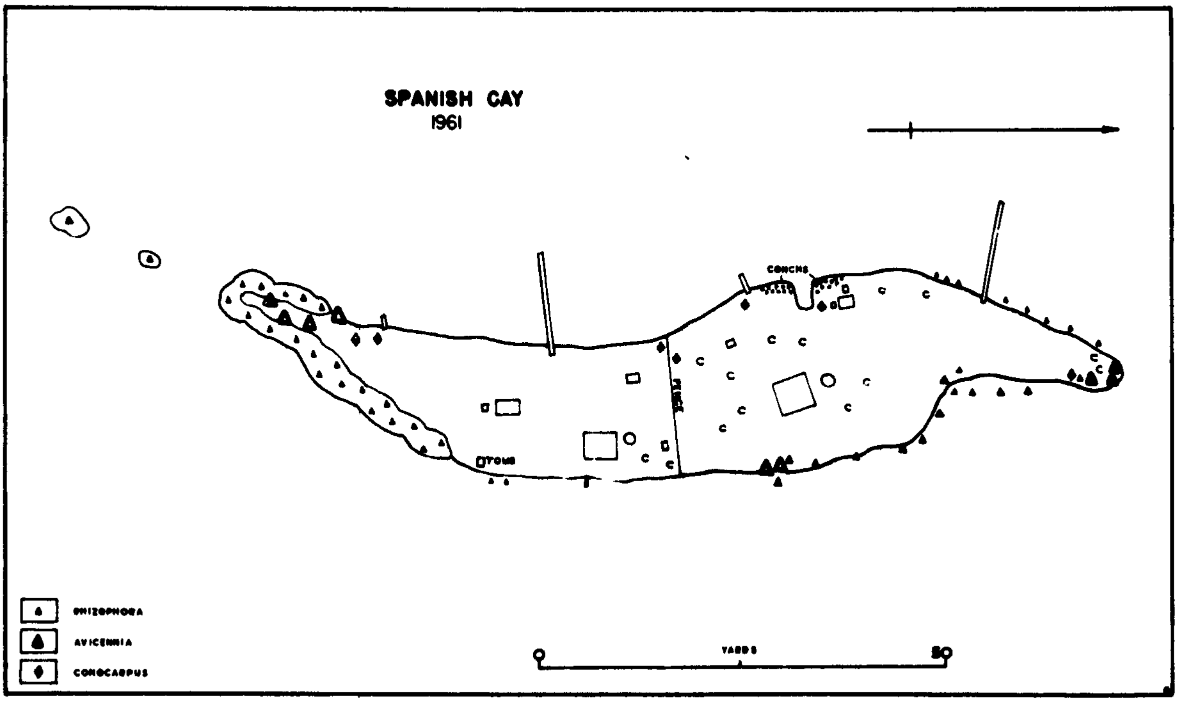

SPANISH CAY
1961
CONCHS
TOMB
RHIZOPHORA
AVICENNIA
CONOCARPUS
0
YARDS

FIG. 27

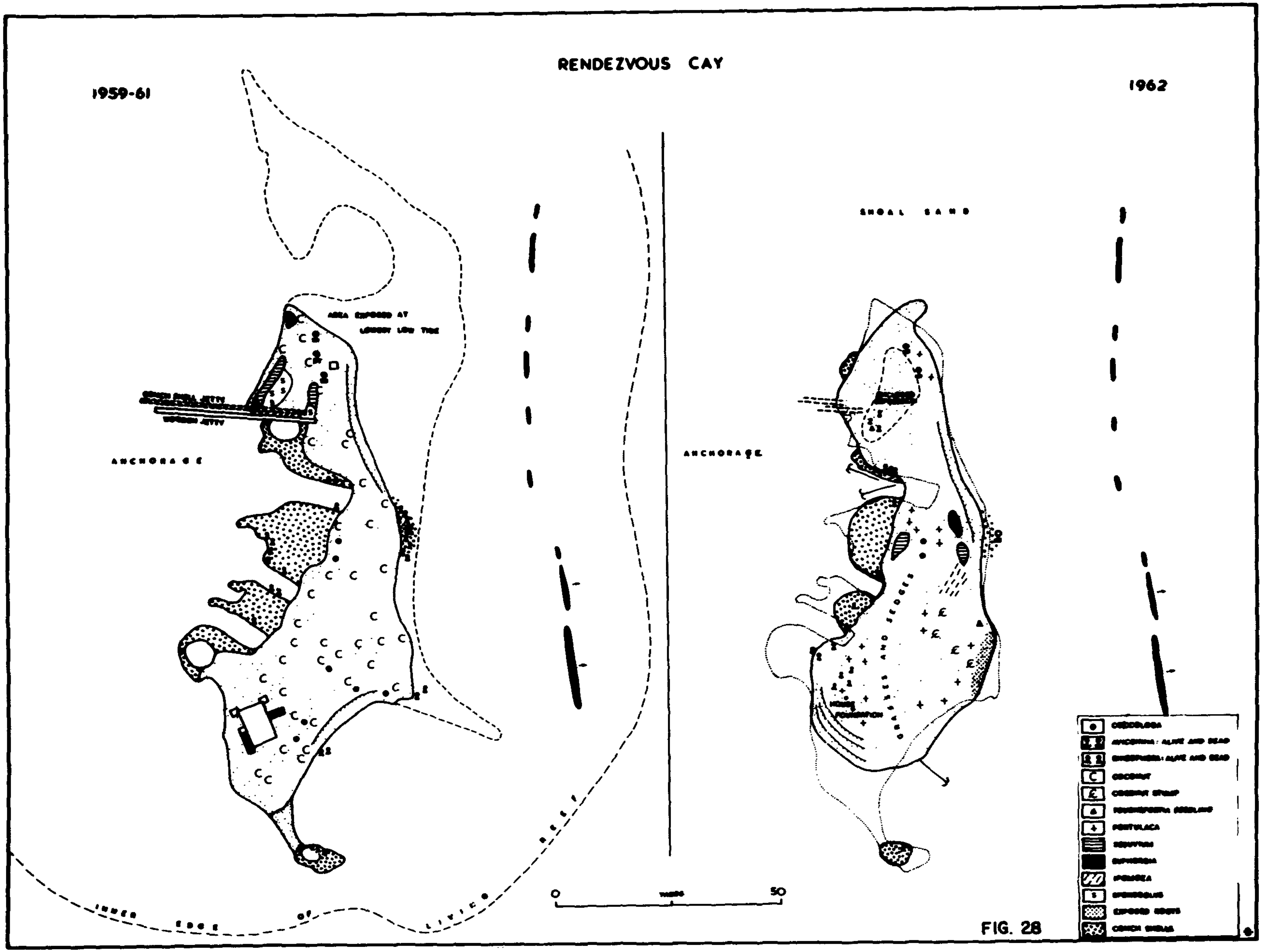

RENDEZVOUS CAY
1959-61
1962
AREA EXPOSED AT
LOWEST LOW TIDE
ANCHORAGE
SHOAL SAND
GRASSES AND SEDGES
HOUSE
FOUNDATION
INNER EDGE OF LIVING REEF
0
50

FIG. 28

V. HURRICANE DAMAGE TO CENTRAL BARRIER REEF CAYS

A. Cays between Rendezvous and Weewee Cays

The barrier reef lagoon between the Deepwater Channel and latitude 16°45'N forms a distinct physiographic region: from the coast the lagoon floor falls steadily eastwards to depths of 10-12 fathoms, the 10-fathom isobath lying an average of 5-7 miles from the coast. At a distance of 7-12 miles from the coast the lagoon floor rises abruptly to a flat shelf-edge platform, 3-5 miles wide and 2-3 fathoms deep, with the barrier reef itself rising to sea level at its outer edge. This wide submerged feature is here termed the "lower platform"; it maintains its horizontality over the whole length of the barrier reef, and is also found on Glover's Reef (ARB 87, 121). Its dissected margins and irregular surface indicate karst erosion conditions during glacial low sea levels, and it is thus at least pre-Würm in age. Two sets of cays are associated with this shelf: the sand cays of the barrier reef, and the mangrove cays rising from the low platform itself. Many of these mangrove cays are linear and elongated north-south, and are situated within a mile of the inner edge of the platform. Examples are Middle Long Cay (Figure 29), Bluefield Range, Alligator Cay and Colson Cays. Others, such as Southern Long Cay, Columbus Cay and Cross Cay, are more irregularly shaped mangrove islands located close to the barrier reef itself south of the Cay Glory elbow. For the most part the barrier reef is remarkably unbroken, and there are few patch reefs rising from the lower platform; exceptions are the numerous patch reefs between Alligator Cay and English Cay, and a group of small patch reefs south of Southern Long Cay. The only extensive area of reef rising from the inner edge of the low platform lies southwest of Fly Range, latitude 16°58½'N.

This section of the coast is well served with charts: Richard Owen made the first outline survey in 1830 and followed this with detailed surveys in the Thunder, 1834 (Admiralty MS H57, L83, L84). The area between Middle Long Cay and Sittee Point was surveyed in very great detail by Capt. H.P. Douglas, HMS Mutine, 1922 (Admiralty MS C8925), and the present charts (959, 1797) are reduced from this survey.

It is not proposed to say much concerning the mangrove cays. Defoliation was intense at Middle Long Cay, and southwards to Colson Cays. At Southern Long Cay, however, latitude 17°05'N, extreme defoliation was apparently limited to northwest and southwest facing shores. *Rhizophora* on these sides was still without leaves in April 1962, whereas trees on the southeast shores were green. This was even more strikingly shown at Cross Cay, 16°59'N; here the south shore of the east-west trending cay is formed by a series of mangrove embayments. In each of these, in April and May 1962, the mangrove on the west side (facing southeast) was green, while that on the east side (facing southwest) was completely bare. It has already been shown in Chapter 2 that south of Rendezvous Cay, where Hurricane Hattie crossed the reef, dominant winds were south and west: the survival of *Rhizophora* at Southern Long Cay and Cross Cay is the first indication of this in the landscape, and corresponds with the exactly reverse situation among the cays to the north of the storm track, round about latitude 17°33'N (Chapter 4). It is interesting that the lee-side survival of mangrove, or at least its earliest regeneration, takes place about the same distance, 12 miles, to north and south of the storm track, and that within these limits defoliation was total.

For further notes on these mangrove cays and on this section of the lagoon, see Vermeer (1959, 59-71, 79) and Cebulski (1961). The Phillips Petroleum Company is at present (1961-2) drilling a test well west of the northern end of Tobacco Range, which sould provide much information on shelf structure.

Cay Glory

Cay Glory was visited a number of times in 1959 and 1960, and photographed from the air in 1959 and 1961. At this time it was situated on the south side of a reef gap carrying 4-5 fathoms water, some 9 miles south of Rendezvous Cay. It was a narrow strip of sand 115 yards long and nowhere more than 23 yards wide (Figure 30). Winzerling (1946) has suggested that the gap is of largely artificial origin, and was cut to play a part in the outer defences of a somewhat hypothetical Puritan colony at Stann Creek; but this speculation seems to have no factual basis. Northwards the barrier reef extends with few breaks to Rendezvous Cay; southwards it projects to the east in a prominent elbow, backed by a wide, sandy, rippled reef-flat. Two miles south of the cay a number of huts had been erected on the shallow reef-flat, and were occupied during the grouper fishing season; there were two huts there in 1922 and over a dozen in 1960.

The cay was wholly built of sand, with maximum heights of nearly 4 feet along the undercut western shore near its north end. The southern, unvegetated part of the cay was subject to considerable changes: Figure 30 shows its plan in February 1960; when revisited in April the whole west shore had retreated 2-3 feet, the southern spit had decreased in length by 15 yards, and had recurved towards the east. The vegetation cover at the north end was sparse and low, consisting of <u>Sesuvium portulacastrum</u>, <u>Euphorbia mesembrianthemifolia</u>, <u>Philoxerus vermicularis</u>, <u>Cakile lanceolata</u>, <u>Paspalum distichum</u> and <u>Ipomoea asarifolia</u>. There was a single young coconut tree 4 feet high, and the cay was more conspicuous for a small thatched hut than for its vegetation cover.

There is no doubt that the island was formerly more extensive. As late as 1922 Capt. Douglas noted coconut trees 70 feet tall (MS C8925), and many fishermen remember when the cay was larger than at present and was inhabited. It was destroyed in the 1931 or 1945 hurricanes (information differs). Beachrock relics of this older cay are widespread to west and northwest of the 1960 cay, and seem to indicate that the old island was larger than the present. There are four lines of beachrock dipping north, the longest 70 yards long, all massive, slightly undercut, supporting algae and some corals, and little fractured. All these lines were slightly drowned and could be swum over at high tide; modern reef growth extended within the outer lines. More lines of rock dip southwards, one being exceptionally massive, the other being thinner and drowned sufficiently for the growth of <u>Acropora cervicornis</u> colonies on its upper surface. The massive block was deeply undercut, rose 5 feet from the reef flat and just broke surface. It was the only exposure visible from the island at any stage of the tide. One interesting feature, not marked on the map, was a circle of coral blocks 15 yards in diameter between the two northernmost lines of beachrock, which recalls the conch shell fishtraps built by fishermen on present shores, and may have a similar origin.

During Hurricane Hattie, Cay Glory was completely destroyed, and no cay existed at this point in 1962. The only feature to attract attention was the crest of the massive beachrock still breaking surface. All the beachrock seems to have survived, though completely stripped of corals and algae. The reef flat floor near the beachrock is barren, 5-6 feet deep, and covered with strongly rippled sand. About 20 yards to the east is a steep-sided zone of rippled sand rising to within 2-3 feet of the surface - an embryonic cay which, as at Paunch Cay, will eventually break surface as a sandbore. Round this rippled-sand area the floor is covered with Thalassia, littered with small coral debris; the reef itself (see Chapter 3) has been largely destroyed and replaced by a rubble carpet. The beachrock itself seems more fractured than previously, though this may only be an apparent change resulting from the stripping of algae.

Tobacco Cay

Tobacco Cay (Figure 31) lies at the southern end of a long unbroken section of the barrier reef, 12 nautical miles due south of Cay Glory. The reef flat immediately north of the cay has a width of 500-600 yards; while the lower platform to leeward is here 3½ miles wide and carries 2½-3 fathoms of water, with deeper holes up to 6½ fathoms. Maximum depths in the lagoon here reach 13 fathoms. The Tobacco Cay entrance itself carried 2-3 fathoms, sufficient for small sailing vessels, which even today regularly use this or nearby reef-gaps when making for Glover's Reef. In the eighteenth century the gap was also an important entrance to the barrier reef lagoon: it is marked with great prominence in Speer's 1771 chart, and Jeffreys in 1775 names the cay and also gives soundings in the channel. Caiger (1951, 28-29) follows Winzerling (1946) in speaking of tobacco cultivation here in 1630-1640, but there is no evidence of this apart from the name. The first mention of Tobacco Cay in the colony's archives seems to be in 1753, in connection with alleged English "barbarities" against the Spanish on the cay (Caiger, 1951, 74). The 1922 Mutine survey did not extend as far south as Tobacco Cay, and current charts date from Owen's Thunder survey of 1834. The island was mapped in early 1960, remapped in July 1961 following Hurricane Abby, and mapped again in April 1962 following Hurricane Hattie.

In 1960 Tobacco Cay was roughly triangular, with a greatest N-S length of 300 yards and a maximum width of 150 yards. The whole island was sandy, rising on the seaward side to a height of 5 feet above sea level near the southeast point; but the greater part of the surface was remarkably flat and featureless, with a near constant elevation of 3½-4 feet above the sea. Towards the north and west shores this sinks to less than 3 feet. Conch shells had accumulated along the west shore, and there was a short fresh sandspit at the north point. The largest fresh sand accumulation in 1960, however, was along the south shore, where white sand, contrasting sharply with the dark humic sand of the cay proper, had been thrown up in two ridges, the innermost rising to 3 feet above sea level and enclosing two brackish pools. The shore behind this accumulation, and behind the northern sandspit, was undercut. Two lines of southward dipping beachrock were found 40 yards off the south shore.

The cay was inhabited, with 10 huts, some substantial, in 1960-61, and wells tapping ground water gave a notable supply. In 1960 the island was covered with thick vegetation. In mid-1834 Owen noted trees 70 feet high; Lieut. Smith (1842, 732) stated that "Tobacco Cay cannot well be mistaken, having a high fig-tree (70 feet) near the northeast extreme." In 1960 coconuts were dominant, some reaching heights of 80 feet, together with a number of tall 'almonds', Terminalia catappa, and short bushy Coccoloba uvifera and Cordia sebestena. The undergrowth was dense, mainly of Conocarpus, with a continuous ground cover, consisting of large patches of Stachytarpheta jamaicensis, Wedelia trilobata, Ipomoea pescaprae, I. stolonifera, Sesuvium portulacastrum, Hymenocallis littoralis, with species of Euphorbia, and Canavalia rosea and Vigna luteola. There were a number of Rhizophora seedlings on the west shore. It is worth noting that on the 1945 1:40,000 air photograph cover, vegetation on the cay seemed extremely sparse, probably as a result of the hurricane of the year.

In mid-1961, before Hurricane Hattie, the cay had suffered considerable changes. Hurricane Abby of 15 July, 1960, had swept away the southern sand ridge and the northern sandspit (the new shoreline is shown in Figure 31a), and blown down a number of coconut trees in the south-central part of the cay. In addition, most of the bushes had been cleared by the inhabitants, to give a very different aspect to the island. The ground cover of creepers and recumbent plants, however, remained the same.

The damage caused by Hurricane Hattie may be summarised as follows. The old cay shores were eroded on the east side, and particularly at the southeast point, where the retreat totalled 14 yards. Coconuts roots were exposed by sand stripping along the central part of the east shore, and for short distances near the north point. Fresh sand has been piled up over the old surface along the west and south shores. It is most noticeable along the south shore, where it forms a steep ridge rising to a height of 2-3 feet; and at the southeast point, now rising in a gradual slope to a height of 6 feet, 2 feet higher than formerly. Along the south shore the fresh sand carpet has a maximum width of about 15 yards. About 70% of the coconuts were knocked down, the direction of fall varying from 10-60°, average 40°, indicating winds slightly south of southeast. The greatest sand deposition also indicates similar water movement; but the greatest erosion is on the east, seaward side. In falling, many of the trees left surface holes now filled with brackish water. The island is said not to have been submerged by a storm surge, but the freshwater lens was so contaminated that well water is now almost undrinkable; the inhabitants, who have no alternative, nevertheless survive on it. All the houses collapsed, and in 1962 a single family was living in a makeshift tent of polythene sheeting.

Terminalia resisted destruction in near-shore locations, but *Coccoloba* and *Cordia* were both much broken. Coconuts, including some of the tallest and most fragile-looking, stood on the east and north sides of the cay. None of the fallen trunks have yet been cleared. The cay surface is covered with a very similar plant assemblage to that existing before the storm: *Stachytarpheta*, *Sesuvium*, *Wedelia* and *Ipomoea*; though *Wedelia*, which appears to like shade, was much less widespread, and *Ipomoea* had relatively increased. Much of the *Hymenocallis* was buried by fresh sand but survived. Along the south shore the fresh sand ridge has been invaded and almost completely covered in the period November-April by *Ipomoea*. Other plants collected in 1962 included *Eleusine indica*, *Vigna luteola*, *Eragrostis ciliaris* and *Euphorbia blodgettii*. *Portulaca oleracea*, dominant coloniser on the heavily damaged northern sand cays was seen, but not in profusion.

Cays between Tobacco and South Water Cays

In June 1834 Owen charted three islands along the reef between Tobacco and South Water Cays, with the annotations, "dead trees" ¼ mile north, "trees 15 feet" 1¼ mile north, and "trees 20 feet" 2½ miles north of South Water Cay respectively. The *Mutine* did not find these cays in 1922, nor do they exist today. However, three sandbores were seen here, in these approximate locations, in 1960. Similar sand patches were also seen north of Tobacco Cay. They were all linear, oriented paralled to the reef, up to 50 yards long and less than 10 yards wide, built of very fresh sand, almost overtopped by the waves, and clearly ephemeral. They were not seen in 1961 or 1962.

South Water Cay

South Water Cay (Figure 32) is situated on the northern side of a reef gap, at the end of an unbroken reef segment 5½ miles south of Tobacco Cay. It is prominently marked on Jeffrey's chart (1775), and was last charted by Owen in 1834, when he noted trees 50 feet tall. The general physiography of the reef is similar to that described at Tobacco Cay. The island was mapped in 1960, revisited in 1961, and re-mapped in 1962.

In 1960 the cay had a maximum north-south length of a little more than 700 yards; its width varied from 75 to 200 yards; and it was aligned at an angle to the barrier reef, which it approached closest at its northern end. The island falls into two distinct parts: over the southern three-quarters the natural vegetation has been completely cleared for coconuts, while the northern sector is still partly covered with dense palm thicket. In the centre of the cay there is an area of ornamental gardens with exotic plants, a hard tennis court, tomb (incorporating a freshwater well), and house. At the northeast point, where the shore lies 50-100 yards from the reef, the beach is composed of coral rubble, much pitted and blackened, merging into the scattered debris of the shallow reef flat, and backed landward by a shingle ridge 4 feet high. In pockets in the face of the shingle ridge, small sand beaches have accumulated, composed entirely of *Halimeda* fragments. As the beach trends away from the barrier reef towards the south the amount of shingle and rubble decreases rapidly, and the greater part of the east shore, before the hurricane, consisted of fine sand, rising to a crest 4-5 feet above sea level, and overlooking a wide, sandy and very shallow reef flat. The reef flat itself is covered with Thalassia: close inshore are numerous Rhizophora seedlings, with a few mature clumps. Behind the shingle ridge at the north end of the cay is an area of black swampy soil with standing water, separated from the lagoon on the northwest side by a low sand ridge, the outer margin of which was slightly cliffed in 1960. In 1960 and 1961 there was a prominent spit of fresh sand at the south point, where the margin of the island core was also undercut, and at the north end of the west bay. No beachrock was seen on the seaward shores of the cay, but immediately south of a 70 yard long masonry wall in the west bay three patches of cemented sand were noted in 1960, emerging from underneath the beachridge. Part of the rock was well cemented, but much was still friable; its outer edge extended 2-3 feet from the base of the beach, and trenching showed that it extended at least 4 feet under the beach sands. Its total thickness was 12 inches.

Almost all the island is covered with coconuts, with a sparse ground cover of Euphorbia blodgettii and grasses; the Mutine survey noted trees 60 feet high in 1921 (West Indies Pilot, I, 463). The northern shingle ridge was covered with a prostrate zone of Sesuvium and a crest-zone of Tournefortia and Suriana. Ground cover in the northern palm thicket consisted of Wedelia, Cakile, Ipomoea, Euphorbia, Cyperus planifolius, Sporobolus and Andropogon glomeratus, with Borrichia arborescens and Coccoloba round the margins. Borrichia and Coccoloba were also scattered along the eastern sand ridge, with patches of Euphorbia and Ambrosia hispida.

During Hurricane Hattie the shoreline retreated discontinuously on all sides of the cay: along the whole of the northwest shore, along the northern section of the west bay (i.e. that part facing southwest), at the south point, and in places along the east shore. Retreat on the northwest shore exposed three patches of cemented sand standing 6 inches above high tide level, with no discernible dip, permeated with coconut roots, and still friable. The exposure lies 120 yards from the north point, where the sand ridge narrows between swamp and sea, and is probably a cay sandstone rather than a beachrock. The incipient beachrock noted in the west bay in 1960 was completely exposed, forming three overlapping lines, now standing 2-3 yards offshore, with a total length of nearly 30 yards. The rock is now generally well cemented, and has a marked lagoonward dip. It is located immediately south of the end of the concrete wall, now much broken and no longer in contact with the shore. The southernmost sand spit was washed away, and the southern part of the cay has the appearance of submergence by the sea. On the east side there are a number of shallow scour holes which may have been cut by southwesterly storm waters crossing the cay surface. Along the shores of the west bay, there is first a narrow beach zone, then an undercut sandcliff, topped by a zone of bare coconut roots from which the loose sand has been stripped, and then a wider but irregular zone of patchy fresh sand, deposited by storm waves. These fresh sand deposits are found only on the west and south shores of the cay.

Tree fall direction is in harmony with the picture of erosion and deposition: direction of fallen coconuts varies from 11-62° and averages 30-40°, corresponding, as at Tobacco Cay, to southwesterly winds. Many trees are still standing at the south and north ends of the cay, but in the centre about 80% of the trees are down. The shores of the northern part of the west bay are lined by the upturned boles of fallen trees. According to inhabitants other trees were defoliated, but in 1962 Borrichia and Coccoloba were still living, and two large Avicennia on the east shore were not killed.

The jetties and some houses were destroyed, but the cay is still occupied and several houses are inhabitable. Most severe property damage was limited to nearshore locations on the west side.

Carrie Bow Cay

Carrie Bow Cay, owned by and named after the Bowman family of Stann Creek, was mapped by Owen as "Jack Ellin's Cay" (H57, 1830) and appears on charts as "Ellen Cay". It is situated at the southern end of a small section of the barrier reef, bounded north and south by channels carrying 1½ fathoms, and it lies about ¾ mile south of South Water Cay. The island itself was an elongate strip of sand 150 yards long and 35-45 yards wide when mapped in 1960 (Figure 33). At the time of this survey a temporary fresh sandspit extended 35 yards to the north of the main body of the cay. The surface of the island is flat, of rather grey sand, rising to a maximum height of 3-4 feet above sea level along the east shore. The eastern beach was then narrow and covered with small loose blocks of dead coral. At the northern and southern ends, where this rocky zone was absent, the shore was slightly cliffed, and littered with fallen and leaning coconut trees. The sand cliff was up to 2 feet high, the top 12 inches forming an impenetrable tangle of coconut roots. The east shore overlooks a shallow and sandy reef flat, thickly covered with Thalassia, with a number of strips of relict beachrock. In 1960 these were not visible from the shore, but were easily seen from the verandah of the house, and from the air. The strips of beachrock were roughly parallel to the beach; Group I (Figure 33) showed no clear dip and were little more than cleared patches in the turtle grass. Between Groups I and II the reef flat was scattered with Porites, Siderastrea, and A. cervicornis, and carried about 2 feet of water at low tide. Beachrock II shows a definite seaward dip; living reef approached within a short distance of this outer exposure. No beachrock was seen along the shores of the cay itself.

In 1830 Captain Owen noted "tops of bushes 20 feet" (Adm. MS H61), probably denoting a thicket of Suriana, Coccoloba, perhaps Cordia, palms and strand plants. By 1960, however, all these had been removed for coconuts and the ground was kept clear of all vegetation, except for scattered grasses and Euphorbia. The island was used as a holiday centre; it had a large house and chalets, and a reinforced concrete pier giving anchorage in 1½ fathoms on the lee side.

Physiographic change during Hurricane Hattie was minor. There was a little shore retreat at the south and north extremities, giving low sand cliffs, and the whole of the east shore retreated 5-6 feet, exposing a fresh line of beachrock (III). This new line of beachrock showed a distinct dip to landward along its whole length (cf. a similar exposure at Southwest Cay II, Glover's Reef: ARB 87, 97). The northern sandspit was also washed away, revealing two lines of poorly cemented beachrock, corresponding to its former shorelines (Group IV). The sandspit in 1960 was low and continually overtopped by waves; it is difficult to reconcile this exposure with the view that beachrock formation is connected with a freshwater horizon (Russell, 1962). A further exposure in Group I was also seen in the Thalassia.

A number of coconut trees still stand, especially at the north end; fallen trees trend from 345-035°, and average almost due north, indicating more southerly winds than at Tobacco and South Water Cays. The jetty was undamaged, while damage to buildings was considerable, though all except one house stood. A boat is now stranded near the north end of the cay, presumably by storm waves. The only plant coloniser since the hurricane appears to be Euphorbia. The island has a resident caretaker. Damage to the reef has already been outlined (Chapter 3); southeast of the cay in April 1962 a strip of coral rubble broke surface to form a ridge everywhere less than 2 feet high.

Curlew Cay

Curlew Cay (Figure 34) must at one time have been very similar in appearance to Carrie Bow Cay, one mile to the north. Here also Owen noted bushes 20 feet high in the 1830's (H61), but in 1960 and 1961 the island was simply a low, crescentic sandbore, 40 yards long and up to 10 yards wide, built of fresh sand and unvegetated apart from two Rhizophora seedlings. Traces of the older island can be seen in the extensive development of beachrock east of the cay. There are three distinct exposures. The first trends SW-NE and shows a characteristic dip to the NW; it was thickly covered with algae, just broke surface, and was partly buried by the sandbore. The second consisted of a single line of beachrock trending E-W; it was rather more submerged and dipped to the north. The third lies 60-70 yards seaward of the first zone, was 1-2 yards wide and its upper surface lies 1-1½ feet below sea level. At its northern end it was a low mound with no discernible dip; in the south the dip was definitely seaward. This line of rock marked the inner edge of living reef, and the rock itself was colonised by Porites and Millepora. The area enclosed by these three zones of beachrock carried 2 feet of water, and its floor was covered with Thalassia and scattered Porites. It is unlikely that the beachrock was all of the same age. The date of destruction of the vegetated cay is unknown; it may have been during the great hurricane of 1945.

Curlew Cay presumably disappeared after Hurricane Hattie, but by April-May 1962, it had again built up, a few yards to the west of its 1960 position. The beachrock was undamaged. The cay is still unvegetated and of fluctuating dimensions.

B. Cays of Central Barrier Reef Lagoon

South of Curlew Cay the barrier reef is fragmented for four miles to South Cut, and thereafter is continuous and without sand cays for the 14 miles to the Gladden Spit elbow. The next southernmost sand cays on the barrier reef proper are 21 miles due south of Curlew Cay. At the Gladden Spit elbow the coastal shelf and lagoon reach their widest extent of 23 miles; in this latitude the maximum lagoon depth is 19 fathoms. Within this area, delimited by Sittee River and Great Monkey Cay on the coast, and by Curlew Cays and Silk Cays on the barrier reef, is an area of extremely intricate bottom topography, with a large number of cays, both sand and mangrove. The bottom topography cannot be discussed in detail, but some brief consideration is necessary for an understanding of the development and location of the cays.

The floor of the lagoon, as in the north, falls away from the coast toward the barrier reef, reaching maximum depths at distances of 10-14 miles from the coast, or generally two-thirds the width of the coastal shelf. Near the edge of the shelf there is an abrupt rise to the lower platform at 2-4 fathoms depth, which is itself edged on the seaward side by the present sea level barrier reef. The greatest depths in the lagoon increase from 12 fathoms in the latitude of Curlew Cay to 24 fathoms in the latitude of Silk Cays, a straight-line distance of 21 miles. This increase in maximum depth is about ten times greater than that between the Triangles and Curlew Cay (2 fathoms in 40 miles), but still gives a north-south gradient of only 1:1800. Figure 35 shows the distribution of depths less than three fathoms in this part of the lagoon; this isobath approximately delimits the lower platform. Note how a long narrow submerged spur trends away from the main lower platform near South Water Cay, and continues southwards by Blue Ground Range to Peter Douglas Cay. From there, Admiralty charts, based on the 1830-34 surveys, show the continuation southwards of arcuate ridges, parallel to the barrier reef and convex to the east. The most prominent of these is that connecting Crawl Cay, Baker's Rendezvous, Cary Cay and Long Cocoa Cay. East and west of this ridge dozens of smaller patches, some with cays, many without, rise to or near the surface. These are apparently concentrated along an axis extending from Placencia on the coast to Gladden spit; in this latitude many of the patches support cays. Immediately to the south of this axis is an area of numerous shoals rising to within 3 fathoms of the surface (Pantile Heads), without cays; and yet further south a zone of apparently similar patches which do not rise above a depth of 4-5 fathoms. Finally, there is a zone where such shoals are almost entirely absent. This depth-distribution may suggest differential movement along an axis transverse to the barrier reef lagoon, which may also have shaped the Gladden Spit elbow. It is clear that the difference in height of the patches is not a reflection of differing degrees of reef growth depending on differences in depth of the lagoon floor; for in this case the tops of the patches would become deeper the farther from the shore, and this is not so. But the problem here is more complex than simple warping or faulting about an east-west axis, for the topographic highs are themselves not simple features. In those close to the shore corals are not significant, and it is probable that in all of them present-day corals only veneer pre-existing structures.

Figure 36 is derived from an airphoto mosaic of the area between South Cut and Mosquito Cay; for its precise location, see Figure 35. The intricate nature of the "patches" is at once apparent: many form elongate, almost closed rings, rising extremely steeply from depths of 15 fathoms or more. The rims of these rings are everywhere narrow, rise to within three fathoms of the surface, and are interrupted by deep gaps; they enclose a central "lagoon" with depths often comparable to those outside the rim. These ring-like features vary up to 7 miles in length, but most are smaller. Cays are located at intervals on the rims. The rims themselves have a further distinguishing characteristic: their outer margins are smooth in plan and gently curved; the channels between the rings pass smoothly into each other without marked angles; and their general shape is smoothly curvilinear, or lozenge-shaped. But the inner edges of the rims are intricately dissected and highly irregular. The upper surface of each rim is also irregular and pitted with deep holes. The only extensive surface-breaking reef is that between Baker's Rendezvous and Crawl Cay, but most of the patches have moderate reef growth on their eastern sides.

These features are clearly not the result of modern reef growth; their general form and intricate dissection point to karst erosion during glacial low sea levels. The channels between the patches may represent lagoon floor drainage channels of glacial age. It is possible that part at least of their form results from solution weathering of limestone of the type described from Okinawa by MacNeil (1954) and demonstrated experimentally by Hoffmeister and Ladd (1945); some of the small patches, with their arcuate outline and deep holes, recall in a striking way the small elevated limestone islands of the Palau Archipelago (Fosberg, 1960, Plate 12), except, of course, that in British Honduras the forms are entirely submarine. They may originally have been extensions of the Tertiary limestone hills of the mainland, or old reef forms, but in the latter case it is difficult to explain their absence in other parts of the barrier reef lagoon. Very similar features lying at greater depths (4-7 fathoms) can be traced on air photographs at the southern end of the barrier reef, west and southwest of Seal Cays. These may represent erosion features either down-warped since foundation or developed at a lower level on lower limestone masses. If down-warping or faulting has occurred it must have predated the foundation of the horizontal lower platform. The idea that the patches have developed on drowned limestone hills explains more easily their restricted location and entire absence over the greater part of the lagoon. If the features did predate the lower platform they were presumably all truncated at the 2-4 fathom level when the platform was formed. Enough has been said to indicate that the recent history of this part of the shelf may be more complex than Vermeer (1959) supposed; deep drilling for oil at Placencia may help unravel events when the results are available.

In the following sections the cays of this central barrier reef lagoon are discussed in turn from north to south. No early descriptions of these cays exist: it is not possible to identify Speer's (1765) brief references, nor to reconcile the rather schematic charts by Speer (1765, 1771) and Jeffreys (1775) with modern maps. Only the present False Cay and Placencia Cay were named by them; the rest were grouped as Reed's Cays (Tobacco and Blue Ground Ranges?) and the Coconut Cays (all the rest). Jeffreys (1775) additionally names Bugle, Colson, Scipio and adjacent cays the "Placentia Triangles".

Weewee Cay to Baker's Rendezvous

Weewee Cay lies on a reef patch 4 miles west of the barrier reef and 4½ miles southwest of South Water Cay. It is a small triangular island with sides 100-150 yards long, enclosed on the north and southeast sides by dense mangrove. Rhizophora also extends along the greater part of the N-S trending west shore, except for a small opening giving access to the low-lying sandy interior. In April 1962 the peripheral mangrove was still alive along the north and southeast facing shores, and had been killed only at the southern tip, where for a short distance the shore trends N60°E. Living reef fringes the entire eastern side of the cay, but is absent along the west side; a protected situation presumably accounts for the absence of a weatherside sand ridge on the island, and the apparent reversal of physiographic zones compared with the normal mangrove-sand cay. The cay is not permanently inhabited, but is used as a fishing station by Stann Creek Caribs; a number are buried on the island under piles of conch shells. Fish are cleaned, salted and dried (corned) here. The dry land area has a circumference of about 75 yards; its vegetation is restricted to coconuts and an undercover of grasses and sedges including Cyperus peruvianus, Fimbristylis cymosa, Chloris petraea and Batis maritima. A large number of trees was knocked down by Hurricane Hattie; direction of fall varied from due north to due south, with a few due east and due west. The pattern is in fact almost radial, perhaps as a result of the enclosed character of the dryland area; perhaps 50% of the measured directions lay between 345° and 045°, indicating predominantly southerly winds.

Stewart Cay (un-named on charts, bearing 316-323° from Weewee Cay) and Bread-and-Butter Cay (bearing 274-282° from Weewee Cay, named Stewart Cay on charts) are mangrove islands, lacking dry land, with no important hurricane effects except mangrove defoliation on south-facing shores. Crow's Nest Cay (Spruce Cay on charts) lies 2½ miles SSW of Weewee Cay; it is entirely of mangrove, and because of its sheltered position escaped much defoliation. Peter Douglas Cay (Douglas Cay of charts) lies 1¼ miles SW of Crow's Nest Cay; the intervening Norval Cay of charts was not seen in 1962. Peter Douglas is a large island, mainly mangrove, of irregular outline, fringed by reef on its northeast and east sides. Rhizophora on the northeast and southeast shores was not seriously defoliated; but complete defoliation occurred at the south point, and along the west shore a number of tall Rhizophora had been uprooted, apparently by south-westerly waves. There is a small area of dry land on the west side of the cay; nearshore, it is formed of coarse sand with much shell debris, rising 1½ feet above the sea; it extends for an unknown distance toward the centre of the cay, and supports a dense palm thicket with Sophora tomentosa. According to informants there were about 30 coconuts before the hurricane; 12 were counted afterwards. Little Peter Cay is a small island immediately to the south, the greater part being defoliated Rhizophora, with Sophora on the dry land area; and immediately to the south of this lies another very small mangrove island, Old Rendezvous Cay, almost completely defoliated. Neither of these small islands is named on charts.

South of Peter Douglas Cay, Saddle Cays (Elbow Cays of charts) were not visited, but instead we sailed through Northeast Cay Range, the Pelican Cays of charts, in latitude 16°41'N. These cays are situated midway between coast and barrier reef, here 7 miles distant. They consist of a single large mangrove cay, Northeast Cay, with many small mangrove cays, defoliated on the west side, some with small amounts of shingle thrown up on the west shore. Of these, Cat Cay lies on the southwest side of the group. It is a small island with a narrow fringe of Rhizophora on its north and east shores, and along the greater part of the west shore also. The greater part of the cay is dry land, though the centre is low-lying and marshy, with scattered Avicennia. Fresh small shingle has been thrown up along the west shore, and a number of coconuts have been knocked down. Direction of fall varies from 270-020°, with the majority 340-360°, again indicating southerly winds. The vegetation of the dry land area includes, in addition to coconuts, the palmetto Thrinax, and Thespesia populnea; together with Conocarpus erectus, Euphorbia sp., Cyperus sp., Wedelia trilobata, and grasses. Ospreys (Pandion halietus) were nesting here in 1962. Man-of-War Cay is one of the southernmost of the Northeast Cay Range. In April-May 1962, though small and consisting only of almost completely defoliated Rhizophora, it was inhabited by large numbers of Fregata magnificens, preparatory to nesting. This bird was not seen on any of the neighbouring cays at this time.

Other cays merit little comment. The two Lagoon Cays so called because they each enclose deep lagoons (the larger carrying 8 fathoms), and Crawl Cay are entirely mangrove; Quamino Cay is almost entirely mangrove, with a little dry land on its east side. Slasher Sand Bore, where Owen noted trees 15 feet high in 1830, has not been visible for many years, but reappeared as an unvegetated sandspit following the hurricane. Baker's Rendezvous consists of two long mangrove islands and two much smaller ones to the south; they are wholly mangrove, except for two coconuts on the southern long island. All these cays show some mangrove defoliation on their south shores.

Cary Cay

Cary Cay (Figure 37) occupies a very similar position to Crawl Cay and Baker's Rendezvous, but is much further south, where the linear reef on which it stands trends NNE-SSW, rising from maximum depths of 17-18 fathoms. The island itself trends north-south, and has a maximum length of 500 yards; its width varies, from a narrow sandy strip only 10 yards wide in the south, to a 200 yard wide mass of Rhizophora in the north. Reef extends along the whole east side, but not on the west. Along the east side of the island there is a narrow dry-land area, with palms and strand vegetation; and a lower dry area, planted to coconuts, extends along much of the west side. These two dryland areas diverge northwards, and the intervening area is occupied by standing water, Acrostichum marsh, and, towards the north Rhizophora.

During the hurricane, fresh shingle was thrown up for 400 yards along the east shore, and also in the form of separate ridges at the south end. These shingle spreads consist mainly of cervicornis debris; the separate ridges have a maximum height of 2-2½ feet, though on the southern tip of the cay the shingle is piled against vegetation to a maximum height of 5½ feet. In places along the shore there are small stretches of erosion, with cliffing and root exposure. Immediately offshore, toward the south, are numerous scattered coral blocks, mostly less than 1 foot diameter. The main western shingle ridge varies in height from 2-5 feet, and in width from 10-20 yards; it is often higher where narrower, because of banking against vegetation. The inner edge of the shingle ridge, where it abuts against standing water rather than vegetation, is characteristically steep. The calibre of the material varies from fine shingle up to coarse rubble and some large coral blocks.

Near the north point, and along much of the west shore, the sandy beach is slightly cliffed, in spite of patches of protecting Rhizophora. Thin blankets of fresh sand cover the nearshore area in the south. The vegetation of the dryland area consists of coconuts, Thrinax (especially along the northeast shore), Coccoloba, Cordia sebestena, and an undercover of Hymenocallis, Wedelia, Ageratum, Stachytarpheta, grasses and sedges. Only a few coconuts have been knocked down, and these have generally fallen to the north and northeast. The Acrostichum aureum marsh is surrounded by Avicennia and Rhizophora. Major hurricane effects at Cary Cay are thus practically limited to shingle and sand deposition, apparently in response to mainly southeasterly waves.

Trapp's Cay

Trapp's Cay (Figure 38), the Moho Cay of charts, lies 2 miles southeast of Cary Cay on an isolated reef patch rising from 18 fathoms. The island is regularly shaped, with maximum dimensions of 260 and 210 yards, N-S and E-W, and an area of some 55,000 sq. yards. The margins of the cay are low and sandy, except on the southwest, south and east sides, where the old shore was buried by fresh shingle during Hurricane Hattie. Underneath this shingle accumulation, and intermittently exposed, the old shore is undercut and eroded; much of the finer material has been washed out, leaving only a root mat. Before the hurricane these shores were probably comparable to the present north and east shores. Vegetation approaches close the shore on all sides, except at the northeast corner, where a new spit of fresh sand is building outwards.

The whole of the east shore is blanketed by a carpet of shingle, varying in width from 10-25 yards, and in calibre from small cervicornis debris to occasional large blocks, including one Montastrea annularis block 3½ feet long. The old shoreline along this side of the cay has clearly been much eroded; its edge can be traced along the centre of the shingle carpet. The old nearshore vegetation has been largely destroyed or buried by the shingle, but in many places broken palmettoes (Thrinax) protrude through the shingle carpet. The inner edge of the fresh shingle is everywhere arcuate in plan and steep in section, rising 18-24 inches above the old cay floor, here low-lying, with coconuts or Conocarpus bushes. Along the south shore the shingle carpet has a similar width but is much thinner, and the eroded old shoreline is visible everywhere within a few feet of the present shingle shore. Patches of a rather soft sand-shingle conglomerate are exposed at sea level at one point. The height of the step at the landward edge of the shingle is here generally less than 1 foot. Northwards along the west shore, the shingle tails off rapidly in both width and thickness. At is greatest accumulation on the east shore the shingle carpet is probably not thicker than 2½ feet. A low arcuate spread of shingle has been thrown up off the south shore; it is about 100 yards long, and probably did not exist before the hurricane.

The vegetation of the island was not investigated in detail; hurricane effects were limited to near-shore felling of coconuts, largely by wave-sapping of the substrate itself. A large Coccoloba was also uprooted on the west shore. Dominant direction of tree fall indicates winds from the south and southwest, in contrast to the southeasterly direction indicated by shingle deposition. Thrinax is widespread round the cay margins, and appears to have resisted the hurricane better than coconuts. Other trees noted include Thespesia populnea and Coccoloba uvifera; with a ground vegetation of Hymenocallis littoralis, Cyperus, Phyllanthus amarus, Chloris petraea and Paspalum paniculatum. The centre of the cay was not investigated. There are a few Rhizophora bushes round the shore.

The name Trapp's Cay is preferred to that given on charts, which invites confusion with other Moho Cays (latitude 17°31½'N, 88°12W; and 16°09'N, 88°40'W) and is not known locally. Co-ordinates of Trapp's Cay are 16°30½'N, 88°10'W.

Islands between Trapp's Cay and Gladden Spit

Some of the islands lying to the northeast of Trapp's Cay were also visited. Rendezvous Cay is a mangrove island with a small central sand area covered with coconuts, used by Carib fishermen but not permanently inhabited. A number of coconuts had been knocked down, their direction varying from 305-355°, with a few 140-150°. As on other cays near Gladden Spit, some of these trees were certainly knocked down by Hurricane Anna in 1961; and there was no doubt that at least two different sets of fallen trees were represented here, distinguished, for example, by greater amounts of fungal growths on the older trunks. Long Coco Cay is very similar to Rendezvous Cay, but there has been little damage to coconuts. There is some defoliated mangrove at its southeast point, but no deposits of fresh sand or shingle. This cay was briefly described by Vermeer (1959, 91-92). Tarpum and Jack's Cays are wholly mangrove, with little of interest. Litter Water Cays, noted by Vermeer (1959, 91) was not visited, but seemed from a distance to be similar to Rendezvous and Long Coco Cays.

Buttonwood Cay (Figure 39) was mapped in 1960, shortly before its vegetation was severely damaged in Hurricane Anna. The sand area is low-lying, measures 80x100 yards, and is surrounded on its west and southwest sides by mangrove. The vegetation consists of coconuts, Coccoloba, Conocarpus, Rhizophora and Avicennia, with Cyperus planifolius, Eragrostis domingensis, Portulaca oleracea, Euphorbia sp., and Vigna luteola. The name itself is the local term for the buttonwood mangrove, Conocarpus erectus. Because of the occurrence of two hurricanes since the island was mapped, it was not thought worthwhile to re-map the cay.

Laughing Bird Cay

Laughing Bird Cay (Figure 40) is the southernmost of the central barrier reef lagoon cays, and the most attractive; it lies 4½ miles from the barrier reef and 6 miles from the coast, on a narrow reef patch, aligned NE-SW. The bottom to the northwest is fairly shallow, but depths of up to 24 fathoms are found within very short distances to the southeast. The island, like the reef on which it stands, is long and narrow, with a total length of nearly 500 yards, but varying in width from only 10 to 45 yards. Before the hurricane the island seems to have been completely sandy, with a beachridge rising to a height of 3-4 feet on the southeast side. The vegetation, which consisted chiefly of coconuts, was distributed in three distinct clumps, the longest in the centre, and the trees were only about 40 feet high. During the hurricane, few of these trees were knocked down, except along the central part of the southeast shore, where the beach itself was cut back and a number of undermined trees fell towards the north. A number of Rhizophora trees on the southeast side were also defoliated and killed.

The dominant storm effect, however, was the deposition of shingle and rubble on the southeast side. These deposits are most extensive towards the ends of the cay, where they blanket the old surface and are piled up against the now dead vegetation; between these extremities there are occasional high patches of gravel, reaching 4-5 feet above sea level, but most of the shingle takes the form of an off-shore ridge 5-10 yards from the southeast beach. The greatest height reached by the shingle on the cay surface is at the bushy northern end, where it is banked up to 6 feet above sea level. At the south end the rubble and shingle forms an arcuate ridge enclosing two stagnant pools of water. It is, of course, impossible to say whether this off-shore ridge was previously more extensive and has been partially eroded since the hurricane, or indeed whether the hurricane succeeded in breaching the sandy island between the vegetation 'islands', though no sign of such breaching was apparent. However, the shingle itself is clearly of hurricane origin, and my local companions, who had previously often slept here, confirmed the changes. The leeward beach is wide, long and sandy, and except at the extremities shows no unusual features. It overlooks a shallow sand-floored anchorage.

The ground cover under the coconuts consists of Sesuvium, Ipomoea, Euphorbia, and in places Hymenocallis. Except where buried by rubble the vegetation seems to have been little affected, except for the mangrove on the windward side.

Owen Cay

Finally, we come to the cays between Laughing Bird and the coast, Jeffrey's "Placentia Triangles". These fall into three groups: (a) those with considerable dry land, on the south and east of the group, including Owen, Scipio and Colson Cays; (b) the mangrove islands, with no dry land, including Lark Cay, once known collectively as "Scruffer's Range" (Owen, 1830) and situated on the north side of the group; and (c) Bugle Cay, a mangrove cay with a narrow sand zone. All these islands are situated on small discrete shoal patches, generally with reef growth, rising steeply from 10-15 fathoms water.

Owen Cay (Figure 41), the easternmost and situated on the most extensive shoal patch lies 2½ miles due west of Mosquito Cay and 8 miles from the coast. It is uninhabited, not named on charts, nor have I been able to discover a local name for it, even from the keepers of the Bugle Cay lighthouse. For ease of reference it is here named Owen Cay, after Captain Richard Owen, first surveyor of these reefs; its co-ordinates are 16°29½'N, 88°15½'W.

The island is 180 yards long, with a maximum width towards the north end of 40 yards. The centre of the cay is low and sandy, with numerous large *Avicennia* and *Rhizophora* trees, and considerable area of *Batis maritima* (typical of such mangrove-sand cays), *Hymenocallis*, and grasses. There are numerous low coconuts, some *Thrinax*, and occasional *Cordia sebestena*. None of the trees were blown down or uprooted by the hurricane, but shoreline *Rhizophora* has been defoliated on the south and west sides of the cay, but not on the north and east. The main hurricane effect has been the deposition of peripheral shingle ridges, highest at the southern end, where the shingle is banked against the coconuts, covers the whole surface, and rises to 5 feet above sea level. Elsewhere the shingle carpet is thinner and does not exceed 10 yards in width; it is highest on the west side. Along the east side, where there is some undercutting of the old shore, the shingle has spread out in a wider offshore carpet, 1-2 feet above sea level. The calibre of the shingle is small to medium and the constituents only exceed 6 inches in diameter along the southernmost ridges.

Scipio Cay

Scipio Cay (Figure 42) has much in common with Owen Cay 2¼ miles to the ENE. It is located at the northern end of a small shoal area, surrounded by water 12-15 fathoms deep. The island itself is aligned north-south, is 270 yards long and up to 100 yards wide. The island before the hurricane was largely low-lying, sandy, covered with coconuts, and with a large central *Avicennia* marsh. Peripheral beach ridges, especially on the east and southwest sides, were thickly covered with *Thrinax*. The rest of the vegetation was limited to scattered *Cordia*, sedges and grasses. Vegetation approached close to the shore and was very dense. When mapped in April 1962 there was considerable undercutting of the old shore along the east and south sides of the cay, exposing mats of characteristic brown coconut and orange palmetto roots. The upper edge of this undercut shore lies 1-2 feet above sea level; landward the cay surface falls rapidly toward the *Avicennia* marsh or other low-lying ground. It is covered by a wedge of fresh shingle, tapering at the top of the shoreline cliff, thickening landward, where it ends abruptly in a steep slope 1-2 feet high. *Thrinax* trees protrude through this fresh covering, which is everywhere less than 20 yards wide. On the east side the deposit consists only of *cervicornis* and small *palmata* shingle; on the west side the material is sandy and finer. On the west shore also there is little evidence of cliffing and shore retreat. This pattern of deposition is similar to that at Trapp's Cay and other cays in the central barrier reef lagoon; it is shown diagrammatically in Figure 42.

Below the undercut eastern shore, for the greater part of its length, is a ridge of hurricane shingle and rubble 10 yards wide and generally less than 3 feet high, enclosing arms and isolated pools of seawater. It is impossible to tell how much these ridges have altered since their construction in October 1961. Apart from the shingle carpets and ridges, there are few other visible effects of Hurricane Hattie; a handful of coconut trees have fallen, but apparently under the influence of wave rather than wind action, since they are all close to the shore. The cay is uninhabited and no beachrock or similar material was seen.

Colson Cay

Apart from its rather different shape, Colson Cay (Figure 42) perfectly reproduces all the features of Scipio Cay. The two islands are only one mile apart, and separated by 14 fathoms water. Colson Cay is triangular, 190 yards long, with a maximum width of 150 yards; the greater part is low and sandy, with a dense vegetation of coconuts, with Thrinax, Cordia, and grasses, enclosing a large central area of Avicennia marsh and standing water. Like Scipio Cay, the old shore has been subject to undercutting on the southeast side, and hurricane shingle has been deposited both on the cay surface and in front of the cliff as a separate ridge, enclosing pools of seawater and low-lying shingle spreads. The shingle carpet on the old cay surface is generally about 20 yards wide, and rises to a maximum height of 4 feet above the sea. The shingle spread below the cliff is 15-20 yards wide, and the outermost shingle ridge is 2-2½ feet high. At the extreme southeast point this ridge is itself now being destroyed by wave action, flushing out the fine material to leave a lag of larger palmata slabs. The material on the west shore is finer than that on the east. Very few trees are down, and those noted indicate S-SW winds. On the east shore the shingle has invaded a stand of Thrinax most of which are still standing. Changes on the north side are very slight, though even here there is a thin deposit of sand overlying the old surface.

Bugle Cay

The intensity of hurricane change at Bugle Cay, compared with the mainly constructional physiographic and very slight vegetational changes at other cays in the Placencia Triangles, is at first sight surprising, but provides yet another illustration of the increased liability to catastrophic damage of islands, whose natural vegetation has been cleared for human occupation. Only the western end of the island is free from mangrove (Figure 43): here there is an arcuate strip of low sand 160 yards long and 15-50 yards wide, covered with coconuts with no under-vegetation. The present steel-frame lighthouse dates from 1951; there are also the brick remains of a former lighthouse, and the lighthouse keeper's wooden house. Unfortunately the cay was not visited before the hurricane, and this account of change is derived from a post-hurricane survey and conversations with the inhabitants. Erosion of the shore was general on the west and south sides of the sand area: on the west side this is revealed by surface-sand-stripping, root exposure and combing, and shore-cliffing; on the south side the erosion has been much greater, and the former extent of the land is now revealed only by remains of the old lighthouse and other buildings a short distance from the present shoreline. Retreat here has been at least 10-20 yards. Great damage was sustained by the mangrove, which was not only defoliated but much broken and swept away over a large area immediately adjacent to the sand strip. Between the sand area and high mangrove there is now an open muddy marsh with small Rhizophora seedlings and open water. At the same time as the sand strip was being eroded on its outer side, deposition of fresh sand was occurring to leeward, extending the sand area across the marsh by up to 15 yards. The remains of the old lighthouse were broken down, but the new light was undamaged. One house disappeared when the land under it was washed away; the main house was broken from its stilts and carried 60 yards due north by winds and waves before being deposited on the marsh surface. Since the hurricane a wooden causeway has been built across open water and mud to reach it, and it is still inhabited. Many coconuts are still standing, and those which fell had been cleared at the time of my visit in April 1962. The pattern of erosion and deposition, however, clearly indicate southerly winds.

At the time of my visit there was a 60 yard long fresh sandspit at the north side of the sand area, which appeared to be a post-hurricane construction.

Other barrier reef and lagoon cays

Placencia Cay (True Point Patience Cay of Speer, 1765, 23; Patience Brother Island of Jeffreys, 1775) is a mangrove island with a small area of strand vegetation and coconuts, located half a mile east of Placencia Point and village on the mainland coast. Rhizophora was defoliated and some coconuts felled, but otherwise there was no significant damage. At Placencia itself, considerable damage was caused by Hurricane Anna, 1961, when I had the opportunity to inspect changes on the same day. Minor damage was caused to buildings, many coconut trees were blown down, the whole village was inundated, and fresh sand carpets were piled round the shores. Similar changes occurred during Hurricane Hattie, except that house damage was more considerable; a more detailed account is outside the scope of this report.

Jeffreys also mapped the small mangrove islands at the mouth of Placencia Lagoon as The Virgins, a name not now used, and Speer commented on these "several small Kays ... at the mouth of a large lagoon, where there is plenty of Turtle passes morning and evening ... in the day you can get none" (1765, 23); regrettably the turtle have also become less numerous. These cays suffered heavy defoliation.

Harvest Cay, three miles to the south, is the "Hobbe's Kay" of Speer (1765, 23). This and other islands to the south, such as Palmetto Cay, are more properly barrier beaches, built of terrigenous quartz sand, backed by mangrove swamp, than true coral cays. Harvest Cay bears a dense vegetation of coconuts, Thrinax, and mangrove, with a tall undergrowth of Batis maritima, and Cladium jamaicense and other grasses. Landings were made at three points along the seaward shore, but no trace could be found of the so-called "Harvest Hill", "a small wooded, table-topped hill, 82 feet high to the tops of the trees, which is a good landmark" (West Indies Pilot, I, 467; and Vermeer, 1959, 28).

Cays of southern barrier reef

Twenty-three further cays were mapped in detail on the southern barrier reef and in the barrier reef lagoon in 1960 and 1961; they were all photographed from the air in 1961, together with a number of others not investigated in detail. After the hurricane they were again all photographed and observed from the air in 1962. Observation during these flights, and comparison of the air photographs, showed that virtually no change to either physiography or vegetation had occurred on any of these islands during Hurricane Hattie. Such changes as had occurred were all minor, and may or may not have resulted from the hurricane itself. The northernmost islands not affected by the hurricane were the three vegetated Silk Cays. These will not be discussed here, but it is worth noting that the name "Queen Cays" of charts is locally unknown. Winzerling (1946) alleges that the name of Queen Cays derives from the seventeenth century vessel *Queen of Bohemia*, and I regret having repeated this (in Carr and Thorpe, 1961, 167). According to Lieut. Smith, of the first Admiralty survey, "the Queen Cays ... were formerly named the Seal Cays (sic), now altered to prevent confusion" (1842, 732). The name Silk Cays, on the contrary, is given to no other island on this coast, is the only name known locally, and should be restored to charts in place of Queen Cays.

In the absence of any hurricane changes on these cays, they will not be discussed here, but will be described in a further paper now in preparation.

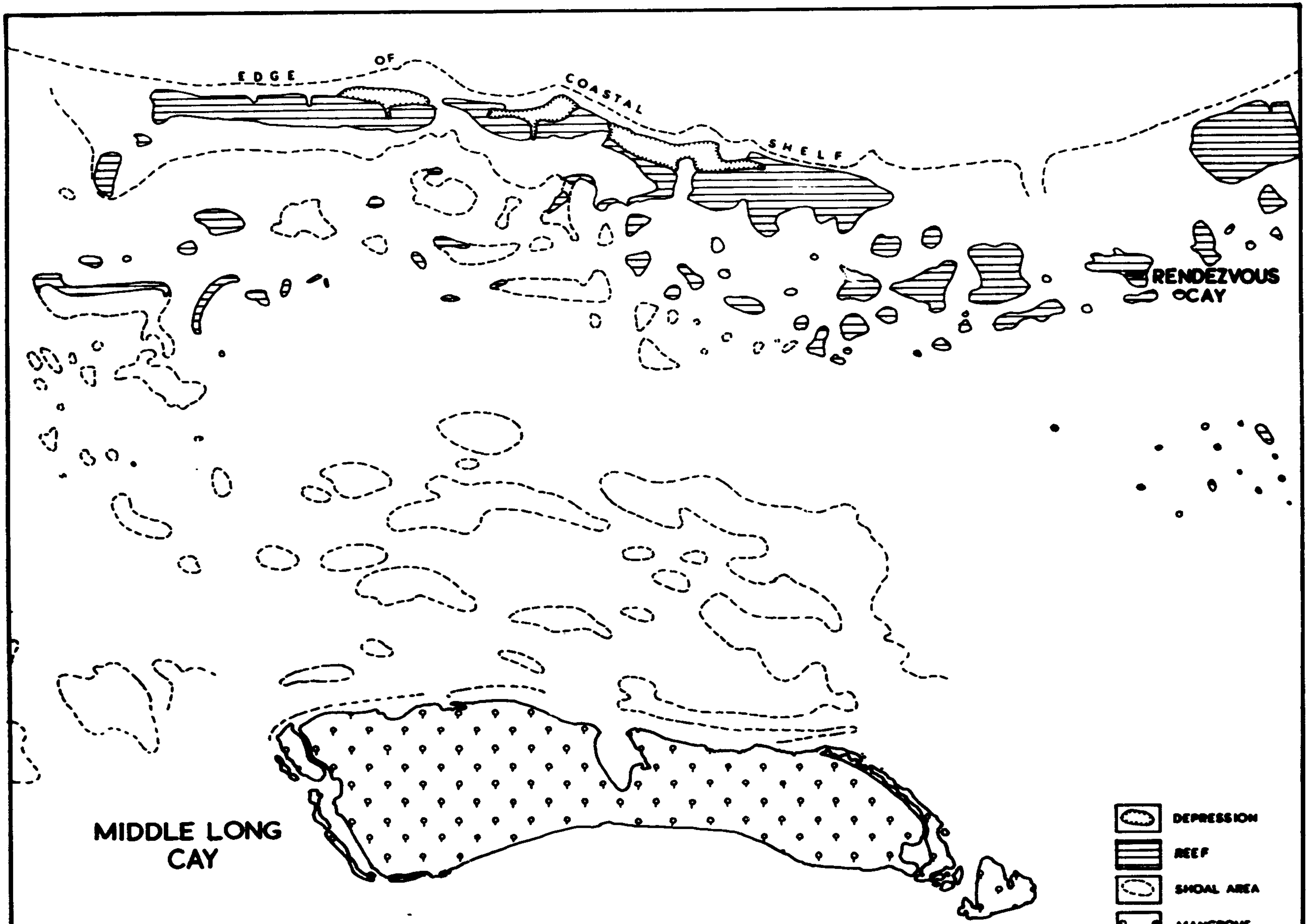

EDGE OF COASTAL SHELF
RENDEZVOUS CAY
MIDDLE LONG CAY
DEPRESSION
REEF
SHOAL AREA
MANGROVE
0
MILES
1

FIG. 29

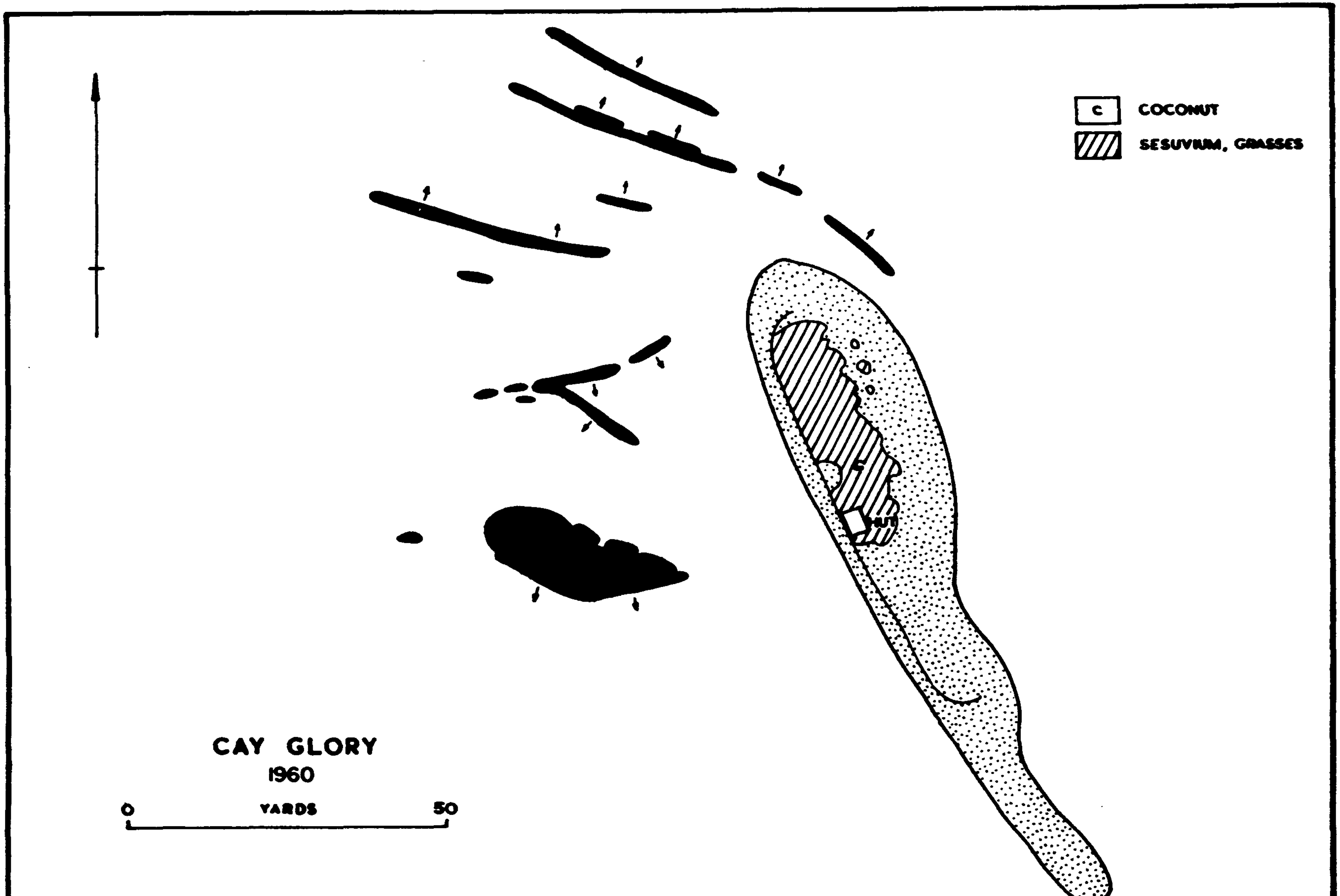
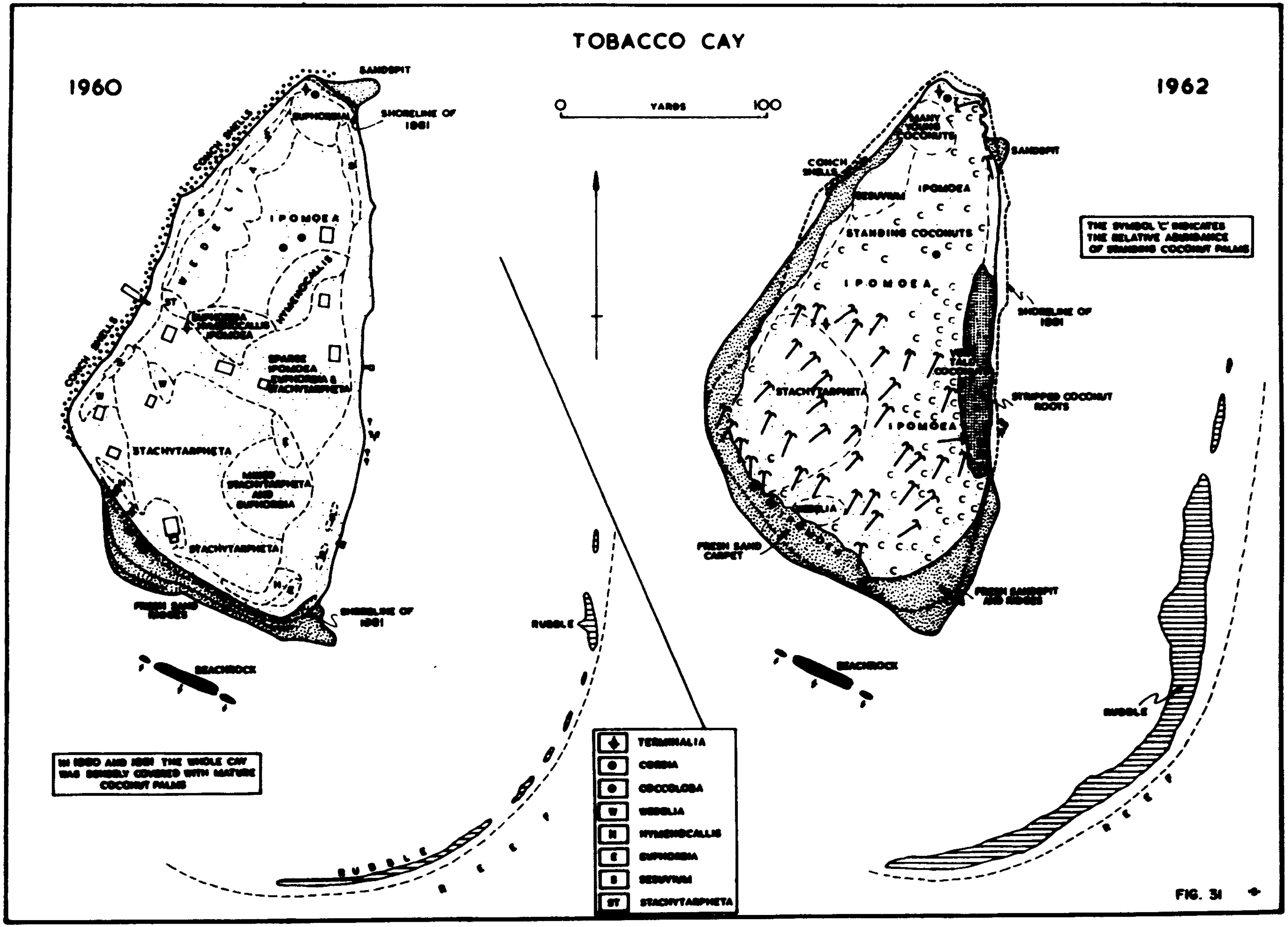


FIG. 30


TOBACCO CAY
1960
1962
0 YARDS 100
SANDSPIT
SHORELINE OF 1961
CONCH SHELLS
IPOMOEA
STACHYTARPHETA
MIXED STACHYTARPHETA AND EUPHORBIA
SPARSE IPOMOEA EUPHORBIA & STACHYTARPHETA
HYMENOCALLIS
FRESH SAND RIDGES
BEACHROCK
RUBBLE
REEF
IN 1960 AND 1961 THE WHOLE CAY WAS DENSELY COVERED WITH MATURE COCONUT PALMS
MANY YOUNG COCONUTS
SESUVIUM
STANDING COCONUTS
STRIPPED COCONUT ROOTS
FRESH SAND CARPET
FRESH SANDSPIT AND RIDGES
THE SYMBOL 'C' INDICATES THE RELATIVE ABUNDANCE OF STANDING COCONUT PALMS
TERMINALIA
CORDIA
COCCOLOBA
W WEDELIA
H HYMENOCALLIS
E EUPHORBIA
S SESUVIUM
ST STACHYTARPHETA
FIG. 31

SOUTH WATER CAY

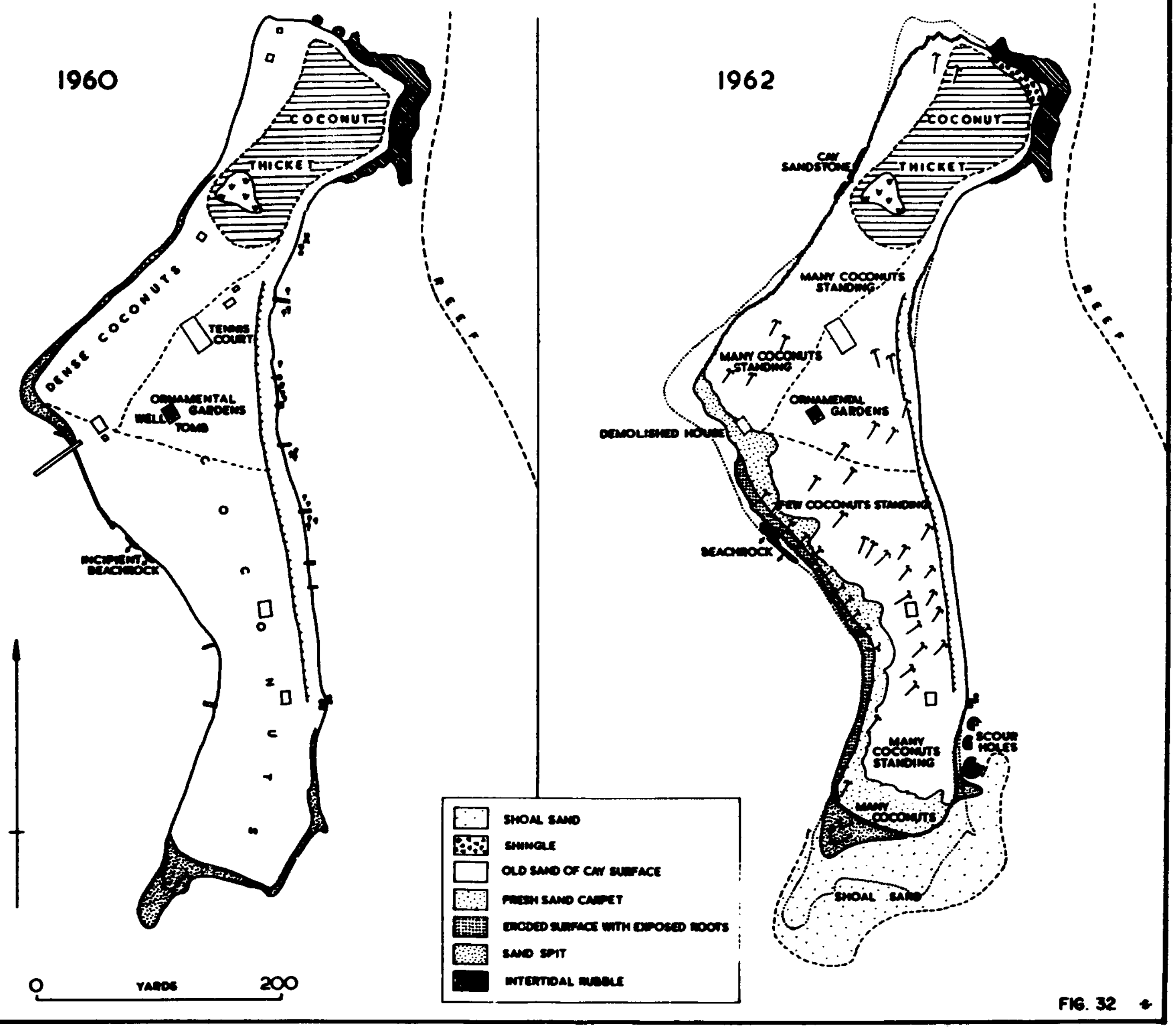


FIG. 32

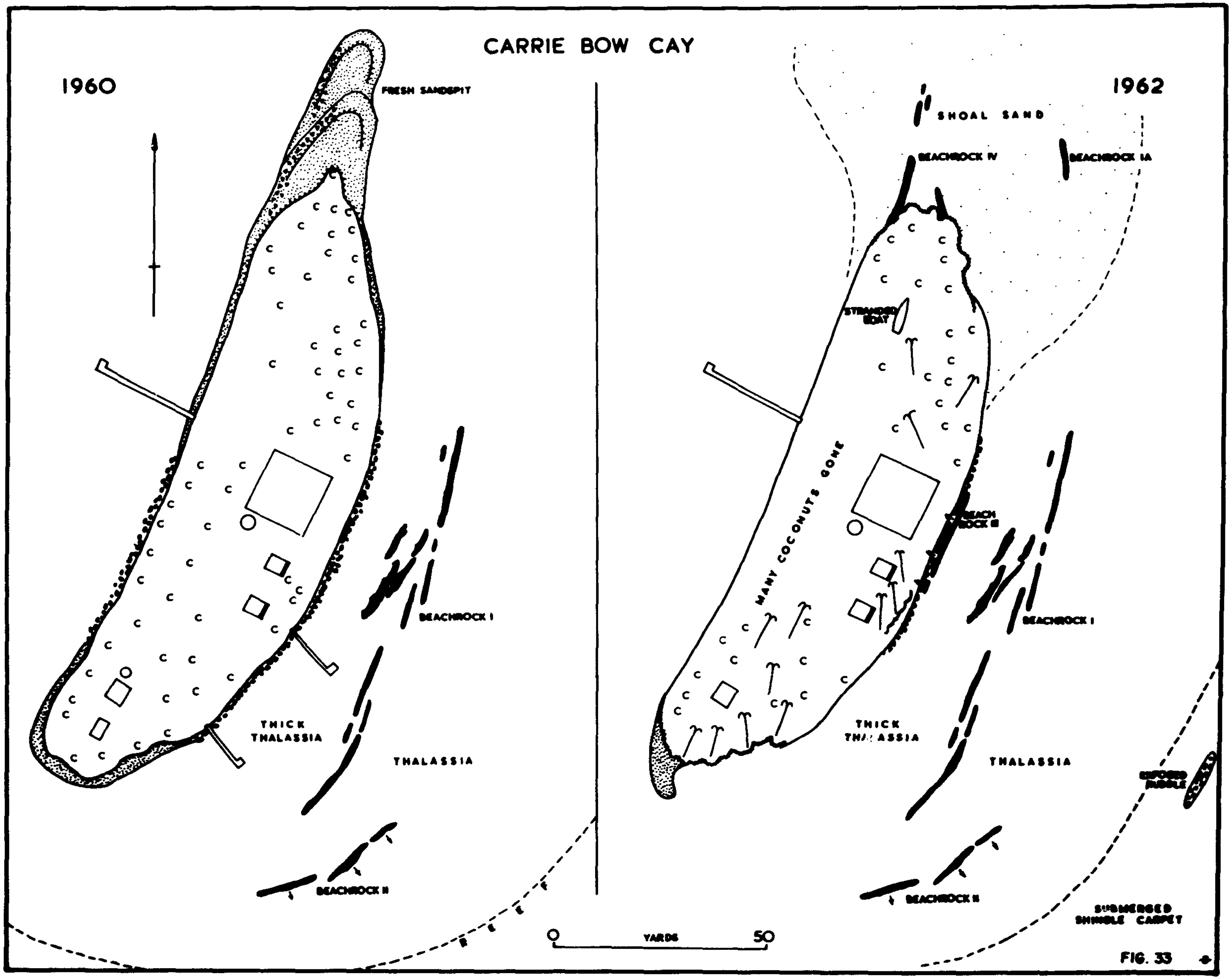

CARRIE BOW CAY
1960
FRESH SANDSPIT
BEACHROCK I
THICK THALASSIA
THALASSIA
BEACHROCK II
REEF
1962
SHOAL SAND
BEACHROCK IV
BEACHROCK IA
STRANDED BOAT
MANY COCONUTS GONE
BEACHROCK III
BEACHROCK I
THICK THALASSIA
THALASSIA
EXPOSED RUBBLE
BEACHROCK II
SUBMERGED SHINGLE CARPET
0
YARDS
50

FIG. 33

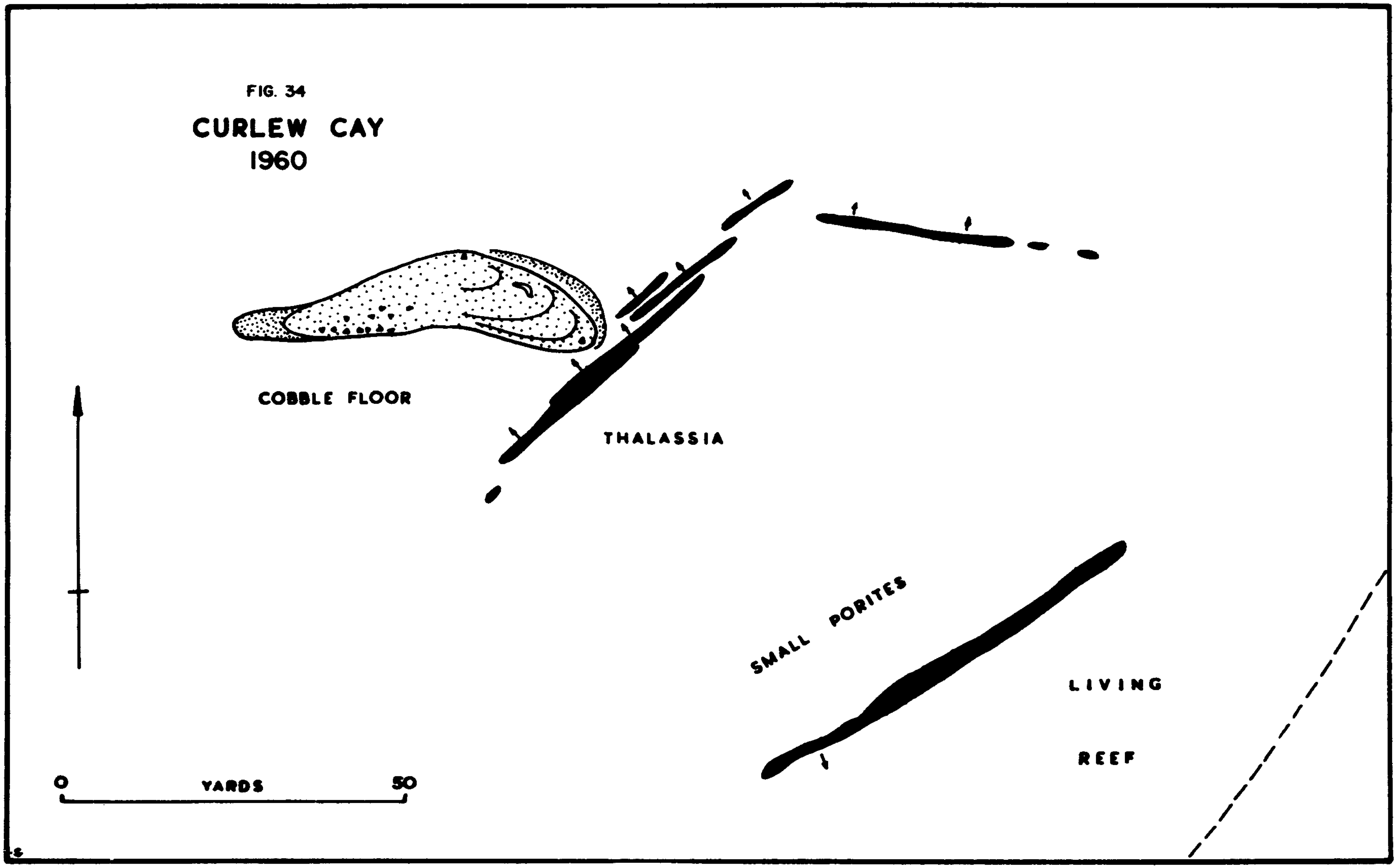
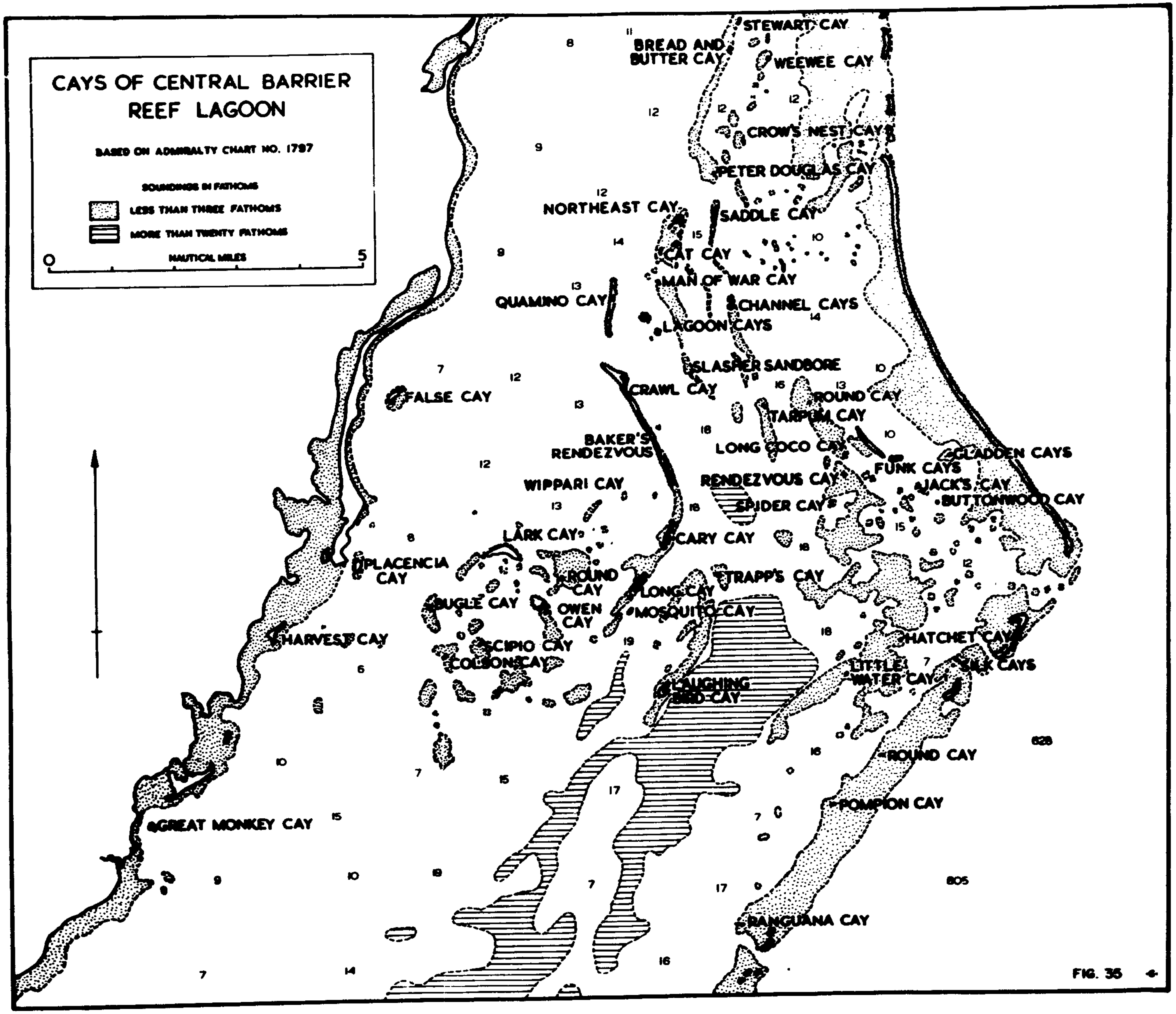


FIG. 34
CURLEW CAY
1960
COBBLE FLOOR
THALASSIA
SMALL PORITES
LIVING
REEF
0
YARDS
50


CAYS OF CENTRAL BARRIER REEF LAGOON
BASED ON ADMIRALTY CHART NO. 1797
SOUNDINGS IN FATHOMS
LESS THAN THREE FATHOMS
MORE THAN TWENTY FATHOMS
0
5
NAUTICAL MILES
STEWART CAY
BREAD AND BUTTER CAY
WEEWEE CAY
CROW'S NEST CAY
PETER DOUGLAS CAY
NORTHEAST CAY
SADDLE CAY
CAT CAY
MAN OF WAR CAY
QUAMINO CAY
CHANNEL CAYS
LAGOON CAYS
SLASHER SANDBORE
FALSE CAY
CRAWL CAY
ROUND CAY
TARPUM CAY
BAKER'S RENDEZVOUS
LONG COCO CAY
GLADDEN CAYS
FUNK CAYS
JACK'S CAY
BUTTONWOOD CAY
WIPPARI CAY
RENDEZVOUS CAY
SPIDER CAY
LARK CAY
CARY CAY
PLACENCIA CAY
ROUND CAY
TRAPP'S CAY
LONG CAY
BUGLE CAY
OWEN CAY
MOSQUITO CAY
HARVEST CAY
SCIPIO CAY
COLSON CAY
HATCHET CAY
LITTLE WATER CAY
SILK CAYS
LAUGHING BIRD CAY
ROUND CAY
POMPION CAY
GREAT MONKEY CAY
RANGUANA CAY
FIG. 35

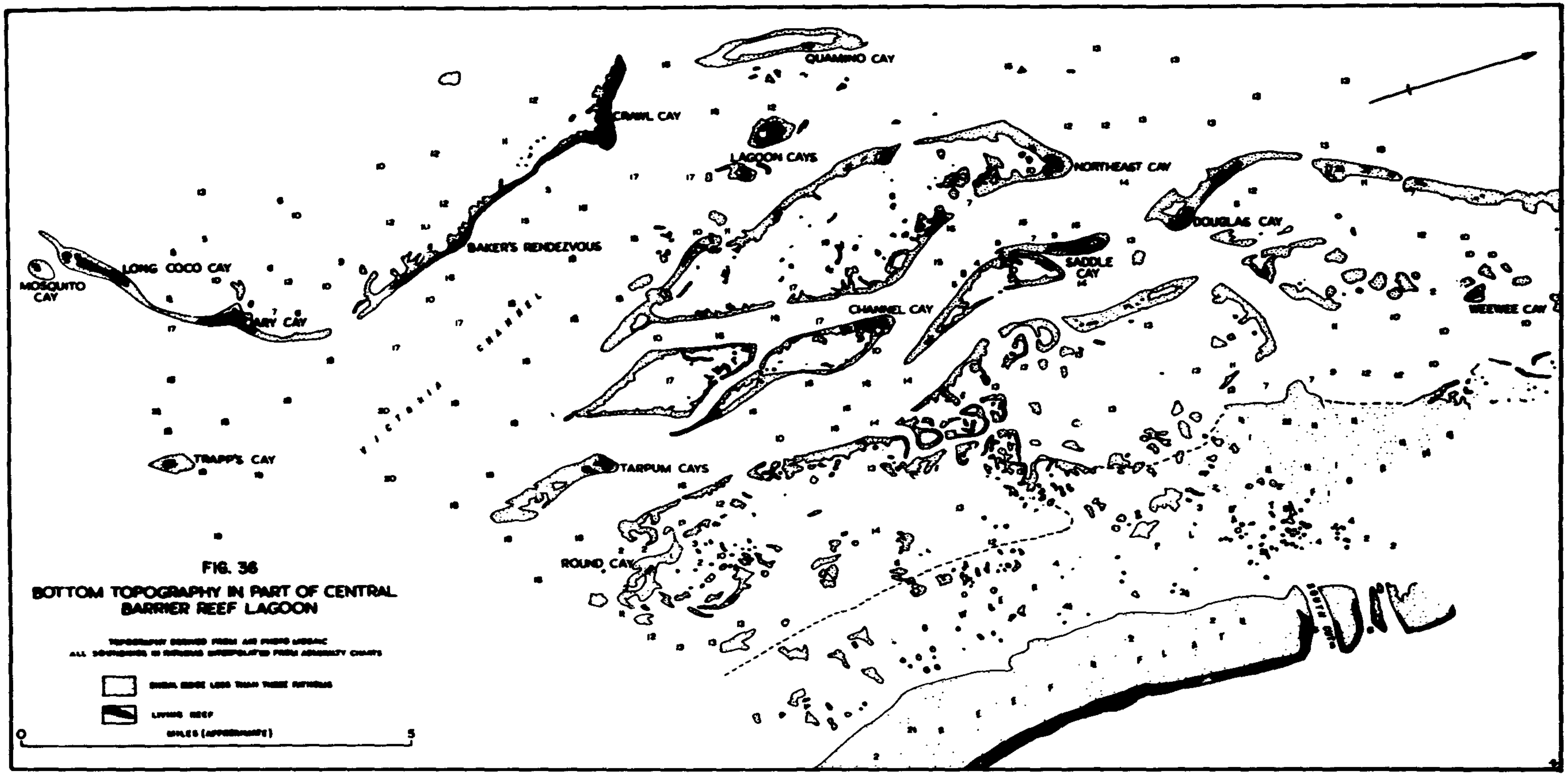


FIG. 36

BOTTOM TOPOGRAPHY IN PART OF CENTRAL BARRIER REEF LAGOON

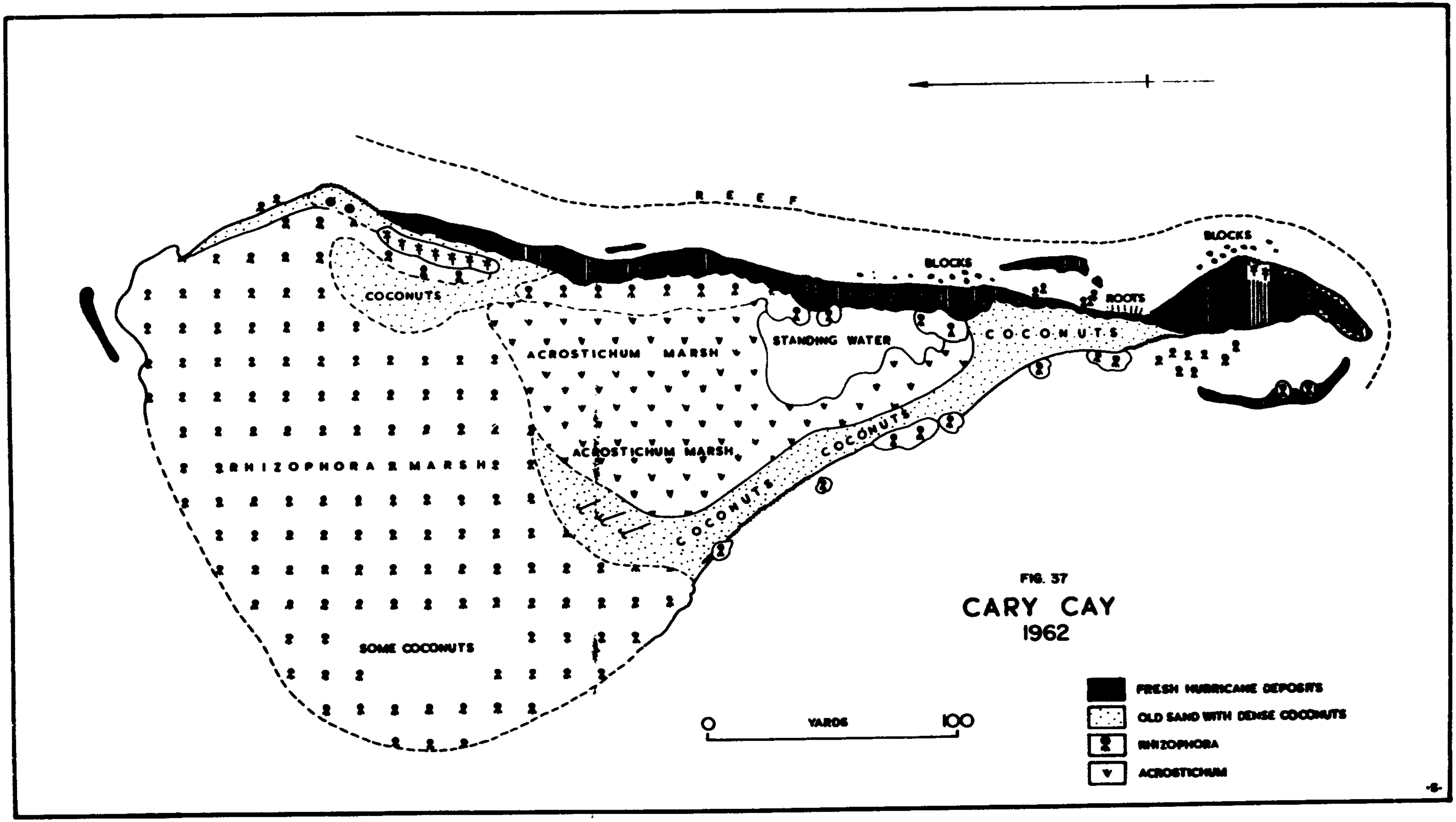


FIG. 37

CARY CAY
1962

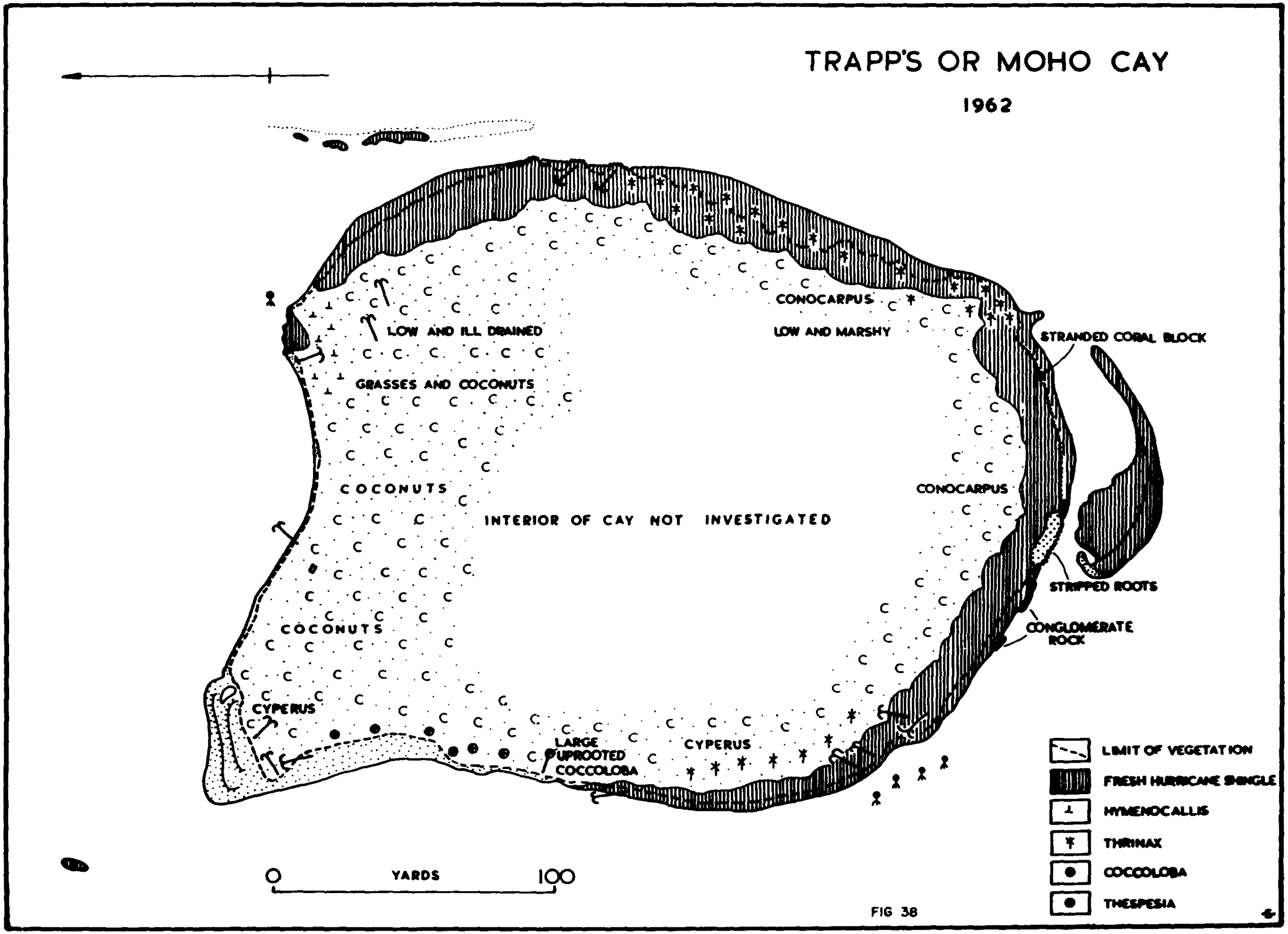
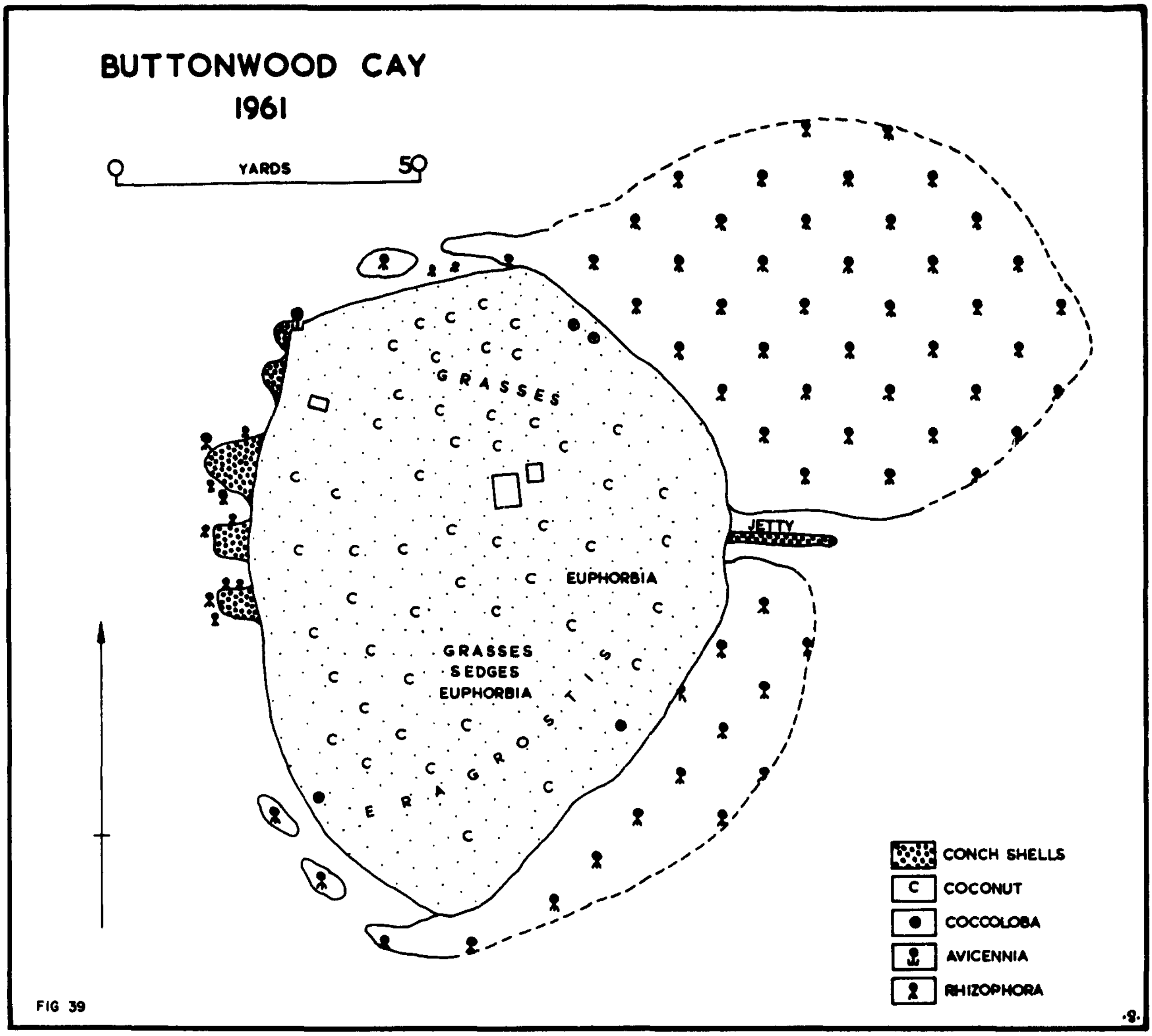

TRAPP'S OR MOHO CAY
1962
LOW AND ILL DRAINED
GRASSES AND COCONUTS
COCONUTS
COCONUTS
CYPERUS
CONOCARPUS
LOW AND MARSHY
CONOCARPUS
INTERIOR OF CAY NOT INVESTIGATED
CYPERUS
LARGE UPROOTED COCCOLOBA
STRANDED CORAL BLOCK
STRIPPED ROOTS
CONGLOMERATE ROCK
LIMIT OF VEGETATION
FRESH HURRICANE SHINGLE
HYMENOCALLIS
THRINAX
COCCOLOBA
THESPESIA
0
YARDS
100

FIG 38



BUTTONWOOD CAY
1961
0
YARDS
50
GRASSES
EUPHORBIA
GRASSES
SEDGES
EUPHORBIA
ERAGROSTIS
JETTY
CONCH SHELLS
COCONUT
COCCOLOBA
AVICENNIA
RHIZOPHORA

FIG 39

FIG 40

LAUGHING BIRD CAY
1962

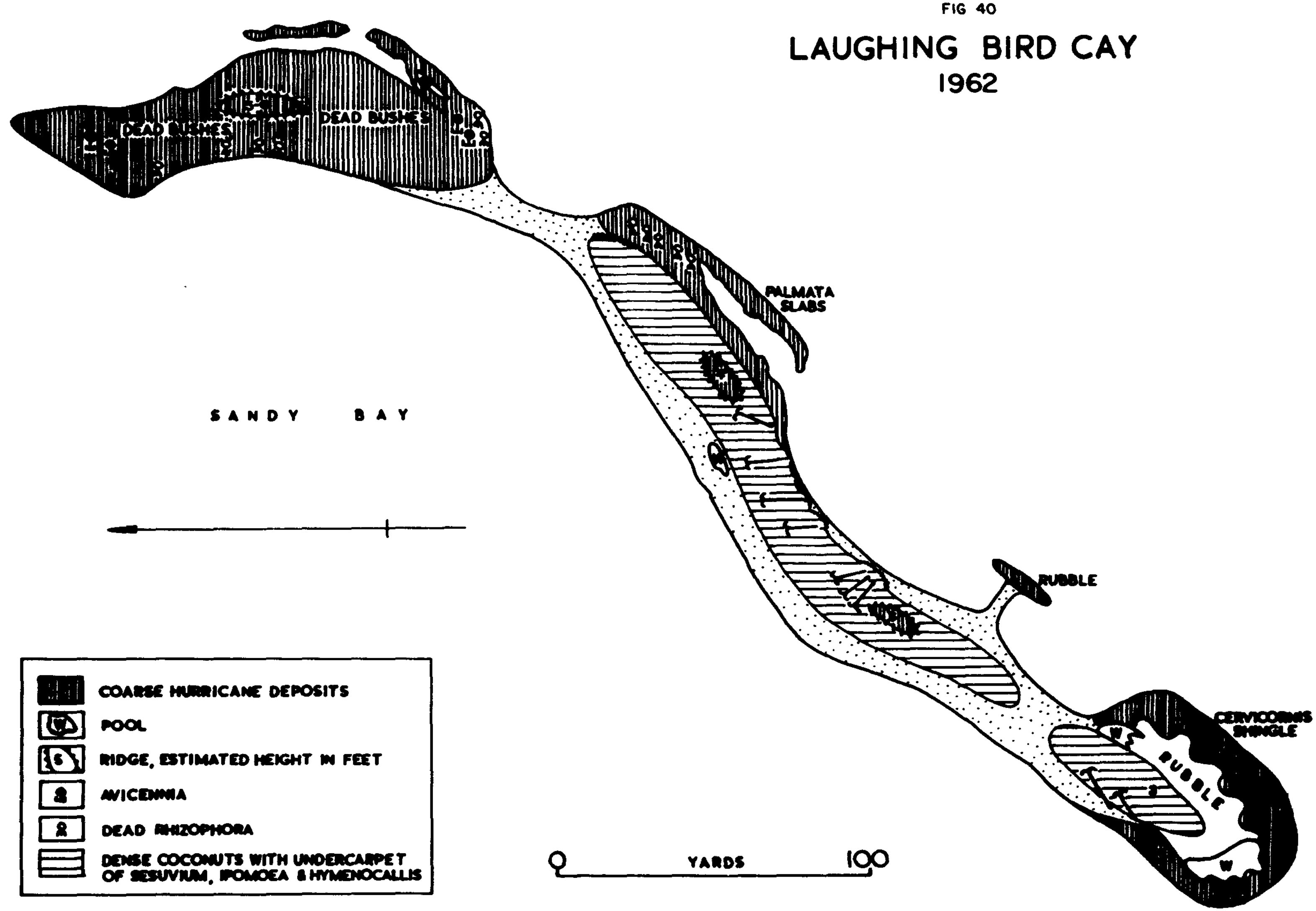
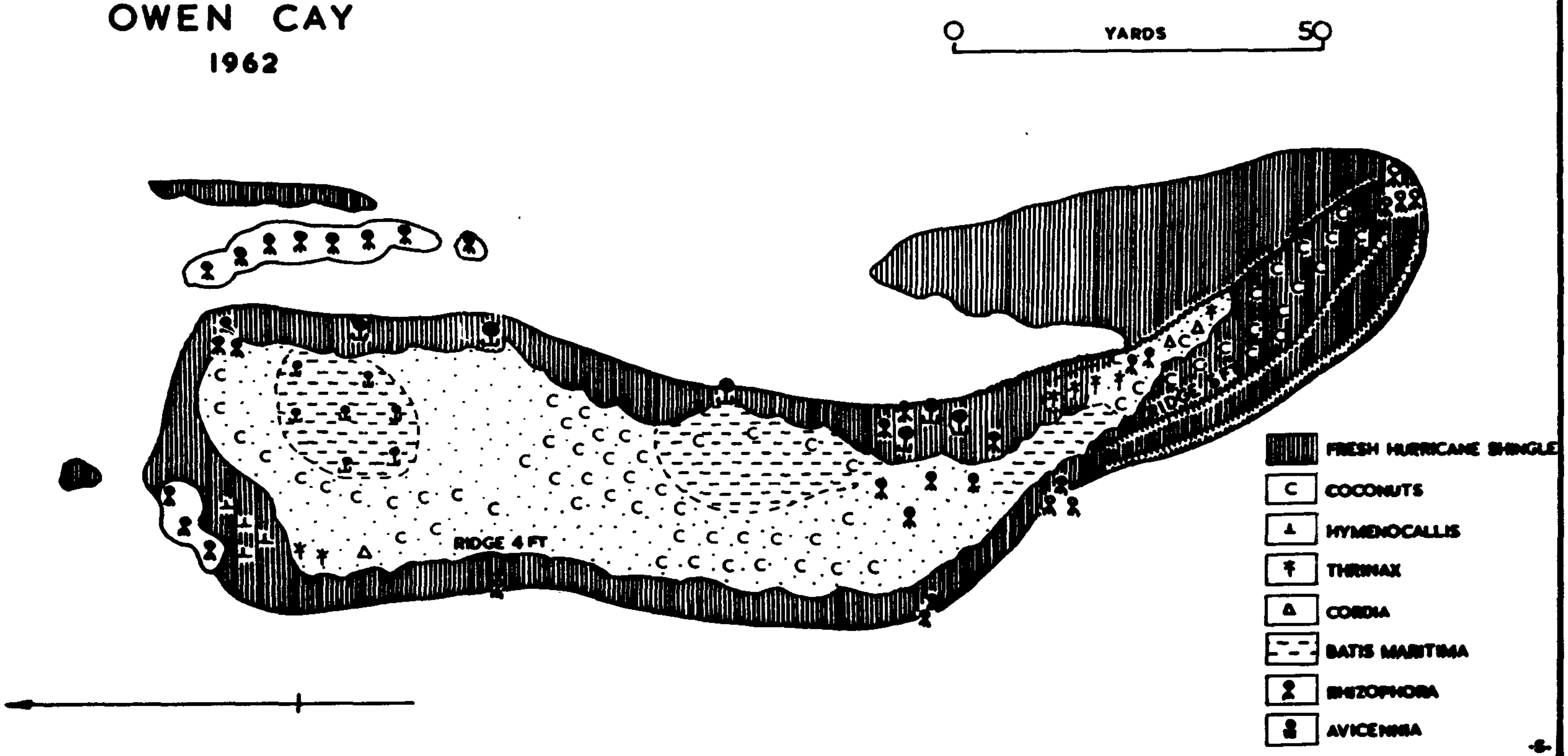


FIG. 41

OWEN CAY
1962



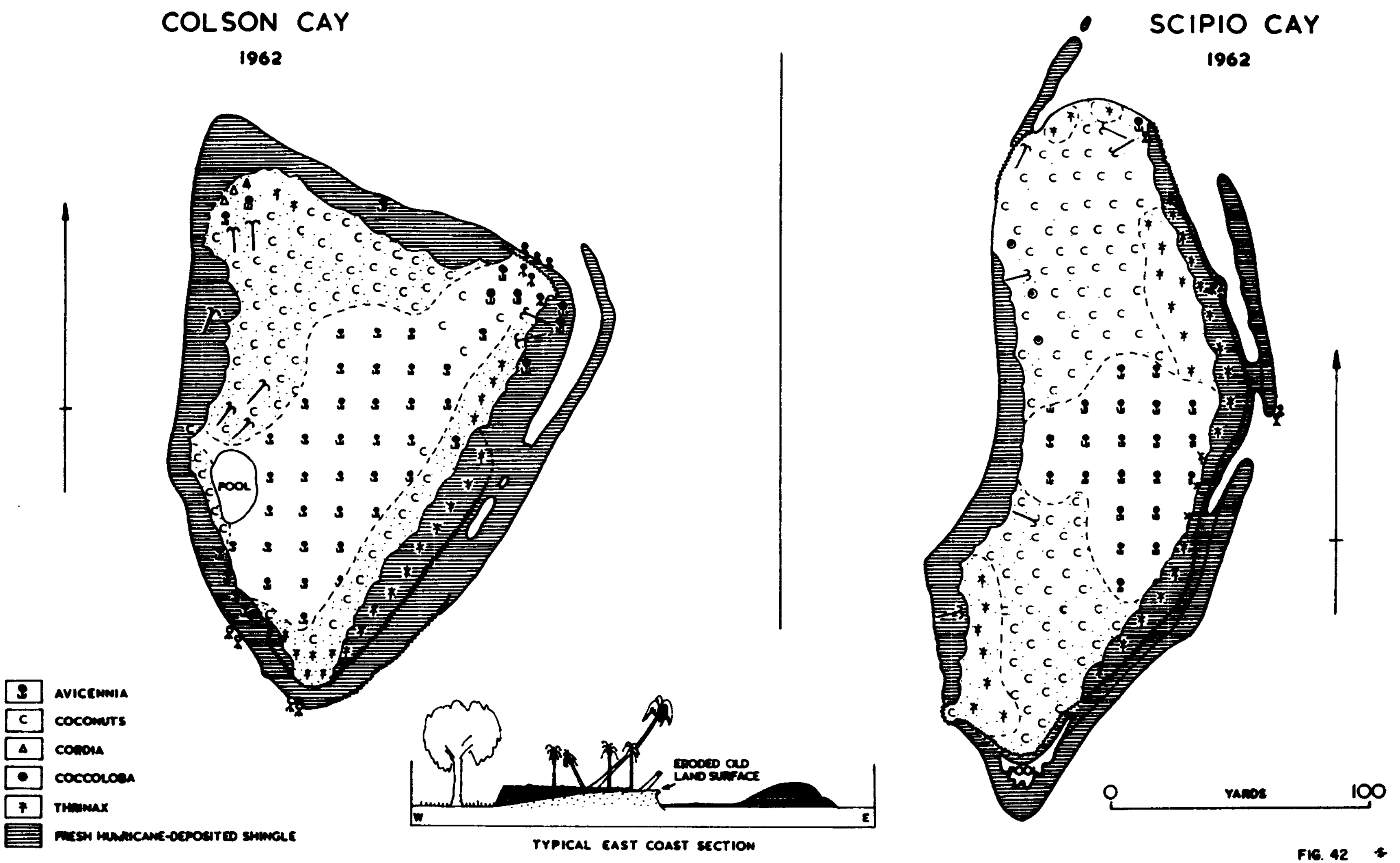

COLSON CAY
1962
POOL
SCIPIO CAY
1962
AVICENNIA
COCONUTS
CORDIA
COCCOLOBA
THRINAX
FRESH HURRICANE-DEPOSITED SHINGLE
ERODED OLD LAND SURFACE
W
E
TYPICAL EAST COAST SECTION
0
YARDS
100

FIG. 42

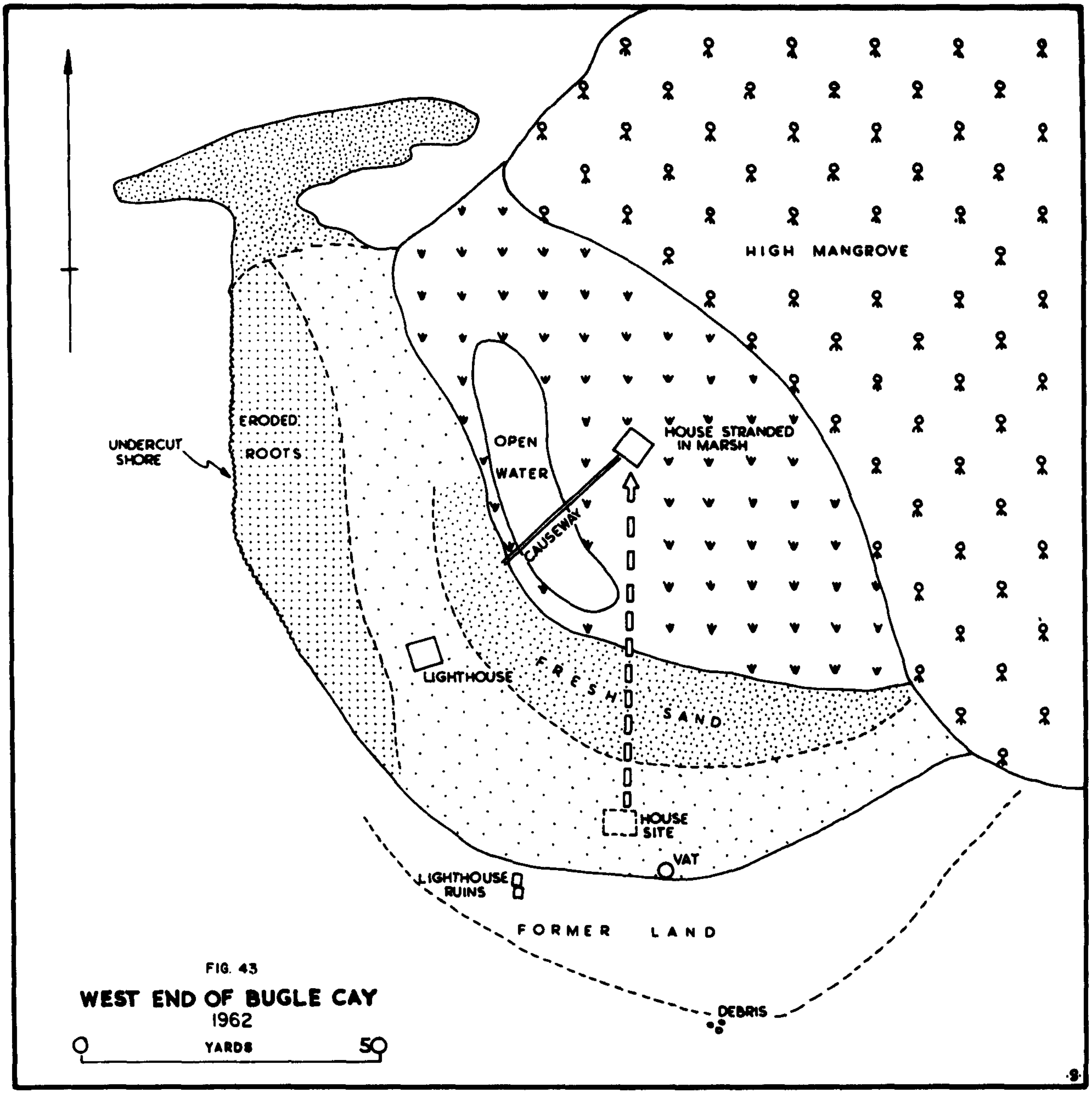


FIG. 43

WEST END OF BUGLE CAY
1962

VI. HURRICANE DAMAGE ON TURNEFFE ISLANDS

Turneffe Islands consist of a group of mangrove cays on a shallow reef-fringed bank 30½ miles long and 10 miles wide at its maximum extent. The mangrove forms a rim on both east and west sides of the bank, enclosing two shallow lagoons with depths of 1-3 fathoms. Much of the more exposed eastern side of the mangrove rim is fringed by a sand ridge, intermittently developed between Big Cay Bokel and Northern Entrance, and covered with coconuts. A number of small sand and shingle cays have been built at reef gaps along the narrow eastern reefs. Apart from these and the eastern sand ridge, the whole land area of the bank is mangrove,mud, and open water. For a fuller description, see ARB 87, 31-49, Figures 14-26. Hurricane Hattie crossed Turneffe diagonally, from approximately Pelican Cay, 17°24'N, on the east side, to between Crickozeen and Ambergris Creeks, about 17°22'N, on the west side. According to the report from Cay Bokel (Chapter 2) the eye of the hurricane extended sufficiently far south to be experienced for a few minutes at this point; this may indicate a more southerly motion in the channel between Turneffe and the barrier reef. The extent of hurricane damage is here described for individual cays from north to south. The Northern Cays, the Cockroach Group and Pelican Cay lie to the north of the storm track; all the rest lie to the south.

The Northern Cays

North of the main mass of the Turneffe lagoon mangroves are three larger cays: Three Corner Cay, Crawl Cay, and Mauger Cay. Mauger Cay is the northernmost, a long narrow mangrove island, oriented east-west and slightly convex northwards. The central part has been cleared, and when visited in 1960 was low and sandy, with prominent clumps of *Rhizophora* along both its north and south shores. There were at this time several houses and a 64 foot high lighthouse, built in 1885, on this central section, which was bounded along its northern shore by a thick masonry wall. There were less than a dozen coconuts on the cleared area, which did not rise more than 2 feet above sea level; *Batis maritima* covered most of the area, with *Sesuvium*, *Ageratum maritimum* and *Cyperus planifolius*. The lobes of the cay consisted entirely of *Rhizophora*, with no dry land. Hurricane Hattie caused severe damage. The mangrove was completely defoliated, and some clumps along the north shore disappeared. The masonry wall bounding the dry sand area was broken, and sand scoured out on the landward side. Coconuts and other strand vegetation were removed, surface sand was stripped, leaving a low-lying ill-drained surface at or only slightly above sea level. Shallow channels were cut through this surface on either side of the lighthouse, and fresh sand was deposited in the southern bay. All houses disappeared, though the lighthouse stood. In early 1962 the cay was no longer inhabited, and the lighthouse, though still in working order, was no longer functioning.

Three Corner Cay is a large mangrove island, shaped as its name implies, with a small dry land area near its eastern point. This was formerly covered with low coconuts. After the hurricane there were signs of inundation, in sand stripping and root-combing, but most of the coconut trees were still standing. Direction of tree fall varied from 190 to 310°, indicating generally easterly wave directions. Most of the pre-existing ground vegetation must have been swept away; in May 1962, there was only a very sparse covering of Euphorbia and Ageratum.

Crawl Cay, the westernmost of the three northern cays, also suffered least damage; it consists entirely of mangrove, which in April, 1962, was already beginning to bear new leaves.

The Cockroach Group

The name Cockroach Group has been applied to a line of 28 islands, mostly sand and mangrove cays, on the east side of Turneffe, north of Northern Bogue. Cockroach Cay is the largest island in the group, and the only one inhabited when mapped in 1960. The cays between Cockroach Cay and Dogflea Cay were also seen at close quarters at this time; but those south of Cockroach Cay were known only from low-altitude air photographs. After the hurricane Cockroach Cay was re-mapped, and two other cays to the north were also mapped; all the rest were again photographed from the air.

Dogflea Cay, the northernmost of the group, lacks mangrove altogether. Before the hurricane it was a small island, perhaps 30 yards in diameter, with a cluster of coconuts and a dense undergrowth of bushes, probably Suriana and Conocarpus. This island disappeared during Hurricane Hattie, and now exists only as a sand shoal.

Pelican Cay (Figure 44) is a larger island immediately south of Dogflea Cay (Cay II of the Cockroach Group in Figure 24, ARB 87); it was visited for the first time in May 1962. Before the hurricane it had been a mangrove-sand cay, with coconuts, Thrinax, and stands of Cordia sebestena and Bursera simaruba on the sand area, which probably rose to a height of 4-5 feet above sea level. The leeward shores were fringed with mangrove. The physiography of this cay probably closely resembles that of most other cays in the Cockroach Group. The grouping of species in the tree cover is very marked: in the northeast mainly Bursera, much entwined with Ipomoea tuba; in the southwest, only Cordia. The island itself is nearly 150 yards long and 75 yards wide. When visited in May 1962 the highest parts were along the northeastern side, where fresh hurricane shingle was piled up to a maximum height of 7 feet above sea level, its steep-sloping inner edge abutting against a thicket of Thrinax palms. Southwards the height of the fresh shingle spread decreases, at the same time widening from 20 to 50 yards. While along the north shore the surface is undoubtedly higher than before, along most of the east shore there are two zones to be distinguished: an outer zone of erosion and inner one of deposition. The outer zone is revealed not in the usual way by exposed roots and undercutting, but by upstanding remnants of conglomerate rock, presumably formed beneath the previous surface. The rock is cavernous, formed of coarse coral shingle with individual fragments up to 12 inches long, weakly cemented with a brown sandy cement. The cementation, which recalls similar nearsurface cementation at Half Moon Cay (Chapter 7), is too poor for the collection of specimens, but clearly sufficient to preserve the fragments against wave attack. The largest of the outcrops is 8 yards long and trends at right angles to the shore; at its seaward edge it stands 4 feetabove the present shingle surface; its surface inclines slightly upwards inland; but at its inner edge the surface stands only 6 inches above the more steeply-banked shingle. The other main remnant is much smaller, but stands nearly 5 feet above the present sea level. The inner zone of deposition is evidenced by the invasion of Bursera and Cordia stands by fresh shingle. As elsewhere the Cordia is much more broken than the Bursera. Rhizophora has been completely defoliated, but a pair of Ospreys, Pandion haliaetus, were nesting here in 1962. The high bank of white shingle against the dark defoliated vegetation makes the cay distinctive from the seaward side.

Cay III disappeared during Hurricane Hattie, and Cay IV was stripped of vegetation.

Cay V (Figure 45) of the Cockroach Group, not previously mapped, is the next northwards to Cockroach Cay itself. It is similar in size to Pelican Cay, being 150 yards long and 60 yards wide, and it also consists of a seaward sand area, backed by leeward mangrove. The vegetation of the dry area consists mainly of Coccoloba, a few coconuts, Borrichia arborescens, Ageratum maritinum, and now dead unidentified bushes. The fresh shingle spread is here neither so wide nor so extensive as at Pelican Cay, nor has any cemented rock been exposed. The maximum height of the shingle is not more than 3 feet, and the width of the shingle spread is not more than 30 yards. The vegetation has been completely defoliated, but most of the branches remain in place.

Cockroach Cay itself (Figure 45) is a long narrow island, immediately north of a wide gap in the Turneffe east reef. In 1960 it was 310 yards long and 55-60 yards wide (cf. ARB 87, 46 and Figure 25). Its seaward shore for a distance of 180 yards was formed by a shingle ridge rising 3 feet above sea level, back of which the cay surface was composed of sand with scattered broken coral. The cay appeared to be extending northwards, and the northern section is mostly sandy. The vegetation consisted almost entirely of closely planted coconuts, with a few scattered stunted Cordia, and a ground cover of Euphorbia, grasses and sedges. There were numerous Rhizophora seedlings along the leeward shore, and at the southernmost point there was a thicket of dense Avicennia and Conocarpus. During the hurricane the coconut cover was almost entirely stripped; only five dead trunks remain standing. Few fallen trunks remain on the cay surface; most have been washed off the cay into the narrow back-reef lagoon. There has been slight backcutting along the whole of the seaward shore, especially at the northeast end, where retreat has exposed a few patches of poorly cemented sand at sea level. Here the shore is vertical, and formed of coconut roots; elsewhere it is lower and masked by coarse coral rubble. Much of the fresh sand at the north point has also been eroded away, leaving only a submerged sand shoal. On the cay surface there are generally three zones visible: an outer zone, with exposed, combed coconut roots, devoid of vegetation except for battered but recognisable Cordia, and littered with fresh debris; an intermediate zone, retaining some pre-hurricane surface vegetation, including patches of the old turf cover, but much littered with coral debris and with some exposed roots; and an inner or leeward zone of thin rubble deposits, with patches of exposed roots. This rubble has in places slightly extended the leeward shore lagoonward. The Avicennia-Conocarpus thicket at the south end is much broken and now apparently dead. There has been some over-deepening of the floor between Cay V and Cockroach Cay.

Other Cays. The pattern of change on cays VII-XXVIII conforms to that described for Pelican Cay and Cay V. Leeward mangrove has been defoliated; windward bushes appear dead but remain in place, except close to the shore where they have been swept away by wave action or buried by a fresh shingle spread. Local and generally slight over-deepening has taken place between some of the cays. Some of the smaller islands (XI, XIX, XXV) have virtually disappeared.

Pelican Cay

Pelican Cay (not to be confused with Cay II, also so named, of the Cockroach Group) is a small island measuring 100 x 50 yards, situated 1¾ miles south of Northern Bogue (ARB 87, 44-45, Figure 23). In 1960 the whole land area was surrounded by a belt of Rhizophora, with a little Avicennia and Conocarpus; this rim was interrupted in only three places, two of them narrow boat-entrances lined with conch shells. The cay surface, then not more than 18 inches above the sea, was flat and featureless, built of grey sand, and planted to coconuts. In July 1961 the Rhizophora rim had been completely cleared from the northeast side. It was inhabited at this time by a Carib fisherman, and had two small huts; it is very similar in form and appearance to other Carib-inhabited cays of the barrier reef lagoon, such as Weewee Cay and (southern) Rendezvous Cay. During the hurricane the huts were destroyed, all the coconuts felled and the sand area stripped of surface vegetation. The peripheral mangrove was all defoliated and much broken, and had not regained its leaves by May 1962.

Soldier and Blackbird Cays

Soldier and Blackbird Cays are located at the easternmost point of the east reef of Turneffe (ARB 87, 43-44, Figures 21-23). Soldier Cay is the larger of the two; before the storm it was 145 yards long, with a maximum width of 55 yards. The seaward, southeast-facing shore, 110 yards long, was formed of grey interlocking shingle rising to a fairly constant crestline 5.5 feet above the sea. From the crestline, the cay surface, consisting of fine grey sand with coral fragments, sloped gradually towards the lagoon, where the leeward beach, of fine white sand, formed a distinct ridge, especially at the north end of the cay. The seaward shingle ridge itself continued round the north end of the cay, and finer shingle was found for about 20 yards along the northern end of the lee shore. Only at the southern extremity was there any undercutting; but here the low cliff cut in grey sand was fronted by a fresh sandspit, 20 yards wide, already being colonised by vegetation.

Most of the original vegetation had been removed for coconuts, with the exception of low, spray-swept bushes of Tournefortia gnaphalodes, Coccoloba uvifera and Suriana maritima along the seaward shingle ridge and at the north end. There were patches of Sesuvium and Euphorbia along the ridge front, but apart from sparse Sporobolus the cay surface under the coconuts was bare. The coconuts themselves were about 40 feet high. Numerous Rhizophora seedlings were growing in shallow water along the west and south shores of the cay.

These salient features of Soldier Cay can no longer be recognised. The seaward shingle ridge has been destroyed, and fine surface materials scoured from the old cay surface to a depth of up to 2 feet. The surface now consists of a flat, low-lying area of exposed coconut roots, with scattered fresh white coral blocks, generally less than 1 foot diameter. The margins of the old island, which can still be traced as a distinct but low undercut cliff line, demonstrated marginal erosion on all sides of 5-10 yards, greatest at the north and south ends. At the south end the old spit of fresh sand has been swept away, and a number of pillar-like remnants of the old cay now stand some yards from the present shore. Along the east and west shores there has been considerable accumulation of fresh shingle. Along the east shore this forms a low, rather ragged carpet, extending from the old shore across the shallow and drying reef-flat on which the island stands. The seaward shoreline shown on Figure 46 is to some extent an approximation, since the carpet is so low and broken that it is difficult to say where the shingle ends and the sea begins. None of the shingle is higher than the eroded old cay surface. The hurricane deposits along the west side are much more extensive, forming a zone 25 yards wide and 85 yards long. The shingle is thrown up into two ridges, convex westwards, enclosing a low-lying zone between the ridges and the old cay. The ridges themselves have an average elevation of 2 feet but rise to 3 feet in one place. This is now the highest part of the island.

All except four of the coconut trees have disappeared, together with all the Tournefortia, Suriana, Coccoloba, Sesuvium, Euphorbia, and grasses of the old seaward shore. A single withered-looking Coccoloba has survived. The rest of the vegetation in May 1962 was probably a post-hurricane growth. It consists of a very scattered and sparse cover of Sporobolus, Cyperus, Ageratum, and a few patches of Portulaca oleracea. The coconuts which remain do not appear very vigorous. There are now no Rhizophora seedlings round the cay. The pier and all houses have disappeared, except that some house posts can still be seen at the extreme south end of the cay, which enables one to accurately superimpose pre- and post-hurricane maps in Figure 46. Seven people died here during the hurricane. Soldier Cay is now a bleak and desert place, almost devoid of soil, and unlikely to be resettled in the near future.

Blackbird Cay was situated about 100 yards NNE of Soldier Cay: a small, crescentic island, 70 yards long, formed of sand and shingle with larger coral slabs on the seaward side. Along the seaward shore were a number of mature Rhizophora and Avicennia trees, and the main part of the cay was covered with Conocarpus bushes, with three solitary young coconuts. The Rhizophora and Avicennia remain, but are now leafless and apparently dead. The Conocarpus and coconuts have been swept away, and the cay now consists of a rugged accumulation of coarse shingle and sand rising only a few inches above sea level.

Between Soldier and Blackbird Cays a crescentic ridge of fresh shingle and rubble, 30 yards long, has been formed near the reef crest. It is sharply asymmetric, with coral blocks up to 12 inches long on its seaward side, and fine shingle and sand to leeward. More shingle breaks surface to form a ridge immediately north of the Soldier Cay Elbow, and extends for 30-50 yards. Neither of these accumulations existed before the hurricane.

Calabash Cays

Calabash Cays are a group of four islands immediately south of Calabash Entrance on the Turneffe east reefs. Two of the cays are large islands(Big and Little Calabash Cays) and were formerly the centre of the Turneffe coconut industry (see ARB 87, 41-42, Figure 19-20).

Little Calabash Cay

Little Calabash Cay is the most southerly in the group. Before Hurricane Hattie it was regular in shape, with maximum dimensions of 95 x 60 yards. Along the seaward side a ridge of sand rose to a height of 2½ feet above the sea; apart from this the surface was low, flat and featureless. There was a little undercutting along the northeast shore; but erosion on the south side had been retarded by the building of a pile-wall backed by conch shells. Conch shells were strewn along much of the cay beaches, and at the north end there was a 15-yard long peninsula of coconut husks. The island overlooked a reef flat, covered with Thalassia, and carrying only 6-8 inches of water. Immediately to leeward, however, the water deepened rapidly to give anchorage in 7-8 feet of water close inshore. Little Calabash Cay was the main clearing house for the Turneffe coconut trade. There was a long pier and warehouse, a small commissary, and dwelling houses. Coconut boats made regular runs into Belize, and the cay had its own wireless transmitting and receiving station. Natural vegetation had been almost entirely cleared for coconuts, except for a sparse ground cover of grasses and Ageratum.

The hurricane made great changes at this cay. The conch-shell ramparts and the southern palisades proved quite inadequate as a protection against hurricane waves, and along the northeast, east and southeast sides the shore retreated between 10 and 30 yards. The line of the much broken palisades can be traced some yards offshore (Figure 47); between the palisades and the cay the water is 1-2 feet deep. Scour holes along the old shoreline on the southeast side are 4-5 feet deep. Concrete blocks and wooden houseposts in shallow water indicate the former sites of houses. The cay surface has been much eroded; along the east side coconut roots are exposed and the shore is cliffed. Over the rest of the area, in spite of vertical erosion of about 1 foot, few roots are to be seen, but the whole area is now ill-drained, with a number of stagnant pools of water. A low fresh sand ridge 5-8 yards wide has been thrown up along the southwest shore. The considerable erosion on the east side is balanced by deposition on the west. Here the jetty formerly stood in 7-8 feet of water for most of its length. Now the only sections to survive are terminal posts at each end: nearly the whole of the area between these posts is occupied by a peninsula of fresh sand, 25 yards long, and 40 yards wide across its base. The average thickness of this wedge of sand must be 5-6 feet. Immediately offshore the bottom falls away very steeply, so that within 3 feet of the shore depths of 1 fathom and probably nearly 2 fathoms are found. The outer slope of the sand peninsula must be comparable in steepness to outer slopes of fresh sand accumulations on land. Because of weather conditions it was not possible to investigate the reef conditions to seaward of the cay, but much of the Thalassia flat had been buried by fresh medium shingle.

All houses and other installations have been destroyed. In May 1962 the only signs of habitation were house foundations, a solitary typewriter rusting on the sand, and quantities of lead from radio batteries. As an illustration of the extraordinary power of hurricane waves, the radio transmitter itself, measuring roughly 1 x 2 x 3 feet, a heavy object, was subsequently found near Harry Jones Point, having been transported approximately 3000 yards across water everywhere more than 1 fathom deep, and then lodged on a sandy surface, surrounded by vegetation 3 feet above the sea. The coconut trees have been completely destroyed. At the time of the re-survey there was a very sparse ground cover of Ageratum, Wedelia, Cakile and grasses.

Big Calabash Cay

Big Calabash Cay lies some 300 yards northeast of Little Calabash Cay with which it is connected by a very shallow sandy reef-flat. The cay is aligned NNE-SSW, parallel to the reef, and is about 170 yards long (ARB 87, 42, Figure 20). Before the storm its width varied from 35 to 55 yards, and it was uniformly low and sandy. The maximum elevations were on the east side, where a sand ridge rose to 2-3 feet above sea level. There was no shingle on the island, but in several places the shore was marked by banks of conch shells. A spit of fresh sand extended 20 yards southwards from the main island. The whole cay was planted to coconuts, which formed a ragged canopy only 20-30 feet high. Apart from these, the ground surface was covered with grasses, both low, forming a turf, and taller, in scattered clumps. Rhizophora seedlings were numerous close inshore, with taller Avicennia near the north end. There were several houses on the island, one of them very substantial. The leeward bay gave anchorage in 4-5 feet, though some distance offshore, as the floor sloped gradually.

Damage during the hurricane was severe, but less so than at Little Calabash Cay. The whole of the seaward shore retreated from 2 to 12 yards, leaving a ragged undercut shoreline of tangled coconut roots. The leeward shore also retreated from 5 to 10 yards, chiefly through scouring by waves flowing over the cay and forming plunge holes on the lee side; these holes average 5-6 feet deep. The lee shore erosion has not left such an undercut and ragged shoreline as on the seaward side, except at the southwest end, and also where longer scour channels have been cut at the northeast and southwest extremities. That at the southwest end cuts across the base of the former sandspit, a fragment of which survives on its south side; this channel is less than 1 fathom in depth. That at the northeast end extends along the whole of that side of the cay, and is initiated in a scour hole more than 3 fathoms deep, with vertical and in places overhanging sides within a few feet of the shore. Smaller scour holes have been cut in the cay surface, particularly near the north end, where one contains a few inches of stagnant water. One of the old conch shell peninsulas has survived the storm, but its position has shifted slightly and it is now an island.

Nearly all the coconut trees have disappeared; 5 are still standing, and a few fallen trunks near the north end show a fairly constant orientation of 320-330°. Over much of the surface, especially towards the lee side, however, the original ground vegetation has survived, and it is possible to recognise the position of old tracks through the turf cover between houses which have now disappeared. All the Rhizophora seedlings have been swept away.

East Cays One and Two

East and north of Big Calabash are two smaller islands. East Cay One was formerly separated from Big Calabash by a shallow channel only 14 yards wide, carrying up to 12 inches water, with many Rhizophora seedlings. The cay itself was small and round, 40-50 yards in diameter, with much coarse and blackened coral rubble along its east shore. Most of the island was flat and sandy and did not rise more than 3 feet above sea level. In 1960-61 the vegetation consisted of a dense bushy growth of Suriana maritima and Conocarpus erectus, with several low Rhizophora and taller Avicennia trees around its margin. There were two distinct clumps of coconuts, totalling less than a dozen trees, near the centre of the cay. During the hurricane shorelines retreated 5-10 yards round almost the entire margin of the cay; surface sand was removed, and the surface littered with fine-medium coral debris. It seems likely that some of the vegetation had been removed before the storm to build houses, since there were a number of new concrete house foundations near the cay centre in 1962. However almost all the pre-hurricane vegetation has been destroyed: a single coconut still stands, with two Avicennia trees and a small bush of Borrichia arborescens; the former dense growth of Conocarpus and Suriana has disappeared, except for a tangle of dead bushes. Much rubble is scattered along the seaward shore, and a shallow scour channel heads between this cay and Big Calabash.

Big Calabash East Two has suffered even more severely. It was located about 90 yards north of East One, and consisted of a narrow strip of land, 50 yards long and generally less than 10 yards wide, with some shingle at its east end. Most of the cay was low and sandy and did not rise more than 18 inches above the sea. It was prolonged westward by a fresh sandspit. Before the storm the vegetation consisted of a peripheral belt of Avicennia and Rhizophora, a central thicket of Suriana maritima and coarse grasses, and two or three low young coconuts. The island has been almost entirely destroyed: the peripheral mangrove still remain in position of growth, though defoliated and apparently dead, but the area enclosed by them, formerly the cay proper, is now covered with 2-3 feet of water, and of the Suriana tnicket there is no trace. Outside the mangrove the reef flat has an average depth of 1 foot. Towards the west end of the former cay, moreover, erosion has cut a definite scour channel, heading in a scour hole at least 6 feet deep, some 15 yards from the old windward shore, and extending with decreasing depth across the reef flat to leeward. This curious concentration of erosion on what was formerly one of the highest parts of the reef flat is of interest.

The Deadman Group

The Deadman Cays consist of five small islands on the eastern reef flat, four miles from the southern end of Turneffe (ARB 87, 37-40). The cays are numbered for convenience from south to north.

Deadman I

Before the hurricane Deadman I was 110 yards long and varied in width from 20 to 32 yards. The island is aligned transverse to the reef, immediately north of a large reef gap; it was everywhere low, but rose at its eastern end to not more than 3 feet above sea level. The eastern end consisted of small, rather blackened shingle; westward the proportion of shingle decreased, until at the west end it was composed entirely of fine sand, prolonged by a submerged sandspit for a further 10-20 yards lagoonward. Along the south shore cemented sands were exposed for nearly 10 yards; the soft and poorly indurated rock was horizontal and passed under the beach sand; the exposure was only a few inches wide and 3-6 inches above sea level. There were many Rhizophora seedlings along the west, southeast and north shores of the cay. The whole island was covered with coconuts about 30 feet tall, with a ground cover of Sesuvium, Euphorbia, Hymenocallis and grasses. At the low western end, the fresh sandspit was being colonised by Sesuvium and a couple of Tournefortia bushes. There was a single mature Avicennia at the eastern end.

Severe erosion occurred during the hurricane along the whole of the south shore (Figure 49). The large Avicennia at the east end stood, and enables one to accurately locate the two cays before and after the storm. Deposition occurred along the whole of the northern shore; hence the general effect is one of a northward movement of the cay. Surface sand has been stripped from the whole area, exposing combed coconut roots, littered with fresh debris. The greater part of the south shore is now formed by a vertical step of coconut roots from which most of the sediment has been flushed. The previously noted area of cemented sand is now exposed for a total of 75 yards round the cay shore, with a total width of 2½ yards. The upper surface is horizontal but pitted and irregular in detail, and lies a little above high tide level. The cementation is irregular but generally weak; however, if better cemented the feature would closely resemble the wide conglomerate platform described at Half Moon Cay, Lighthouse Reef (ARB 87, 69-72) and the "promenades" found by Steers at Morant Cays, Jamaica (1940a, 1940b). There is no doubt that the Deadman I promenade has been formed at its present level under the old cay surface and is not an uplifted beachrock: the state of cementation, inclusion of coconut roots, and comparison of exposures before and after the hurricane all demonstrate that it is a contemporary feature, simply exposed by erosion.

Rubble is strewn over the eroded cay surface, and blankets it completely along the north side; the maximum height towards the east end is 3 feet above sea level. The coconut cover has been destroyed, though ten damaged trees remain standing. Most of the trunks have disappeared, but a few remain, oriented 355-020°, indicating southerly winds and waves. The former fresh sand spit at the western end has disappeared, but may be beginning to reform. Little vegetation survives from before the storm: a few lilies (Hymenocallis littoralis) protrude through the shingle at the east end, and there are one or two Borrichia bushes near the centre. The Sesuvium patch at the west end survives in smaller form. Otherwise the island is unvegetated apart from very sparse Euphorbia, Ageratum and Cyperus.

Deadman II

Deadman II (Figure 50) lies 150 yards north of Deadman I; before the storm it was roughly circular, with N-S and E-W diameters of 80 yards. The seaward shore was composed of fine shingle rising to a crest 2-3 feet above sea level, from which the surface declined eastwards to the wide and sandy leeward shore. The leeward shore itself faced a shallow sandy bay with numerous Rhizophora seedlings. There was no mature mangrove on the cay apart from one or two tall Avicennia and Laguncularia racemosa on the leeward shore. The cay was planted to coconuts, but the undergrowth was not cleared. The upper beach was covered with Sesuvium and Euphorbia, with Sporobolus and other grasses on the leeward side, passing inland under a dense thicket of Conocarpus, Suriana and Borrichia. Tournefortia gnaphalodes was seen at one point on the northwest shore.

The cay suffered erosion on all sides during the hurricane, but especially on the east side, which retreated an average of 12 yards. Along most of this side a low-lying platform of soft promenade rock was exposed, with horizontal but pitted upper surface, containing coconut roots passing landward beneath a steeply undercut cay margin, also of coconut roots. One or two coconut boles, detached from the cay, are still standing near the east point. The composition of the promenade rock is variable: in the south it includes shingle, northwards it becomes almost clayey. Above the undercut eastern cliffline there is a narrow zone of stripped roots, followed inland by a blanket of fresh shingle piled against dead bushes and trees. The shingle has a maximum width of 25 yards and rises 2 feet above sea level. Its inner edge is arcuate and steep; the rest of the island is covered with dead bushes, with a little living Borrichia arborescens, Ageratum littorale, Sesuvium portulacastrum, Iresine diffusa, Cakile lanceolata, and Sporobolus. All the coconuts except eight have fallen, with directions indicating southerly winds and waves. All the peripheral Rhizophora is dead, and the Avicennia and Laguncularia have disappeared. Much rubble has been scattered over the nearshore area on the east side of the cay.

Deadman III

Deadman III (ARB 87, 38-39, Figure 18) was a small island 50 yards long and 35 yards wide before the hurricane. It was covered with a thicket of Conocarpus, Laguncularia, Avicennia and Tournefortia, with a few coconuts, and an undercover of Sesuvium, Ipomoea and Sporobolus. The coconuts have fallen and the bushes are all defoliated, but otherwise the changes at Deadman III have been minor. Fallen trees are oriented 320°, indicating winds and waves east of south. The formerly sandy surface is now covered with shingle.

Deadman IV

Deadman IV (ARB 87, 39) is the largest island in the group, and lies about 200 yards north of Deadman II. Before the hurricane it was oval-shaped, with maximum dimensions of 125 yards N-S and 95 yards E-W. The eastern shore was formed of low-lying rubble rather than shingle, and the island surface was generally sandy, especially towards the west side. The western bay was very shallow with many Rhizophora seedlings and mature Avicennia along the shore. On the island the vegetation cover was dense and difficult to penetrate. Much of the seaward shore was lined with a hedge of Tournefortia, backed by Coccoloba thicket; elsewhere the upper beaches were covered with Sesuvium, Euphorbia, Sporobolus and other grasses. The centre of the cay was covered with a palm thicket, with coconuts and Thrinax.

Erosion was severe during Hurricane Hattie on all sides of the island except the north (Figure 51). The amount of retreat is shown, for example, by the now nearshore remnants of the Coccoloba thicket on the southeast side. All the vegetation on the windward side - Tournefortia hedge, Euphorbia, Sesuvium - has been destroyed, and the eastern half of the cay is blanketed by fresh shingle up to 30 yards wide. The inner edge of this carpet reaches 3-4 feet above sea level. On the seaward side the old cay surface can only be seen at the southeast corner, where it forms an undercut cliff, mostly consisting of coconut roots, irregular in plan, with a single small area of cemented sand at its base. The western half of the cay is almost unrecognisable, both in plan and in vegetation. It appears to have been inundated and subjected to surface erosion; most of the vegetation has been killed and leaves and branches stripped, but much remains in the position of growth. Eleven coconuts are still standing with a number of Thrinax palms, and there is a fairly luxuriant ground cover of Ageratum, Euphorbia, grasses, and patches of Sesuvium. There is now only a handful of Rhizophora seedlings. The mature Avicennia and Laguncularia has disappeared. The great change in outline of the leeward shore may seem surprising, but it was previously very low-lying, and only a little sand re-distribution would be necessary to shift the shoreline considerable distances landward or seaward.

Deadman V

Four hundred yards north of Deadman IV lies the last of the Deadman Cays: Deadman V (ARB 87, 39-40). In 1960 it was a low-lying sandy island some 50 yards long, with a large area of Rhizophora to leeward. The cay was devoted to coconuts, with a very sparse undercover of Sesuvium, Cyperus and Sporobolus. There was some dead mangrove and small Rhizophora seedlings along the south shore, and a gnarled old Avicennia at the eastern point.

During Hurricane Hattie the dry land area suffered erosion on all shores with the formation of irregular undercut cliffs (Figure 52). Surface sand was stripped over about half of the area, with exposure and combing of coconut roots. The stump of the old Avicennia still stands at the east point. Roots are combed from south to north, and along the north shore there is one major inlet, presumably cut back by water pouring across the cay surface. Most of the coconut trees have disappeared; a few trunks on the cay surface are oriented 320-350°, indicating winds a little east of south. Between the exposed root zone and the much defoliated mangrove is an area of sparse Sporobolus and Euphorbia.

Cay Bokel

Cay Bokel before the hurricane was the southernmost cay of the Turneffe Islands (ARB 87, 35-37). It was triangular in shape with sides about 35 yards long, and was low and sandy. No part of the cay rose more than 2 feet above sea level. A single line of beachrock 55 yards southwest of the island indicated retreat toward the northeast. There was a semi-automatic lighthouse on the cay, built in 1944, and a large house. The lighthouse overlooked the foundations of a second light 7-12 yards offshore in water 1-2 feet deep, said to have been destroyed in the 1931 hurricane. A concrete seawall between this wreckage and the shore was also much broken and awash. Northwest of the standing lighthouse was the concrete base of yet a third, tilted and only partly exposed, said to have been destroyed in the 1945 hurricane. The cay was almost devoid of vegetation except for coconut palms: there was a patchy cover of Ambrosia hispida, and a few lilies, Hymenocallis littoralis. Before the hurricane there were some Rhizophora seedlings, but no mature mangrove.

During Hurricane Hattie the island disappeared, with the loss of six lives (Figure 53). The area of the cay is now covered with 4-5 feet of water, with 6-9 feet in places near the lighthouse. The light itself has fallen on its side, oriented 045°. The 1945 Lighthouse base has been completed exposed, with a large living Diploria adjacent to it. Across the middle of the old cay area there is a shingle shoal carrying only a foot of water, and shingle has also accumulated over a wide zone to south and southwest of the cay, without breaking surface. The jetty has disappeared, and all that remains of the vegetation cover is a single submerged coconut trunk. There is at present no sign of accumulation of sand to form a sandbore at this point; it seems unlikely, after so many losses due to hurricanes, that the present light will be re-erected here, and more probable that it will be transferred to the Turneffe "mainland" at Big Cay Bokel.

The Eastern Sand Ridge

The windward side of the eastern mangrove rim of Turneffe Islands is fringed for much of its length by a low, coconut-covered sand ridge. This extends from near Northern Bogue to Harry Jones Point, a distance of about 8½ miles, though it is here generally separated from the eastern reef flat by a strip of Rhizophora. It extends discontinuously along the embayed east shore between Calabash Entrance and Grand Bogue; and again forms a long unbroken ridge on the south side of Grand Bogue, as far as Rope Walk. Its southernmost extent is found along the southeast-facing shore of Big Cay Bokel. For distribution details, see ARB 87, Figure 14. It is almost wholly sand, generally 3-4 ft in height near its seaward shore, and declines in height westwards to pass beneath the lagoon-fringing mangroves. It is wholly planted to coconuts, with an undercover of Hymenocallis, grasses, and prostrate plants, with intermittent patches of Tournefortia, Suriana and Coccoloba. The ridge is clearly similar in origin to the sand ridges along the windward sides of such barrier reef islands as Ambergris Cay and Cays Caulker and Chapel; but the fact that mangrove is often found to windward of it suggests that it may not now be an actively growing feature.

Lithified sands extending well above high water level have been described from the sand ridge at Harry Jones Point, Calabash Entrance (Dixon, 1956) and ascribed to a recent negative sea-level shift (Vermeer, 1959). The Harry Jones exposure was considered in some detail in ARB 87, 47-49, when it was concluded that because of its variation in height the rock could not be ascribed to eustatic movements, but may indicate tilting. After the hurricane, the whole eastern sand ridge was inspected from the air, and visited at a number of places. Several fresh outcrops of comparable lithified sands were found, which throw doubt on the interpretation of the Harry Jones rock as a true intertidal beachrock; and it now seems that these highstanding lithified sands can be explained without reference to any kind of eustatic or tectonic movements.

Fresh lithified sands were particularly noted at Big Cay Bokel, Grand Bogue Point, and Harry Jones Point.

Big Cay Bokel

Big Cay Bokel is a large mangrove island, some 900 yards north of Cay Bokel, forming the southernmost sector of the Turneffe mangrove rim. It is roughly triangular, with maximum N-S dimensions of 1 mile, and E-W width of two-thirds of a mile. The whole island consists of mangrove, except for a narrow strip facing the southeast reefs, and a small area at its north point, both of which consist of coconut-covered sand ridge. The southeast ridge is the longest, extending for about 1100 yards: for most of its length it is oriented N070°E. The ridge approaches closest to the eastern reef at its northeastern extremity, and diverges southwestwards, becoming lower, and eventually being separated from the reef flat by a narrow mangrove rim.

The south and southwest shores of Big Cay Bokel consisting wholly of mangrove, were devastated by the hurricane, and the Rhizophora is now leafless and apparently dead. On the lowlying sandy area, immediately in the lee of the mangrove fringe, many coconuts have fallen, oriented 020-030°. Along the sand ridge proper orientation of fallen coconuts varies from 300 to 030°, with most 360-010°, indicating southerly winds. Between half and three-quarters of the coconuts have been felled; of those still standing, most have lost their crowns. The ground vegetation has not been destroyed, except close to the shore, where fresh sand has been deposited over a zone 15-30 yards wide. This suggests that damage resulted from storm waves only, and that the storm surge was insignificant here. Ground vegetation consists mainly of grasses and Euphorbia, with unidentified bushes. Broken coconut stumps and exposed roots along the shoreline indicate an unknown, but probably small, amount of shore retreat.

The ridge reaches its highest point, 2½-3 feet, at its northeast end. Here surface vegetation has been completely stripped from the near shore area, leaving only matted coconut roots and a few broken stumps. At this point, too, sand and fines have been flushed away, leaving only shingle. This point is closest to the east reefs, and thus most exposed to both constructive and destructive waves. Lithified sands are exposed for 25-30 yards near the point, and intermittently on the beach to the south and to the west. The sands form a ledge varying in width from a few inches to three yards, standing up to 2 feet above sea level. The upper surface is horizontal, and the rock is undercut at sea level on its seaward side. It is directly overlain by 12-20 inches of dense coconut roots at the point, with shells and shingle; and elsewhere by a gentle sand slope. The lack of surface hardening and erosion indicate that the rock was not exposed before the hurricane. Roots in the root zone can be followed directly into the underlying rock; and the whole horizontal surface of the lithified sands is marked by innumerable short segments of coconut roots, 2-3 inches long, protruding above the level surface.

This rock has clearly been formed beneath the old cay surface at its present elevation, and owes nothing to relative movements of land and sea. It is a cay sandstone (Kuenen, 1933, 86-88; Seymour Sewell, 1935, 502ff.) formed beneath the root mat, presumably at the water table, and exposed by the storm; it is quite probably being formed elsewhere beneath the surface of the Big Cay Bokel sand ridge at the present day. If case-hardened and weathered it would be indistinguishable from the Harry Jones lithified sands.

Grand Bogue Point

The sand ridge also outcrops at the shore, and was visited, immediately south of Grand Bogue, at Grand Bogue Point; it extends southwards from this point for about 3 miles to Rope Walk, but only the northern 600 yards could be investigated (Figure 54). Mangrove fringes each side of the Bogue proper, and the sand ridge only appears at its mouth. In its first 100 yards it rises from 2 to 4 feet above sea level, reaching 4½ feet at its easternmost point, and then falls gradually southwards as the shore curves away into a large bay. The ridge is covered with coconuts, with a fairly dense ground cover of grasses and shrubs. The shore has evidently suffered some retreat during Hurricane Hattie. At the Point itself the shore is steeply undercut for about 170 yards, forming a steep cliff up to 4 feet high, capped with coconut roots, overlooking a very narrow beach and patchily overdeepened water. South of the Point, where the ridge itself is lower, the undercutting is less apparent, but cemented sand is exposed slightly above sea level, the longest continuous exposure stretching for 100 yards. The exposure is intermediate in appearance between that at Big Cay Bokel, and at Deadman I and II; it is lower, but otherwise similar, to that at Harry Jones. It is at present rather poorly cemented and sandy throughout; in places near its southern extent it is almost claylike in texture, though generally harder. The upper surface is horizontal, though irregular, averages 9-12 inches above low water level, and its widest extent is 4 feet. It does not show the usual features of intertidal beachrock, such as seaward dip, and is probably better referred to as a promenade of cay sandstone, without necessarily implying any different origin.

A further point of interest is the occurrence, at the point itself, where the ridge reaches its highest point, of abundant Maya potsherds, in the upper few inches of the soil, entangled with coconut roots, and also scattered on the surface and on the narrow beach below the undercut cliff. The soil here is very black, and this very restricted area is much overgrown with the bush Leucaena leucocephala, by no means common on the cays. The pottery deposits, like the shore, formerly extended further seaward, and fragments are now found for some distance along the beach. All the material found was fragmentary earthenware, with the exception of a single obsidian blade. The crudeness of the pottery, paucity of obsidian, absence of constructional features, whole pots and jade, all contrast with remains on some of the islands of the southern barrier reef lagoon, to be described in a subsequent paper. Pottery from Grand Bogue Point is described by Mr. E.W. MacKie, Hunterian Museum, Glasgow University, who is familiar with mainland British Honduran pottery sequences, in Appendix 2.

Un-named Point

Air reconnaissance showed the existence of further "promenades" of slightly elevated rock similar to that at Big Cay Bokel and Grand Bogue Point, at a conspicuous point on the eastern sand rim 1 mile south of Calabash Cays. Unfortunately there was not time to visit this somewhat inaccessible location.

Harry Jones Point

Harry Jones (ARB 87, 47-49, Figure 26) was revisited after the storm; apart from very heavy destruction of coconut trees, the changes were relatively small. Direction of tree fall varies from 230-018°, the mean being about 300°, indicating southeasterly winds. Nearshore Coccoloba has also disappeared; much of the previously exposed "beachrock" has been destroyed; and at the point itself, retreat of the sand ridge has exposed fresh cemented material. Immediately north of the point, there are now two exposures of fresh rock, with horizontal upper surfaces standing 4½ feet above sea level. The rock is still fairly soft, and the matrix contains coconut roots. At the inner edge, where the rock is covered by the sand ridge, these roots can be traced directly into the overlying root mat. This demonstrates quite conclusively that the rock is forming at its present altitude at the present time, and that it is not an upraised beachrock exposed by negative movement of sea level or by warping of the Turneffe bank. As the fresh rock is followed southwards, its altitude declines, as before the hurricane, but its characteristics remain the same. At one point the rock was broken and found to contain a few fragments of Maya pottery, presumably of fairly recent age in geological terms; this too makes it unlikely that the rock dates from a high stand of the sea several thousand years ago. No other traces of Maya occupation could be found at Harry Jones, though the site is marked by Romney and others, 1959, Figure 10; it has probably been largely destroyed by shore retreat. The pottery was found exactly 200 yards south of the easternmost point, measured along the shore.

These new exposures show beyond doubt that the rock is an exposed cay sandstone, not a beachrock; hypotheses of eustatism or warping are therefore unnecessary. It is presumably a water table or percolation phenomenon similar to that described by Russell (1962); the decreasing height of the rock southwards simply reflects a lowering of the water table with a decrease in the height of the sandridge crest.

The beach was examined for 1½ miles in the Harry Jones area without further features of interest being discovered. The previous steep shore has been flattened, and coconut roots exposed; inland from this erosion zone is a zone of deposition, especially on the east shore north of Harry Jones Point. Many coconuts have lost their crowns in this area. South of the point, into Calabash Entrance, the vegetation was previously denser, with fewer coconuts, and has survived better, in spite of its transverse alignment to major hurricane winds. Cordia was in flower here along the top of the beach in 1962. It was in this section that the Little Calabash Cay radio was found.

Turneffe Lagoon Mangroves

No systematic observations were made on the Turneffe lagoons and mangrove rims, and the following notes summarise miscellaneous points, some of considerable interest, noted during journeys through the lagoons and on aerial traverses. First, the supposed absence of reef-building corals from the interior lagoons must be corrected (ARB 87, 33). A small reef was discovered somewhat unexpectedly late one evening in Southern Lagoon; it lies approximately 1½ miles due west of Small Fishing Bogue, and about 2¾ miles northeast of Shag Cay Bluff. The reef rose to within 2 feet of the surface from water more than 2 fathoms deep and consisted of Montastrea annularis, Siderastrea siderea, Porites astreoides and Millepora. Similar reefs are said to exist near Crickozeen, in the northern part of Southern Lagoon.

As in the barrier reef lagoon, the extent of mangrove defoliation and recovery provides some information on direction and strength of winds and waves. Thus defoliation has been most intense along the eastern rim, though even here small bushes of Rhizophora were bearing leaves on the western side early in 1962. Most of the small lagoon cays, as in Crayfish Range, are completely leafless. The western rim is less severely affected, though defoliation is total on its eastern or lagoonward side. As a result of defoliation and even disappearance of small mangrove areas on this western side of the lagoon, there is now great difficulty in finding the lagoon entrance to creeks giving passage to the sea. In the creeks themselves, especially between Blue Creek and Grand Bogue Creek, defoliation was noticeably greatest and recovery least on the north side of each channel. The general impression, therefore, over the southern half of Turneffe, is one of southerly winds and waves. In the centre of the mangrove rims, defoliation has been less intense. Many trees have been blown down and one's impression is of devastation, but leaves are still growing. Presumably these areas escaped the inundation and intensive wave action which seem to have been responsible for the worst defoliation. Tree fall in the mangrove areas was worst in the area separating Northern and Southern Lagoons, over which the centre of the hurricane passed: trees have fallen in all directions and it is quite impossible to make out any dominant direction from the air.

It is clear that great quantities of water must have passed through the eastern bogues of the Turneffe lagoons under the influence of the storm surge and hurricane winds. This accumulation could only escape through the narrow, often winding western creeks. All of these have been overdeepened by scouring, but to an unknown amount. The overdeepened section of the creek is generally quite narrow with very steep and in places overhanging sides; the overdeepened channel itself meanders within the creek, and variations in depth are abrupt. At the western exits of the creeks there are now wide spreads of fresh sand, forming submerged deltas, together with scattered dead trees and bushes dumped by flood waters in shoal areas. The western rim itself was completely breached at one point a little less than 1 mile south of the exit of Grand Bogue Creek. The narrow, shallow western exits of Northern Lagoon were also widened and deepened, and small sand deltas were deposited on the west sides of all three gaps.

Crickozeen Creek Slumping

Finally, persistent rumours of an "earthquake" at Turneffe, coinciding with the hurricane, led me to visit the west side of the mangrove rim, immediately north of the outlet of Crickozeen Creek. Here, between the edge of the Turneffe bank and the mangrove rim, the floor is composed of fine, compact calcareous silt and sand, bound together with Thalassia. Two or three feet from the mangrove shore for a length of several hundred yards, there is a wide crack in the floor, here under only a few inches of water. The dislocation, up to several yards wide, has vertical sides and wherever tested was more than 3½ fathoms deep. It is arcuate in plan, and there are subsidiary smaller cracks both to the south and to seaward of the main crack. A short distance out into the bay the floor has been thrust up to form an area of shoal sand banks and emerged sand bores; the highest of these reaches 1½ feet above sea level, and they generally present a steep face towards the mangrove rim and a gentle slope to seaward. The general pattern of these features can be seen from Figure 55, drawn from an oblique air photograph. The best explanation seems to be that rotational slumping has occurred in these fairly cohesive sediments, presumably under the stress of extreme wave conditions in the partially enclosed bay to the north of Crickozeen Creek. I was unfortunately unable to investigate this area in any detail or to carry out a network of soundings; this feature seems to be unusual during hurricanes, and so far as I could ascertain, unique in the British Honduras area after Hurricane Hattie.

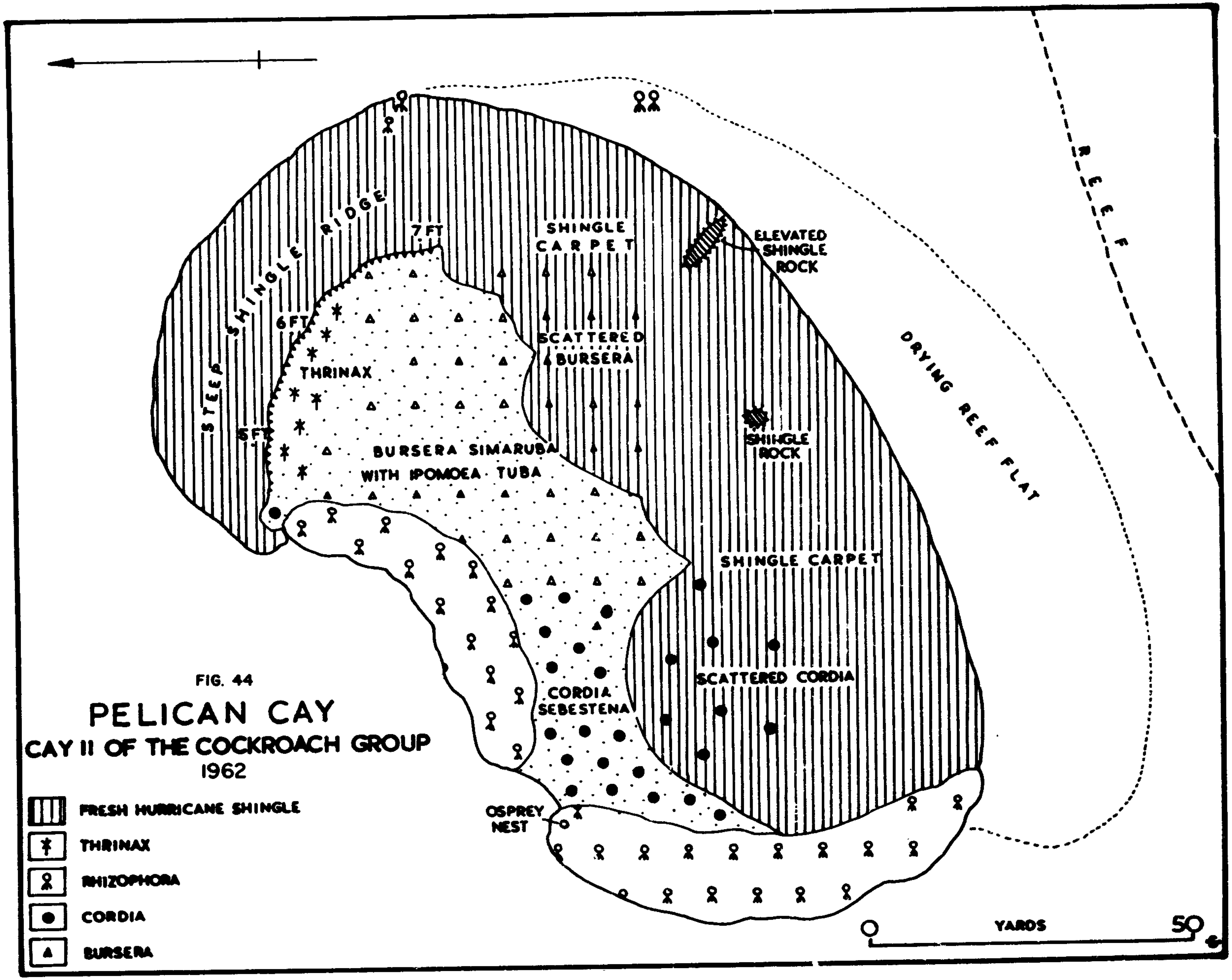
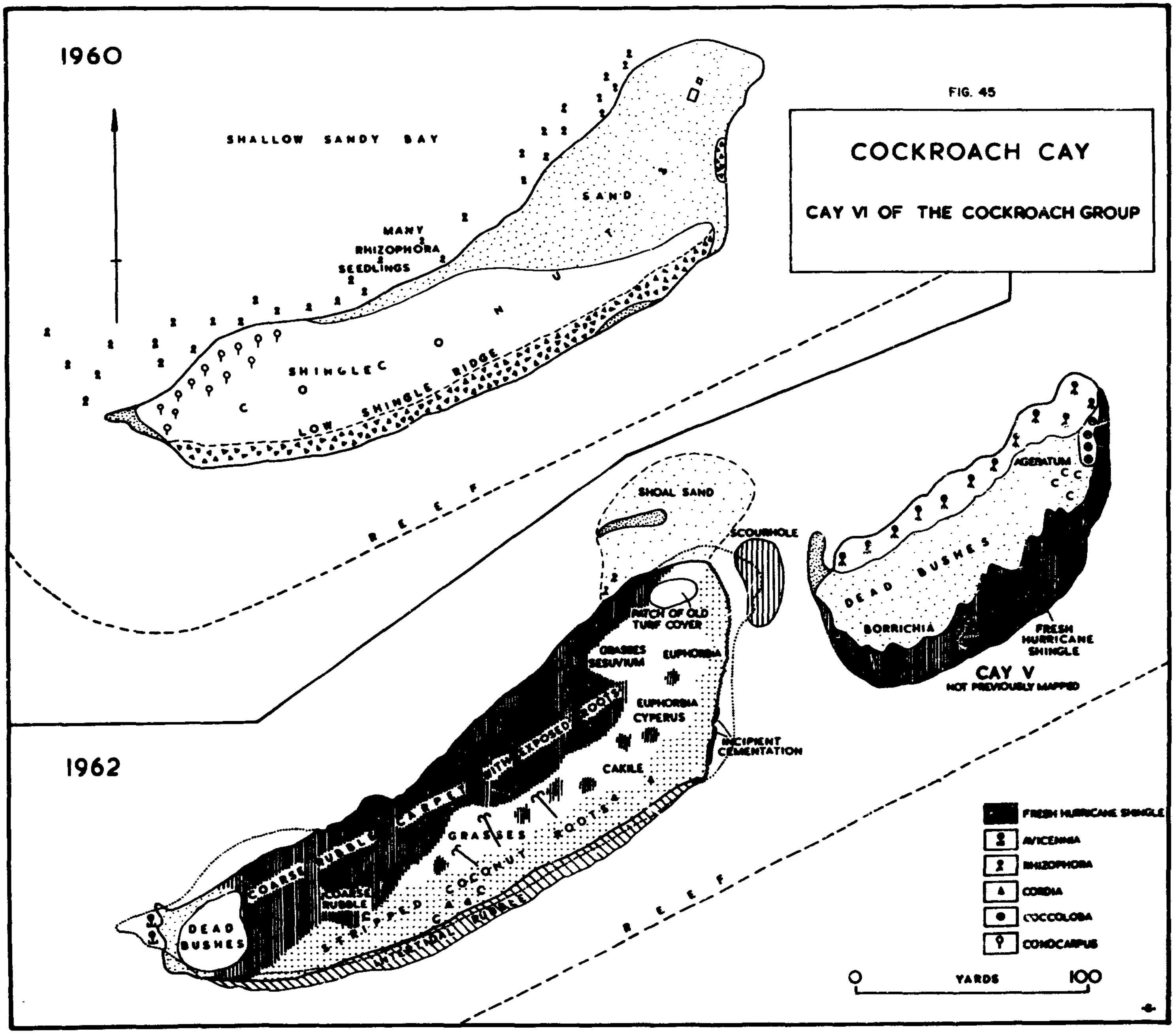


FIG. 44

PELICAN CAY
CAY II OF THE COCKROACH GROUP
1962

FIG. 45


COCKROACH CAY
CAY VI OF THE COCKROACH GROUP
1960
SHALLOW SANDY BAY
SAND
MANY RHIZOPHORA SEEDLINGS
SHINGLE
LOW SHINGLE RIDGE
REEF
1962
SHOAL SAND
SCOURHOLE
PATCH OF OLD TURF COVER
GRASSES SESUVIUM
EUPHORBIA
EUPHORBIA CYPERUS
INCIPIENT CEMENTATION
CAKILE
WITH EXPOSED ROOTS
COARSE RUBBLE CARPET
COARSE RUBBLE
GRASSES
COCONUT ROOTS
DEAD BUSHES
STRIPPED
REEF
AGERATUM
DEAD BUSHES
BORRICHIA
FRESH HURRICANE SHINGLE
CAY V
NOT PREVIOUSLY MAPPED
FRESH HURRICANE SHINGLE
AVICENNIA
RHIZOPHORA
CORDIA
COCCOLOBA
CONOCARPUS
0
YARDS
100

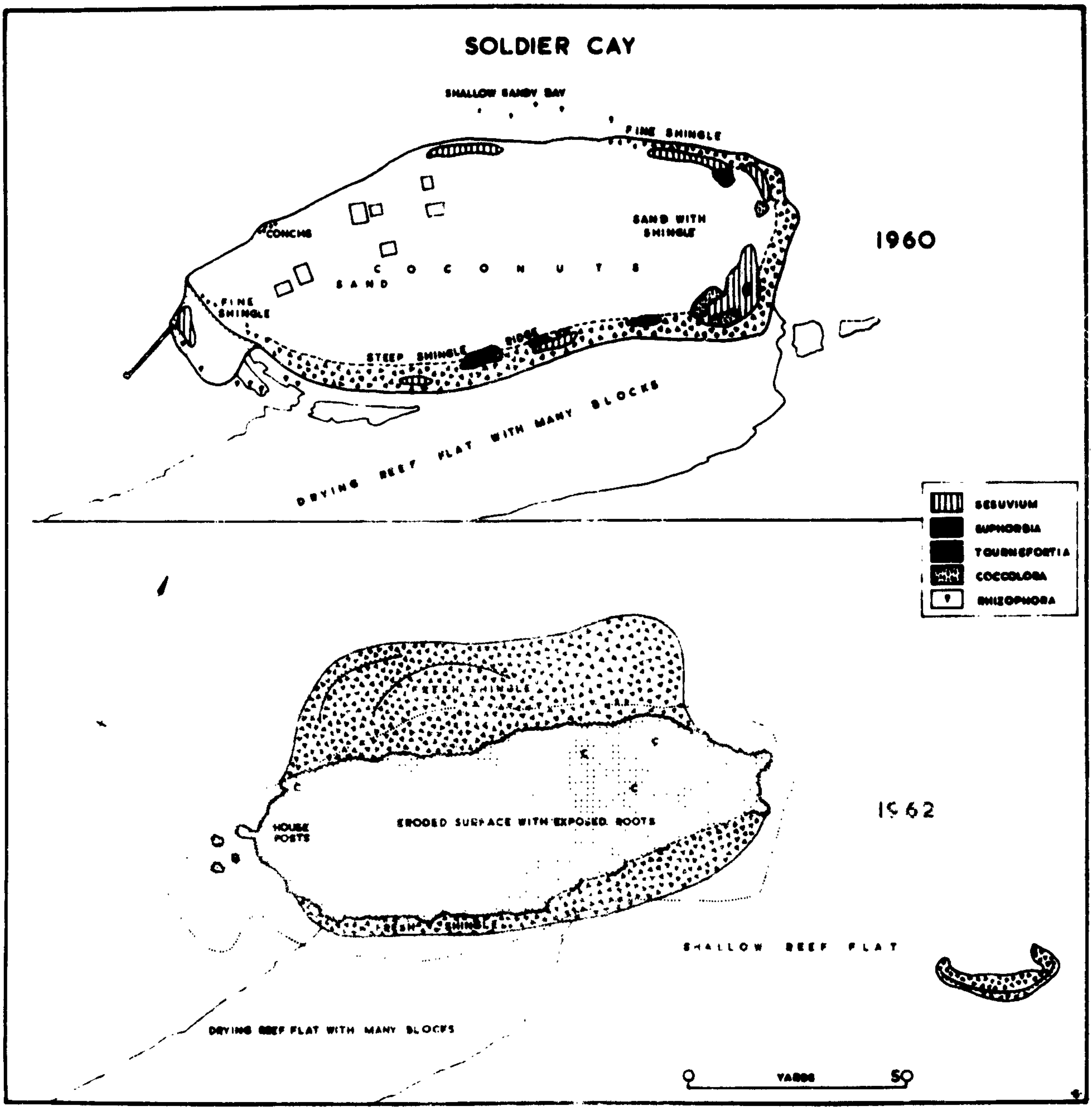

SOLDIER CAY
SHALLOW SANDY BAY
FINE SHINGLE
SAND WITH SHINGLE
CONCHS
C O C O N U T S
SAND
FINE SHINGLE
STEEP SHINGLE
RIDGE
DRYING REEF FLAT WITH MANY BLOCKS
1960
SESUVIUM
EUPHORBIA
TOURNEFORTIA
COCCOLOBA
RHIZOPHORA
FRESH SHINGLE
HOUSE POSTS
ERODED SURFACE WITH EXPOSED ROOTS
1962
SHALLOW REEF FLAT
DRYING REEF FLAT WITH MANY BLOCKS
0
YARDS
50

FIG. 46

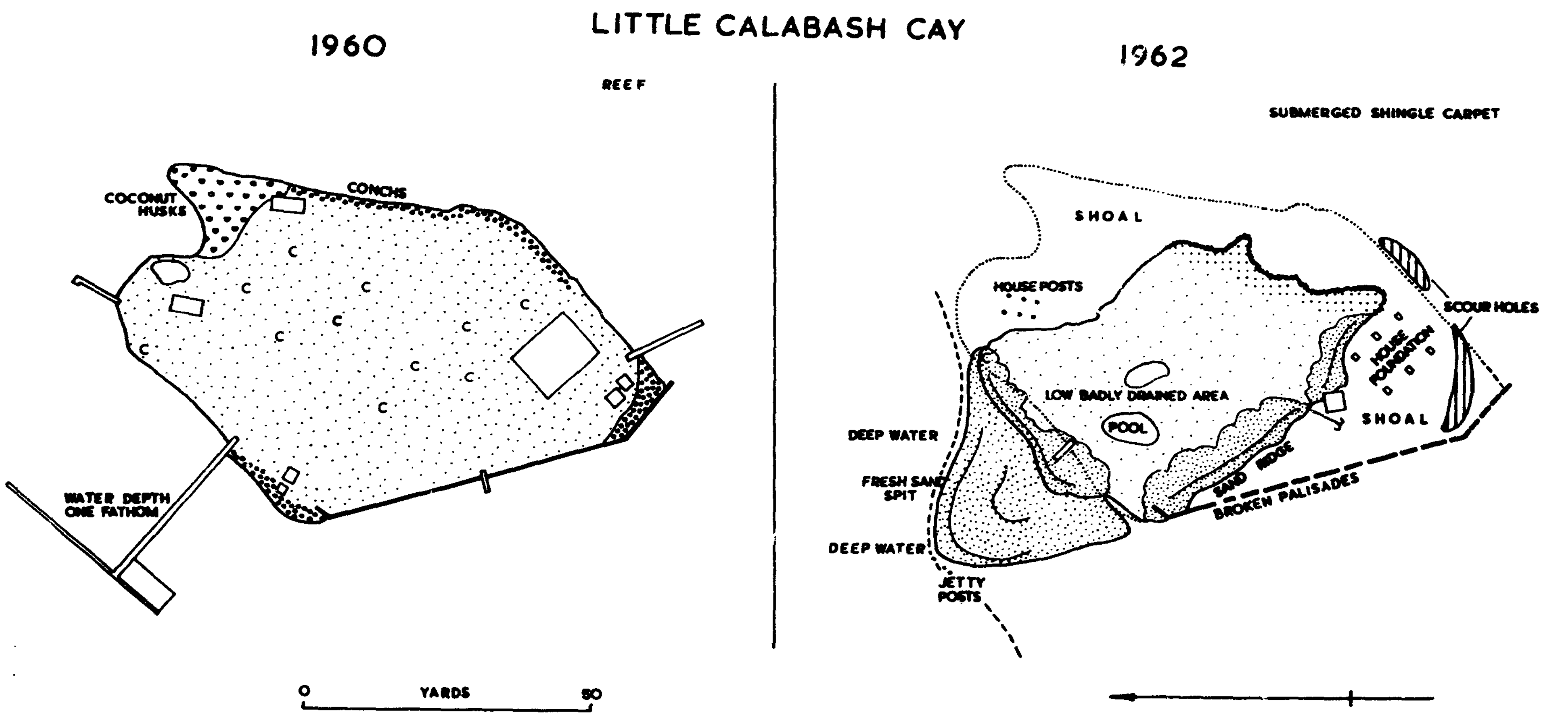
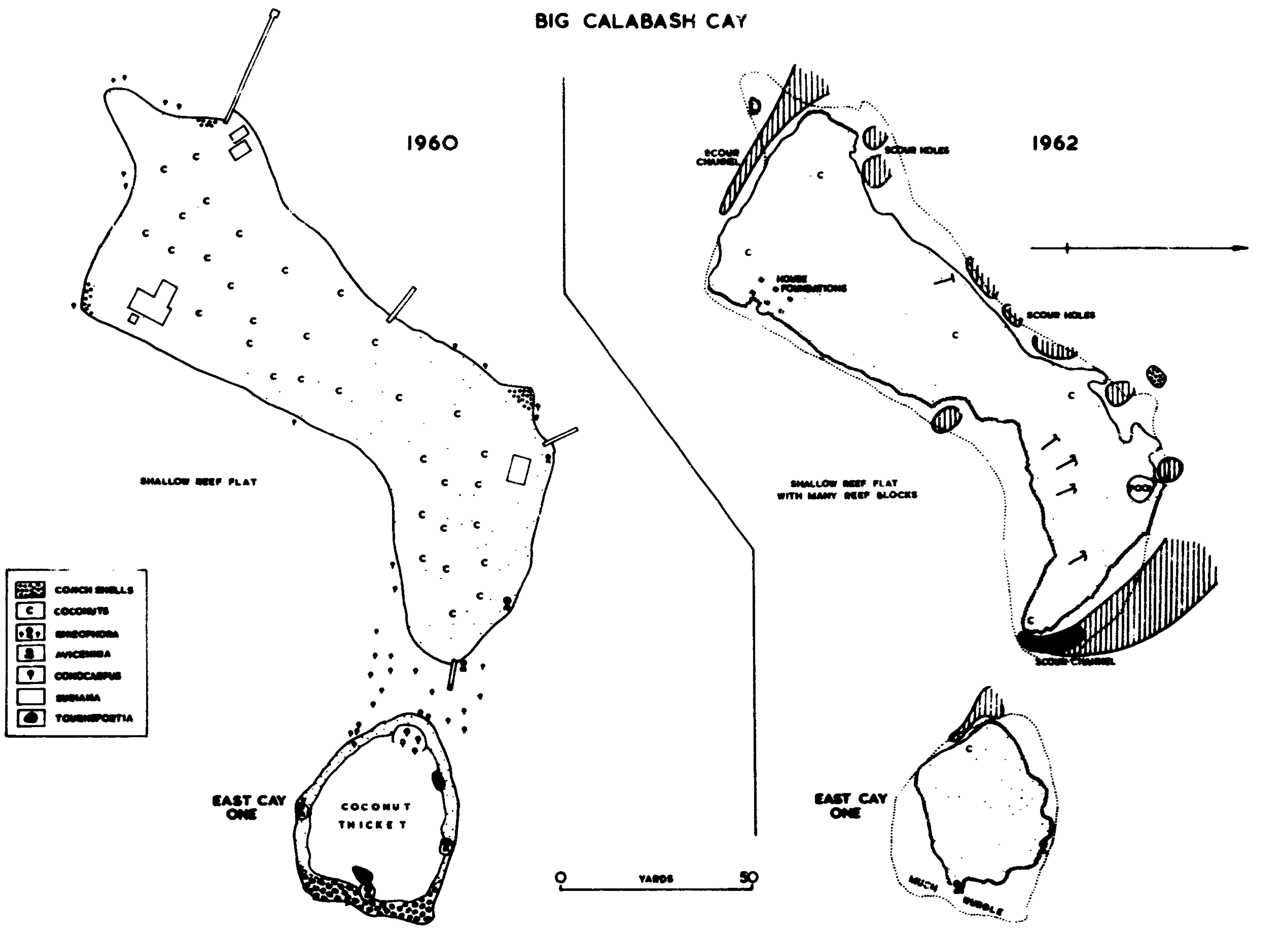
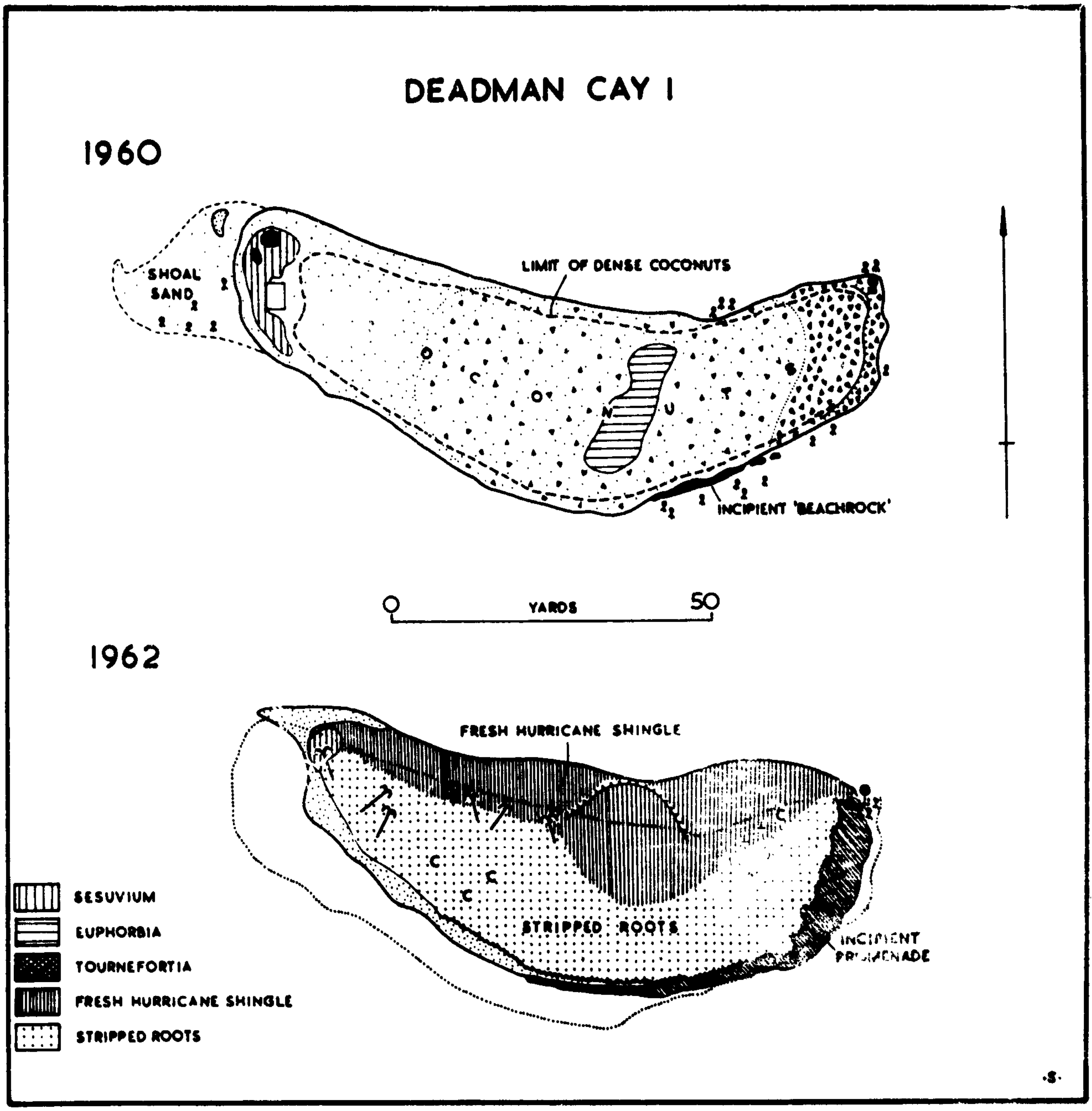

LITTLE CALABASH CAY
1960
REEF
COCONUT HUSKS
CONCHS
WATER DEPTH ONE FATHOM
0
YARDS
50
1962
SUBMERGED SHINGLE CARPET
SHOAL
HOUSE POSTS
SCOUR HOLES
HOUSE FOUNDATION
LOW BADLY DRAINED AREA
POOL
SHOAL
SAND RIDGE
BROKEN PALISADES
DEEP WATER
FRESH SAND SPIT
DEEP WATER
JETTY POSTS

FIG. 47



BIG CALABASH CAY
1960
1962
SCOUR CHANNEL
SCOUR HOLES
HOUSE FOUNDATIONS
SCOUR HOLES
SHALLOW REEF FLAT
SHALLOW REEF FLAT
WITH MANY REEF BLOCKS
POOL
SCOUR CHANNEL
CONCH SHELLS
COCONUTS
RHIZOPHORA
AVICENNIA
CONOCARPUS
SURIANA
TOURNEFORTIA
EAST CAY
ONE
COCONUT
THICKET
0
YARDS
50
EAST CAY
ONE
MUCH RUBBLE

FIG. 48



DEADMAN CAY I
1960
SHOAL SAND
LIMIT OF DENSE COCONUTS
INCIPIENT 'BEACHROCK'
YARDS
0
50
1962
FRESH HURRICANE SHINGLE
STRIPPED ROOTS
INCIPIENT PROMENADE
SESUVIUM
EUPHORBIA
TOURNEFORTIA
FRESH HURRICANE SHINGLE
STRIPPED ROOTS

FIG. 49

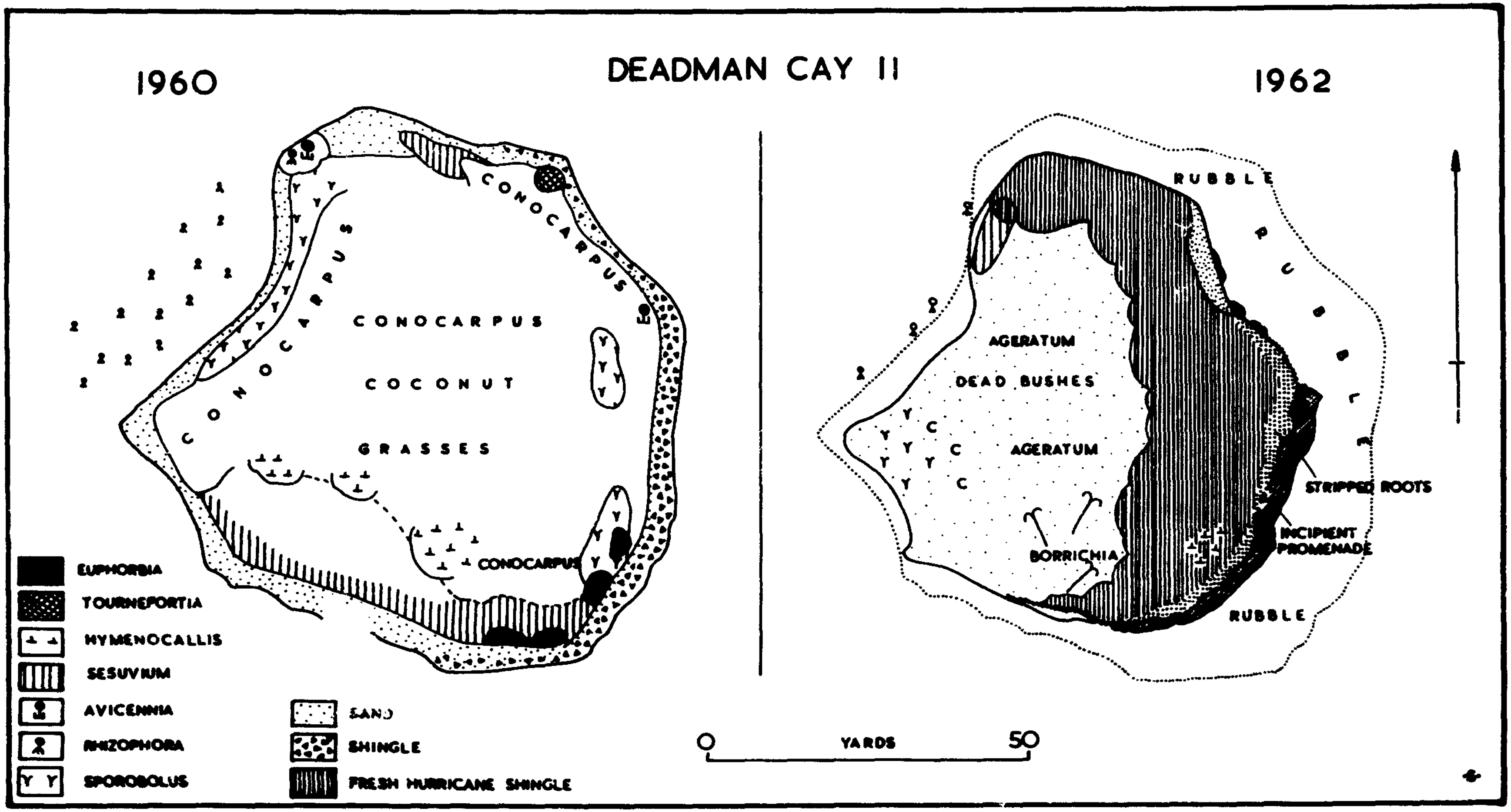
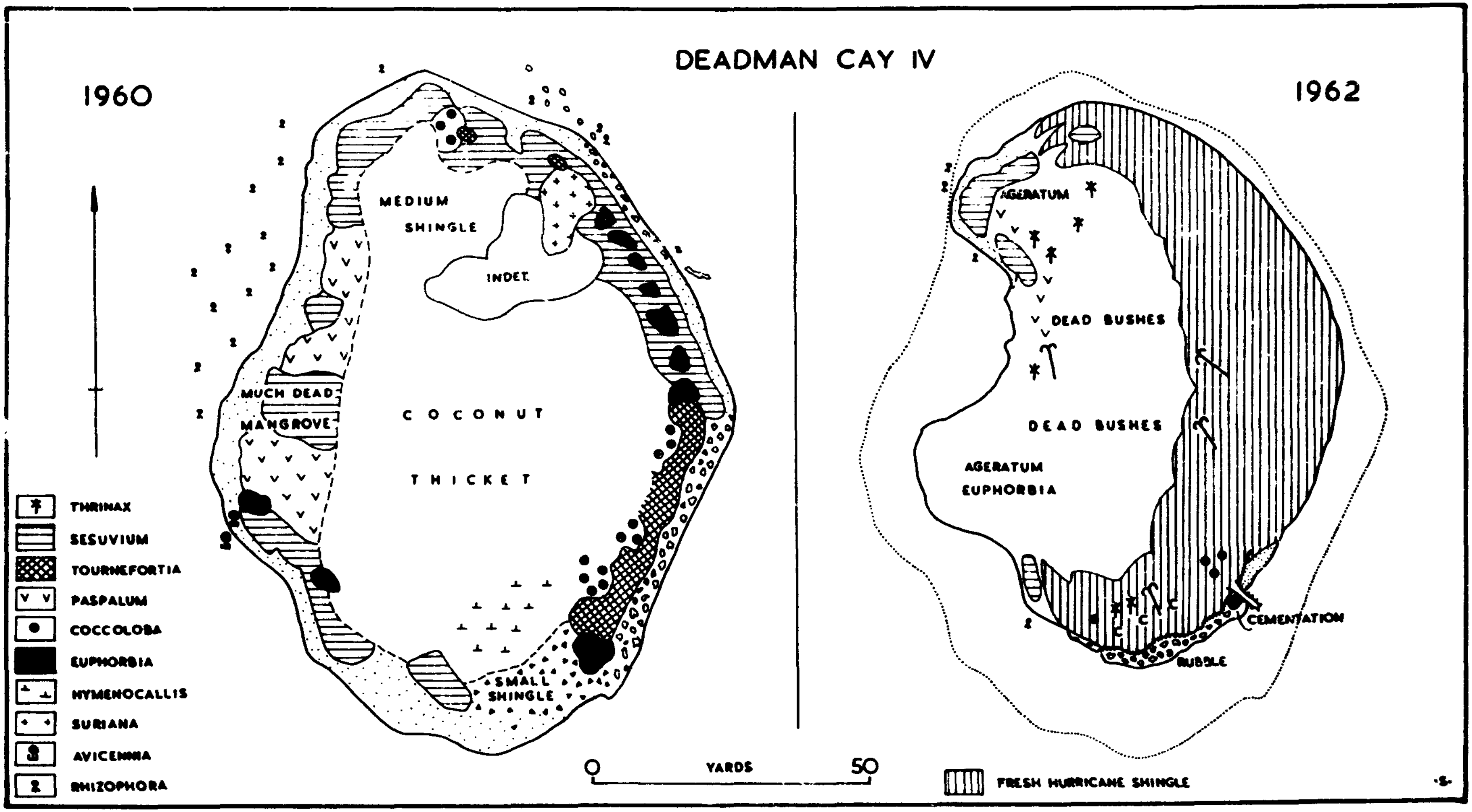

DEADMAN CAY II
1960
1962
CONOCARPUS
COCONUT
GRASSES
AGERATUM
DEAD BUSHES
BORRICHIA
RUBBLE
STRIPPED ROOTS
INCIPIENT PROMENADE
EUPHORBIA
TOURNEFORTIA
HYMENOCALLIS
SESUVIUM
AVICENNIA
RHIZOPHORA
SPOROBOLUS
SAND
SHINGLE
FRESH HURRICANE SHINGLE
0
YARDS
50

FIG. 50



DEADMAN CAY IV
1960
1962
MEDIUM SHINGLE
INDET.
MUCH DEAD MANGROVE
COCONUT
THICKET
SMALL SHINGLE
AGERATUM
DEAD BUSHES
DEAD BUSHES
AGERATUM EUPHORBIA
CEMENTATION
RUBBLE
THRINAX
SESUVIUM
TOURNEFORTIA
PASPALUM
COCCOLOBA
EUPHORBIA
HYMENOCALLIS
SURIANA
AVICENNIA
RHIZOPHORA
0
YARDS
50
FRESH HURRICANE SHINGLE
-S-

FIG. 51

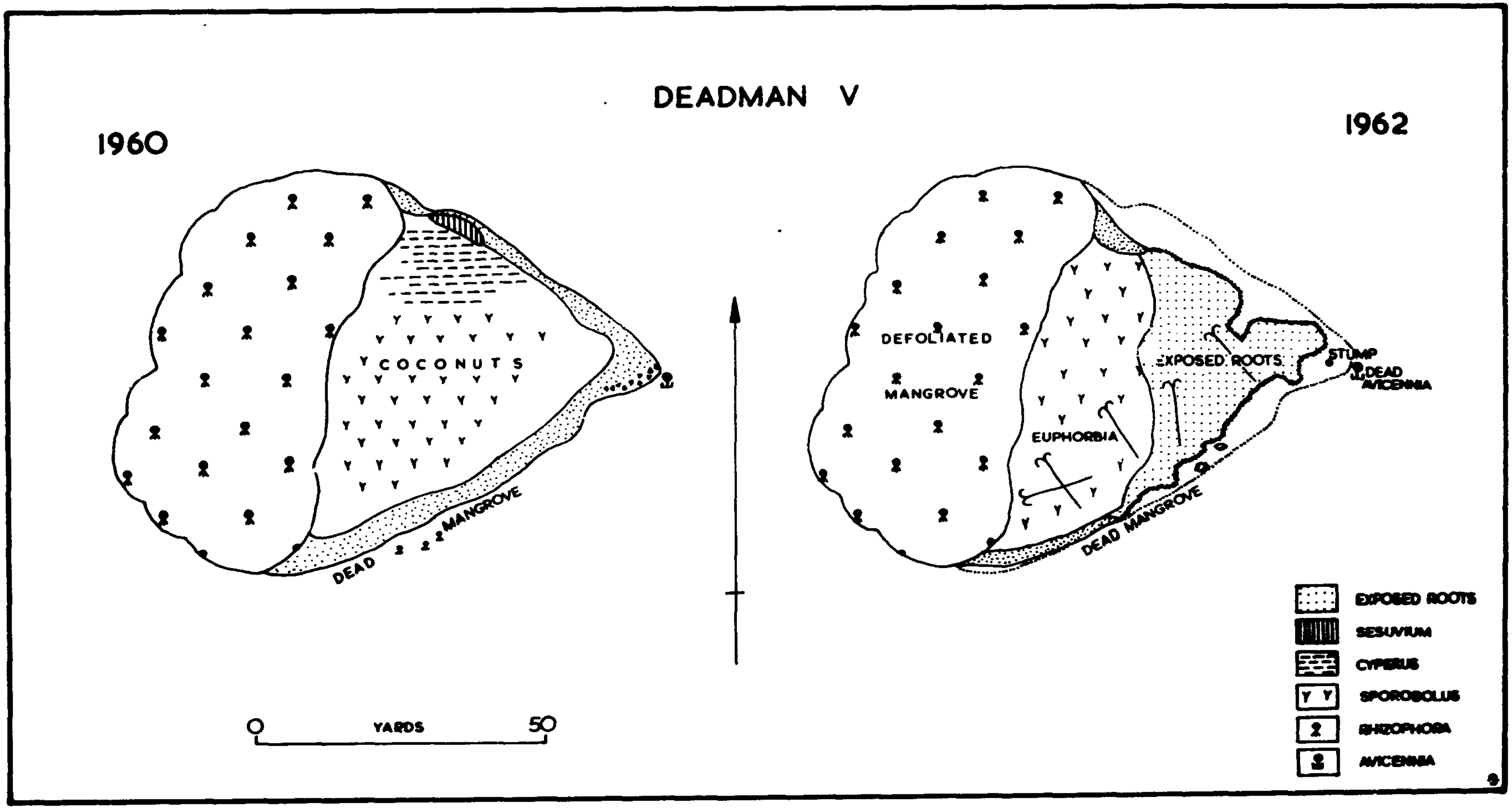
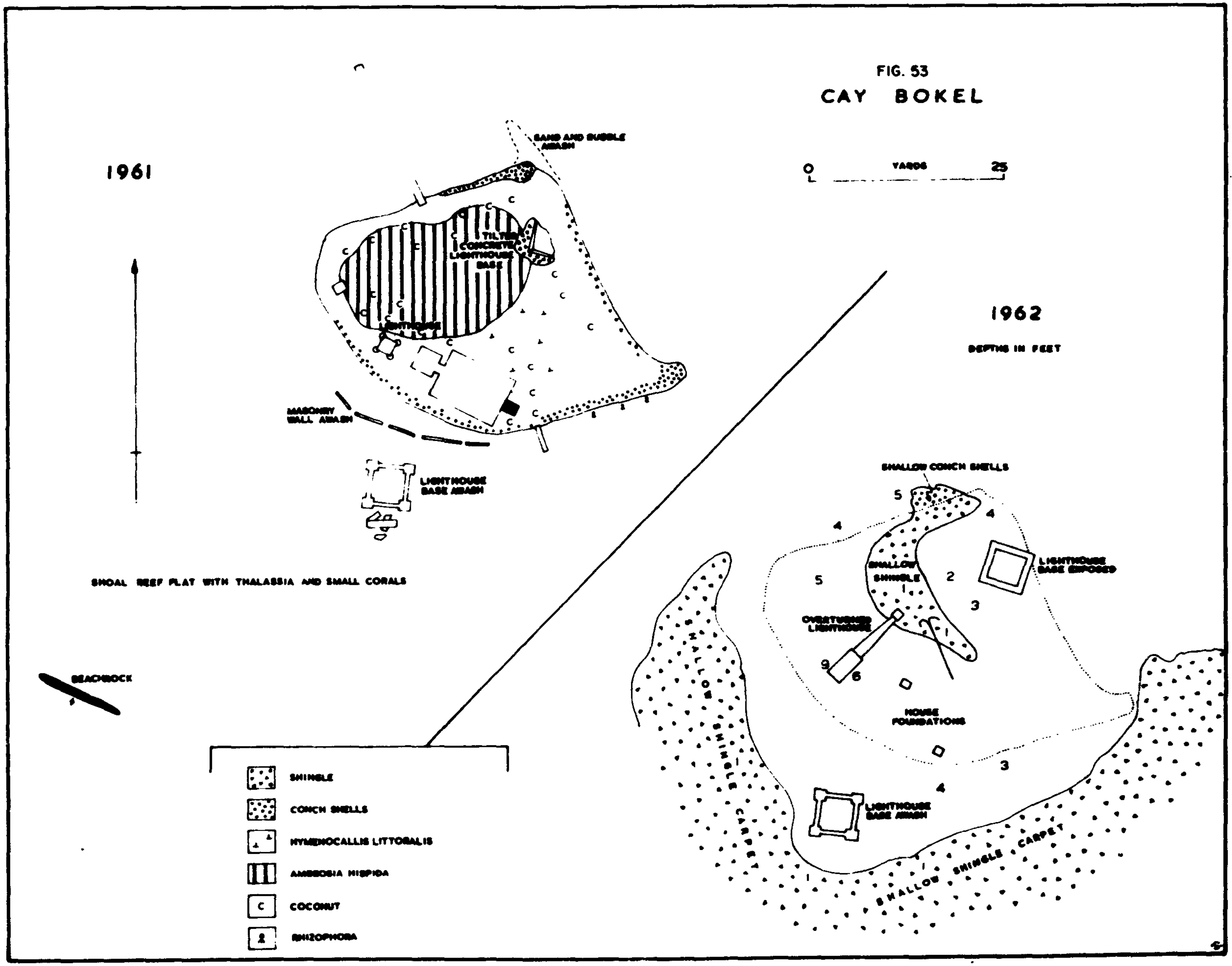

DEADMAN V
1960
1962
COCONUTS
DEAD MANGROVE
DEFOLIATED
MANGROVE
EUPHORBIA
EXPOSED ROOTS
STUMP
DEAD AVICENNIA
DEAD MANGROVE
0
YARDS
50
EXPOSED ROOTS
SESUVIUM
CYPERUS
SPOROBOLUS
RHIZOPHORA
AVICENNIA

FIG. 52

FIG. 53
CAY BOKEL



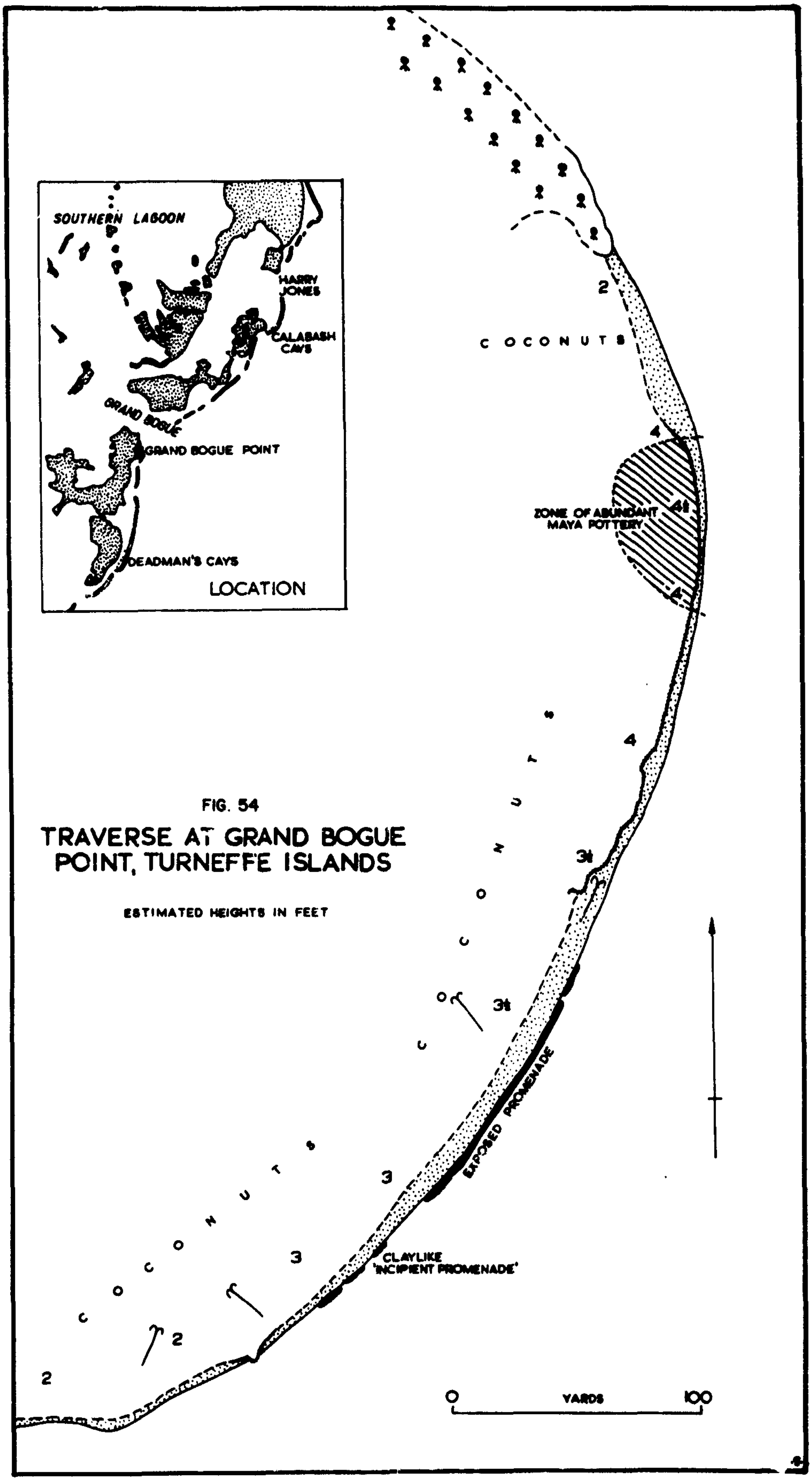


FIG. 54

TRAVERSE AT GRAND BOGUE POINT, TURNEFFE ISLANDS

ESTIMATED HEIGHTS IN FEET

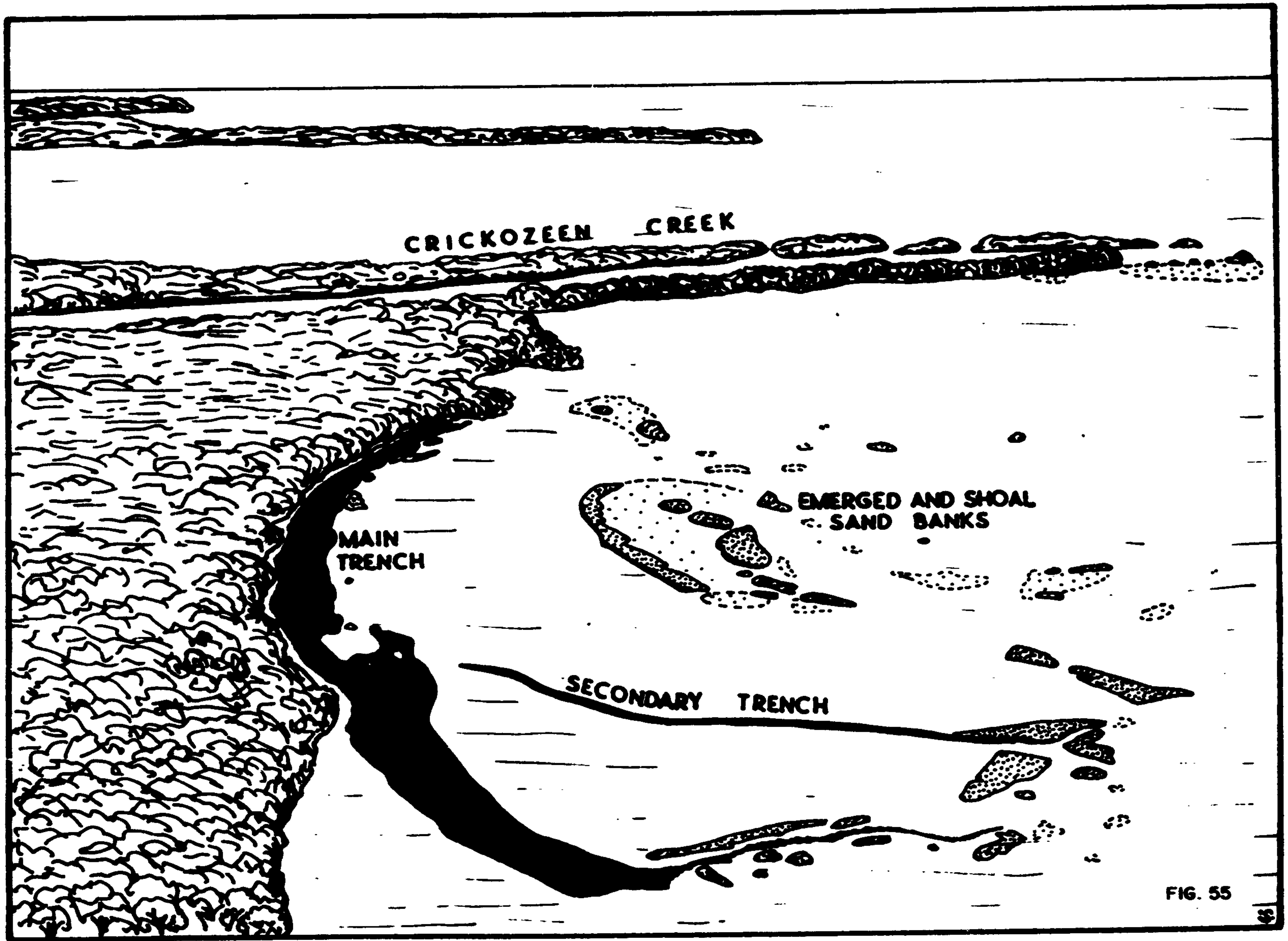


FIG. 55

AERIAL VIEW FROM NORTH OF CRICKOZEEN CREEK SLUMPING

DRAWN FROM A PHOTOGRAPH

VII. HURRICANE DAMAGE ON LIGHTHOUSE REEF

Lighthouse Reef, lying 11-18 miles seaward from Turneffe Islands, is the smallest of the three British Honduras atolls in area: it is 25 miles long, but has a maximum width of only 4½ miles. The atoll is surrounded by a well-developed reef-rim, with only three major gaps, one at the north end, the others near the south end. The whole of the eastern reef north of Half Moon Cay is unbroken and backed by a wide reef flat; coral growth on the windward side is much more vigorous than on the leeward reefs. The central lagoon is generally shallower on the west side and deepens eastwards, with average depths near the east reefs of 2-3 fathoms and maximum depths probably reaching 4½-5 fathoms. The shoal and deeper areas of the lagoon are separated by a "Middle Reef", parallel to the peripheral reefs. For a fuller description of the atoll, see ARB 87, 51-81 and Figures 27-36. There are two cays at the north end of Lighthouse Reef, Northern Cay and Sandbore Cay, collectively known as Northern Two Cays. The former is a large mangrove island with a wide seaward sand rim; the latter a small sand cay. At the south end of the reef, Long Cay is comparable in size and physiography to Northern Cay; Half Moon Cay is a large sand and shingle island; and, before the storm, Hat and Saddle Cays were smaller bush-covered sandy cays. All these islands lay to the south of the hurricane track, though the storm passed over the northernmost tip of the atoll and Northern Two Cays. An in previous chapters the islands are here described from north to south.

Sandbore Cay

Sandbore Cay is the most northerly island on Lighthouse Reef (ARB 87, 56-58), situated at the northern end of the long unbroken east reef, about 1000 yards back from the reef edge. In 1961 (Figure 56) the cay consisted in outline of a "core" at its eastern end, with two long spits extending westwards, enclosing a lagoon 4-5 feet deep. The gross outline of the cay was triangular, with sides of 300-500 yards: the northern spit was composite and formed a block of land some 150 yards square, the southern spit was long and narrow, varying in width from 20-65 yards. The whole island was sandy and nowhere more than 3 feet above the sea. The greatest elevations were found along the northeast and southeast facing shores. Beachrock before the hurricane was exposed at two points: Beachrock I consisted of two, perhaps three subdued lines of rock, dipping north, about 40 yards long, off the east end of the cay; Beachrock II consisted of a single line of rock 50 yards long and 18 inches wide, with a slight seaward dip, just exposed at low tide and rather difficult to see, along the southeast shore.

The east end of the island had been largely cleared for coconuts, but there were large areas of ground vegetation along the southeast shore, and particularly on the surface of the two spits. The southern spit supported _Suriana maritima_, _Tournefortia gnaphalodes_, _Conocarpus erectus_, some _Avicennia_, and an undercarpet of _Euphorbia_, _Ipomoea_, tall grasses, and considerable areas of _Ambrosia hispida_. Along the northeast shore and on the northern spit _Suriana_ and _Tournefortia_ were again found on the beach crest, and Suriana was also scattered over the spit surface. At the head of the lagoon there was a thicket of Suriana, Conocarpus and Coccoloba, tall grasses such as Andropogon glomeratus, low grasses such Sporobolus, and Ambrosia. The pre-hurricane distribution of vegetation is shown in ARB 87, Figure 28.

There was some evidence of erosion along the cay shores, shown by beachrock on the south shore, and undercutting and falling coconuts along the northeast shore. Both spits seemed to be expanding westwards, shown, in the case of the northern spit, by broad concentric ridges of fresh sand in the first stages of colonisation by plants. The main evidence of progressive movement to the west, however, was provided by the lighthouse, built on the cay itself in 1885. Since that time the east shore has retreated, until in 1961 the light stood 80 yards from the shore. A concrete walk connecting cay and light was built in 1945; in 1961 this ended 20 yards from the shore as a result of yet further shore retreat. A wooden causeway had been built to connect the 1961 shore with the 1945 concrete walk. The average rate of shore retreat 1885-1945 was 3 feet per year; 1945-1961, 4 feet per year. Beachrock I at the east end of the cay is clearly related to this retreat of the last half century.

In my previous Bulletin, it was suggested that if the cay continued to retreat westwards at this rate, the time would come when it would be pushed off the reef flat altogether, leaving the lighthouse as its only memorial. Hurricane Hattie, however, disrupted this simple scheme. The centre of the storm passed over this island: wave activity was sufficient to destroy the concrete walk to the lighthouse by the afternoon of 29 October, and as the storm passed shortly after midnight, 30-31 October, the lighthouse itself collapsed in a pile of rubble. Severe physiographic and vegetation damage was caused by wind and wave action as the cay surface was submerged to a depth of 8 feet during the storm surge. Physiographic changes will be outlined first. The main lineaments of the cay still exist, though shore retreat occurred at the east point, along the south shore, and at the western ends of both sandspits. Two channels were cut through the spits: one 65 yards wide through the neck of the northern spit, the other 50 yards wide through the middle of the southern spit at its narrowest point. The first channel had been refilled with fresh sand to approximately its pre-storm height by May 1962, though the new neck is wider than before, with an irregular inner edge, and it is devoid of vegetation. There is no information on the date when the refilling began; the channel immediately after the storm is said to have been 3 feet deep. The second gap, through the southern spit, is still open, and varies from 2-3 feet deep. Beach erosion has greatly increased the exposure of Beachrock II along the south shore: it can now be traced for 140 yards in a wide arc following the old shoreline. The rock is not topographically conspicuous, but shows a noticeable seaward dip, and is distinguished from the surrounding Thalassia by its lack of vegetation. A second line of beachrock, Beachrock III, has been revealed along the old lagoon shore of the spit; it is a massive rock, in five distinct, sometimes overlapping plates, just breaking surface and at least 2½ feet thick; it has a marked lagoonward (northwest) dip. No trace of this beachrock was previously apparent; nor can it be seen along uneroded portions of the lagoon shore, which presumably it also underlies. There is no sign that this channel is about to fill up. Sand from the gap has been deposited in the lagoon itself, forming a wide shoal area which splits the lagoon into two parts: (a) the inner lagoon is now virtually enclosed, the water in it is stagnant and odoriferous, and there are slimy reddish deposits round the shores; (b) the outer lagoon still has depths of 1-1½ fathoms, but the floor is littered with blocks of living coral, some only a few feet from the shore, which were not previously seen. Tongues of shoal sand, emerging as fresh sand spits, have also been built westwards from the ends of the spits. A further fresh sand peninsula has been thrown up at the east end of the cay, flanking an elongate scour hole several feet deep.

Surface erosion of loose sand and exposure of roots has been greatest along the southern side of the island. Almost all coconuts have been swept away from this section, together with the Suriana and Tournefortia bushes, though a few patches of Euphorbia and grasses remain. The surface is now littered with coarse coral fragments, strewn with long coconut roots from which all the fine material has been flushed, and most difficult to walk over. There are numerous small scour holes, mostly at the upturned bases of coconut trees. The deepest hole is found on the southeast side of the only building to survive, a concrete house: the scour hole extends under the house foundations, is filled with water, and is at least 17 feet deep. Had the undermining continued longer the house would certainly have collapsed. A few coconut stumps still stand at the east end of the cay, but otherwise all the surface sand and vegetation has been removed; roots are combed in a NW-SE direction. The house itself is no longer used; only the central concrete strong room remains, the roofs and all remaining wooden rooms have been broken from the construction.

Damage on the northern spit beyond the severed neck has been less severe. The thicket of Coccoloba and Conocarpus still stands at the head of the lagoon, with a number of coconut trees which retained their crowns. The peripheral Suriana and Tournefortia bushes were all swept away, and marginal erosion all round the shores destroyed areas of grasses, Euphorbia, Ambrosia etc. In the centre of the spit the vegetation cover still survives largely intact, though thinner and partly buried by fresh sand. The larger bushes such as Conocarpus, Tournefortia and Coccoloba were defoliated and now appear to be dead, but the ground cover of Sporobolus, Cyperus, Cakile, Euphorbia and Ambrosia is still recognisable. There is a very great increase in the amount of "burr-burr", Cenchrus, throughout the area, but Ipomoea is less widespread. Surface sand has been stripped and roots exposed only in small areas on the southwest shore. One point of interest is the occurrence in the channel-like depressions cut into the old surface round the margins of the northern spit, of surface incrustations of cemented sand, [illegible]-¼ inch thick, covering several square yards. This caliche-like deposit can be lifted up in plates up to a foot in diameter, but rapidly crumbles in the fingers. It may be a salt incrustation produced by high insolation after the flooding of the island by the storm surge. A few Tournefortia seedlings were seen colonising the fresh sand margins of the northern spit in May 1962.

Northern Cay

Northern Cay, the largest island on Lighthouse Reef, has maximum dimensions of 3300 and 3000 yards and an area of 2¼ sq. miles, of which one fifth is interior lagoon, one fifth is dry land, mainly under coconuts, and three-fifths is mangrove and swamp land (ARB 87, 58-62, Figure 29). The dry land area lies on the north and west sides of the cay, where the shore approaches to within 400-600 yards of the reef. The western shore, 2600 yards long, was before the hurricane slightly undercut, forming a cliff 3-8 feet high. At the base of the undercut cliff cemented sands outcrop intermittently for about 1500 yards: the base of the outer edge has a near-constant altitude of about 1 foot above low tide level. In 1961 the exposure was 6-9 inches thick, and varied in width from a few inches to 2 feet; the upper surface was either horizontal or dipped slightly seaward and was much pitted and eroded. Slabs broken from the main exposure lay on the beach at the beach angle. The rock itself was well consolidated on the surface, but rather friable a few inches from it. During the hurricane, this eastfacing shore was not severely affected by wave erosion, though the sand ridge overlying the cemented sand was pushed back several feet. In places the cemented platform is now up to 8 yards in width, and its upper surface rises to 2 feet above sea level. The outer edge, previously exposed, is, as before, much pitted and blackened, and more slabs have been broken off or fractured. The freshly exposed section has a relatively smooth upper surface; cementation in the newly exposed area is poor compared with the outer zone; and the recency of the consolidation is shown by the presence of coconut roots within the rock. At one point along the shore, the cemented platform is buried by the main beach ridge, behind which a temporary section has been opened by the uprooting of a large coconut tree and scouring of the hole by waves. The rock horizon can be seen all round the hole: the upper surface is thin, friable and easily broken, and the sand below is uncemented (Figure 63). These exposures show that the rock is not an intertidal beachrock, but that it is forming at its present elevation as a cay sandstone, comparable to that at Big Cay Bokel, Grand Bogue Point, and Harry Jones, Turneffe. For a photograph of this sandstone before the hurricane, see Stoddart, 1962a, opposite p. 160.

The main shoreline changes at Northern Cay have taken place along the north shores, between the northern limit of this sandstone and the North Point; the changes are shown in detail in Figure 57. North Point, previously consisting of dune sands fixed by vegetation, mainly Euphorbia, Ambrosia, grasses and a few Conocarpus bushes, with ridge crests rising to 4 feet above sea level, has been swept away. A triangular area of sand 80 yards long, with a base of 160 yards, area 6400 sq. yards, has disappeared, though its former location is revealed by an area of shoal sand 2-3 feet deep, surrounded by Thalassia. The shoreline at the base of the peninsula now consists of a steeply undercut clifflet of roots. The shoreline of the northern bay, west of the Point, has retreated an average of 10 yards: actual erosion has, however, been greater than this. The old shore, now revealed by an eroded cliff of grey sand, has retreated 25-40 yards; in front of the cliff a fresh sand ridge has been banked. This ridge is up to 30 yards wide and 2 feet high, with much Thalassia, shells and echinoid remains. The coarseness and unsorted nature of the constituent material show that the greater part of the ridge is a hurricane construction, perhaps slightly altered and augmented by post-hurricane wave action. Shoreline retreat has been greater on the east (northwest-facing) side of the bay, than on the west (northeast-facing) side. As a result of this retreat, the incipient beachrock seen in a small embayment in 1960 has been destroyed, and the nearshore vegetation of Suriana, Tournefortia and grasses has disappeared. Wave action was sufficiently great 30 yards from the shore and 6 feet above sea level to completely destroy and sweep away a large house, water tank and outbuildings on the northwest side of the cay.

On the eastern shore, damage is largely restricted to the north end. The jetty and small huts have been washed away, and much shoal sand deposited along the northern offshore area. Waves also destroyed pre-existing vegetation and smothered the surface with fresh sand over a zone 10-30 yards wide at this northern end. Elsewhere, damage has been slight. Beachrocks III and IV remain intact.

Away from the shores, physiographic change is negligible, even in the exposed higher dune area back of North Point where ridges rise up to 10 feet above sea level. In spite of inundation by the storm surge, at least of the marginal areas, deposition has been very slight. Some pock-marking of the surface has resulted from uprooting of coconuts, but apart from this, change in the interior has been almost wholly vegetational. Before the hurricane the dry sand areas were covered with coconuts, yielding up to 20,000 nuts a month a few years ago; recently, however, ground vegetation had been allowed to invade the coconut areas, making them almost impenetrable in places. The taller ground vegetation has been almost completely swept away by the storm, and access is now easy at all points. Ground vegetation now consists only of grasses, Cyperus, Euphorbia, Cakile, some Hymenocallis, with greatly increased amounts of Cenchrus (burr-burr). Probably 80% of the coconuts have fallen, though large numbers are still standing, with and without crowns, on the west side of the northern bay and along the eastern side of the island. It is said that these standing trees are unlikely to bear again. Direction of tree fall is extremely regular, varying from 100-130°, the majority lying 115-120°; there is a definite minority of trunks, less than 5%, which have fallen in the opposite direction, 320-340°. Since Northern Cay was in the direct track of the hurricane, it is possible that the main period of tree fall occurred between 2200 h, 30 October, and the passage of the eye at 0100 h, 31 October, in response to violent northwest winds immediately preceding the storm centre, and that some of those which survived succumbed to the equally violent south and southeast winds which immediately followed the eye in the early hours of 31 October. Only at the extreme southwest corner of the cay are tree-fall directions at all confused. Recovery of defoliated Rhizophora was beginning in May 1962 on the east shore of the cay; but mangrove at the southwest point seemed quite dead.

The island is no longer inhabited, and it seems unlikely that capital for clearing and replanting coconuts will be immediately forthcoming. It will be useful to observe the development of vegetation on the cay if human interference is kept to a minimum. It is possible, however, t that a lighthouse to replace that at Sandbore Cay may be erected near North Point. This would be safer during hurricanes, but the cay lacks the excellent small boat harbour of Sandbore Cay and its shores are extremely exposed, especially during northers. It is in addition infested by biting flies, which made life difficult even on Sandbore Cay whenever they reached it; on such occasions all persons on the smaller cay used to sleep at the top of the light in order to escape them.

Saddle Cay

Saddle Cay, in 1960-61 a small island 2¾ miles north of Half Moon Cay on the inner edge of the main east reef flat, has had a long history of hurricane damage (ARB 87, 62-64). Before 1931 it was some 50 yards long; it was reduced to half this length in the hurricane of that year, and by half again in 1942. Other hurricanes progressively destroyed the sand area and hindered fresh accumulation until in 1960 only a clump of trees covering a land area 10 yards in diameter remained. The cay supported a thicket of Rhizophora, Avicennia, Conocarpus, and a couple of coconuts, with a ground cover of Sesuvium; it was used as a nesting place by ospreys. In my previous Bulletin I suggested that "a large hurricane passing over the cay now would probably destroy it altogether" (ARB 87, 63). Hurricane Hattie did. Saddle Cay has completely disappeared as a surface feature, though from the air one can still see the arcuate sand shoal on which it stood. The shoal after the hurricane carried 2-3 feet of water.

Half Moon Cay

Half Moon Cay has been described and mapped in some detail (ARB 87, 64-77, Figures 30-34), and an effort was made in 1962 to study hurricane damage in similar detail. Lines of levels were again surveyed across the cay and a fresh contour map prepared (Figure 58); this was then superimposed on the 1961 contour map (Figure 30) and a new map prepared (Figure 59), showing by isopleths the positive or negative change in altitude at any point, especially on the south and southeast shores of the cay. Lines of levels were surveyed across the island in 1962 in the same places as in 1961 to aid comparison. Sediment samples taken in 1961 are in the process of analysis; samples taken at the same locations in 1962 had not arrived in Cambridge when this account was written. This is, therefore, a preliminary account, and it is hoped to deal with sediment changes and distribution on Half Moon Cay in a later paper. Figure 60, showing changes in sediment composition, like the pre-hurricane map, ARB 87, Figure 31, is not based on the sediment samples but on field notes made during traverses, and is also preliminary. Finally, Figure 61 shows in outline the vegetation changes due to Hurricane Hattie; for the pre-hurricane picture, see ARB 87, Figures 33 and 34.

To a large extent these maps speak for themselves, and most of the important changes can be seen from them. The main features of the cay in 1961 (ARB 87, Figure 30) were (1) a steep ridge along the southeast shore of the tapering east end of the cay, the crest everywhere more than 7 feet above sea level, much of it more than 8 feet, and one small area near the northernmost part of the bay, 120 yards west of the lighthouse, reaching more than 10 feet above sea level. The ridge was built of sand with patches of small shingle at its foot; at its base there outcropped an extensive platform of beachrock, and accumulations of blocks torn from this platform were found along the base of the ridge and in places on both the seaward and back slopes of the ridge. (2) The southwest shingle ridge, decreasing steadily in height from 9 feet at the south point to only 3 feet at its western end, with the calibre of the constituent shingle decreasing in the same direction, and covered with a thick hedge of Cordia sebestena. This section too, is fringed at and a little above mean sea level for much of its length by a conglomerate platform. (3) The cay surface to the north of these two ridges. On the eastern, tapering end of the cay, cleared for coconuts, the ridge proper is narrow and much of the back slope lies less than 4 feet above the sea. Along the western half of the island, covered with a dense thicket of Cordia, Bursera, Ficus and Neea woodland, the ground surface is generally more than 3 feet and much of it 4-5 feet above sea level. Near the junction between these two zones is an area in the centre of the cay of subsurface cementation, possibly phosphatic, covered with raw humus, and in 1960 under thick Ficus bush.

When remapped in 1962 the following physiographic changes were apparent: Eastern Section. The easternmost 35 yards of the cay, previously forming a steep shingle peninsula rising 6 feet above sea level, has been levelled by wave action to form a low shingle and sand spread 1-2 feet high. The cay proper now ends in a steep cliff forming a perfect cross-section of the island. Between this cliff and the lighthouse a number of scour channels have eaten back into the surface from the north shore of the cay; these are up to 5 yards long, and 3 feet deep at their inner ends; they are apparently the work of waves crossing the cay from south to north.

The crestline of the main east ridge has been pushed northwards; since the present crest now lies on the old back slope of the ridge, the effect has been to lower the maximum height of the crestline. Previously the greatest elevations lay 12-30 yards from the southeast shore; in 1962 the crestline lay 30 yards from the shore along most of its length. The general level of the ridge crest is now 6 feet; near the lighthouse it rises to 8 feet, and near the middle of the cay to 9 feet. Landward retreat of the crest has resulted in vertical lowering of the surface of at least 3 feet along the greater part of the seaward face of the ridge; over a distance of about 230 yards the vertical lowering has been at least 5 feet, and in one place 7 feet. This to some extent exaggerates the true amount of erosion, which is partially at least a landward shift; nevertheless the crestline is now lower for its whole length by approximately 2 feet and this lowering is not wholly balanced by deposition. Fresh sand has been thinly spread over the backslope of the ridge in arcuate pattern, but only at two points is the measured increase in height at all considerable; in both cases the increase is generally little more than a foot, with a maximum in one small area of 4 feet. Much of the area immediately back of the present crest has had surface sand stripped and coconut roots exposed, and the crest itself is often steeply undercut on the seaward side, in one place forming a vertical sand cliff 4 feet high.

There has been no major change in sediment distribution. The former high shingle ridges at the east point have disappeared, though on the north shore a remnant of the old ridge is now perched high on the cay surface. Fresh shingle is scattered along the ridge foot, and the older accumulations of conglomerate slabs have been shifted and augmented.

Coral blocks and conglomerate slabs are thinly scattered across the backslope of the ridge.

Western Section. The western section of the cay differs from the eastern part in that, first, its south shore faced the main hurricane winds, and second, it was densely vegetated. The old regular decrease in crestline height and shingle calibre from east to west, away from the eastern reefs, has been completely destroyed. In place of the gentle decrease in height from 9 feet to 3 feet east to west, the ridge now rises to a maximum of over 10 feet near the centre, and for about three-fifths of its length the crestline now stands more than 8 feet above the sea. The crest has also been pushed landward: before the hurricane it stood an average of 25 yards from the shore, in 1962 this had increased to 50 yards. Comparison of the two contour maps, therefore (Figure 59), shows an outer zone of net vertical loss, of the order of 1-3 feet, and an inner zone of net vertical gain of at least 1 foot, with an area near the centre of at least 5 feet. The calibre of the material varies. The sorting of sediments normal to the beach has also been destroyed. At present there is an accumulation of coarse shingle and coral blocks at the foot of the ridge; the greater part of the seaward slope is now coarse sand, in contrast to the dominant shingle of the pre-hurricane ridge; and there is a jumble of coral blocks and large debris in the broken bushes at the ridge crest. In places waves overtopping the newly deposited sediments at the ridge crest during the hurricane have scoured out plunge holes up to 2 feet deep in the old cay surface beyond, thus accentuating the sharp break of slope at the inner limit of hurricane deposition. At one place on the seaward slope, cemented rubble has been exposed, comparable to that found in the cay interior in 1961 and recalling the Cockroach II exposure on Turneffe Islands (Chapter 6). There has been some low-level aggradation at the extreme west end of the cay, a fine-shingle ridge enclosing two small pools.

The topographic balance of the cay has therefore been reversed by Hurricane Hattie. Previously the greatest heights, up to 10 feet, were found along the southeast shore; now similar heights are only found on the south shore. The width of the zone affected by the hurricane is very much less in the western section, covered with vegetation, than in the eastern part, cleared for coconuts, and it is clear that the increase in height in the former is largely the result of piling-up of material against the dense vegetation hedge. It is very probable that considerable physiographic damage would have been caused at the west end, had that part of the cay also been cleared for coconuts. Over the greater part of the cay surface, especially at the west end, there has been no topographic change. Erosion along the northern shores has also been slight. At one point, 95 yards from the northwest point, shore retreat has exposed further cemented material similar to that in the middle of the cay. The top of its outer edge lies 2.8 feet above sea level, and its base 1.7 feet. The exposure is 9 feet wide, and rises very slightly inland; it is covered by shingle and dark sand, with the cay surface lying 4 feet above sea level. It is clearly not a raised beachrock, but formed at its present elevation beneath the cay surface, in the same way as the possibly phosphatic rock in the centre of the cay.

It should be noted that retreat of the ridge crest on the seaward side is beginning to expose the base of the lighthouse. This steel structure was built in 1931, on a much earlier brick foundation with the inscription "Completed December 1848. J. Grant, Builder". Several feet of sand were washed away from the base of the light during the hurricane and the bottom of the brickwork is now exposed, free of sand, on the seaward side. Further retreat will certainly endanger the light itself. In parenthesis here, reference may be made to a point made by Vermeer (1959, 9,12) that the original lighthouse was built in 1845 "midway between the north and south sides" of the cay, and that its present position directly overlooking the seaward shore indicates net migration of the cay northwards. This is probably an exaggeration; I have since discovered in the copy of the Honduras Almanack for 1832 which formerly belonged to Mrs. Matthew Newton, wife of the first incumbent of St. John's Cathedral, Belize, a lithograph of the 1820 lighthouse, quite clearly built on the crest itself. It may be compared with the De Mayne sketch, ARB 87, Figure 32. Old brickwork exposed by the 1961 hurricane adjacent to the present light could possibly be the base of the older light. It seems doubtful whether very great retreat has in fact taken place at this point since 1820; most of the shore retreat has taken place at the head of the bay, between the light and the south point, and at the south point itself.

Effect on vegetation

The discussion of effects on vegetation may conveniently be divided into effects on coconuts, the Cordia thicket, strand vegetation, and interior ground vegetation. At least 80% of the coconuts were felled by the storm (Figure 61); the only trees to escape were those near the lighthouse at the east end. Scattered individuals, some retaining their crowns, are found over the rest of the cay, but the general picture is one of innumerable aligned fallen trunks. Direction of fall varies from 30-45° at the east end to 50-75° over the rest of the cay. The majority of the trunks are oriented about 60°, clearly indicating winds a little west of southwest, which is in harmony with the pattern of shore-line change.

Damage was also severe to the Cordia-Bursera thicket. Its seaward margin was pushed landward by up to 25 yards, leaving a wide expanse of bare fresh sand, scattered in the east with isolated broken Cordia and in the west by broken Bursera. In contrast to the straight, extremely regular, pre-hurricane hedge, the seaward margin of the thicket is now extremely irregular, with deep indentations, which at one point almost cut the thicket into two parts. Cordia suffered worst damage, losing branches and trunks and often being wholly uprooted and piled on the ridge crest in great confusion. Nevertheless, even totally dead-looking specimens may still be alive; one much broken tree was seen which totally lacked leaves, but exhibited a solitary flower in April 1962; in such cases, of course, mortality may simply be delayed. Bursera suffered less damage, the trunks generally still standing in the position of growth, and retaining many branches, though losing all leaves and with many roots exposed. Even the inner regions of the thicket were damaged. Thus, in the region of subsurface cementation in the centre of the cay, previously only reached by scrambling through a dense tangle of Ficus and other trees, all the larger plants were blown down. The thin surface humus has since been washed away and the rock is now exposed at the surface. Much of this vegetation rubbish has been cleared away and used for firewood. The main part of the thicket is much broken, and at a rough estimate the mean height has been reduced from 25-30 feet to less than 15 feet. The broken trunks and branches make it virtually impenetrable now.

Strand vegetation suffered more heavily still. All Suriana has been swept away, together with all Tournefortia, except for a single specimen at the east point. Plants such as Sporobolus and Hymenocallis in exposed situations have also disappeared. On the other hand, where thinly buried by fresh sand, Hymenocallis is reappearing, and the strand and fresh sand areas are being rapidly colonised by, for example, Cakile lanceolata, Sporobolus, burrburr (Cenchrus), and even a few seedlings of Tournefortia. Interior ground vegetation has been little affected. Large areas in the middle of the cay and to the north of the Cordia-Bursera thicket are still covered with grasses, Wedelia, Euphorbia, Ipomoea and Stachytarpheta, and bushes such as Rivina humilis, Ernodea littoralis and Conocarpus. Sporobolus, Cenchrus and Euphorbia mesembrianthemifolia are certainly extending on the previously cleared eastern half of the cay beneath the fallen coconuts.

Bird Colony

Half Moon Cay is noted for the colony of Red-footed Boobies, Sula sula sula, recently studied by Verner (1959, 1961) and Van Tets. Verner counted the number of birds in the colony as 3500 in 1958. There does not appear to have been any reduction in numbers as a result of Hurricane Hattie; the casual observer has the opposite impression, largely because of the breaking down of trees, stripping of foliage, and greater visibility of the birds. However, the nesting season may have been delayed. For some weeks after the hurricane the birds were described as wandering on the beaches rather than building nests. Cay inhabitants state that the boobies normally build their nests in November, lay in December, and hatch in January and February. Verner has shown that in 1958 the cycle was rather more prolonged than this: eggs were being laid from mid-November 1957 to mid-April 1958 (Verner, 1961, 584-585). After Hurricane Hattie (October 31), nest building did not begin until February, the birds laid in March, and the first hatched booby was seen on April 21. By contrast, in 1958 Verner saw flying young as early as April 1 (1961, 584). On May 10 1962, during a second visit, there were still very many unhatched eggs. The apparently obvious conclusion that nesting was delayed by the hurricane must, however, be accepted with caution; Verner has suggested that the cycle may be of more than 12 months duration and hence activities all start later every year (personal communication, 1962). Local fishermen all accepted that delay had in fact occurred.

Long Cay

Long Cay, the second largest island on Lighthouse Reef, is similar in build to Northern Cay (ARB 87, 77-81, Figure 35): it is a little more than 2 miles long, and varies in width from less than 300 yards in the south to a maximum of 1200 yards in the north. Its total area is 525 acres, of which 8% is dry land and the rest mangrove swamp, bare mud and standing water. The main dry land area lies at the northwest corner, and has been cleared for coconuts; this section covers 22 acres. A further sand area extends for 1800 yards along the east side of the main mangrove area; it varies in width from 20-40 yards, is generally between 1 and 2 feet high, and is again planted to coconuts.

Physiographic damage to the northern sand area was slight, apart from shore retreat of up to 2 yards on the west and east shores. The north shore is protected by a belt of Rhizophora, which now seems quite dead. Shore retreat involved destruction of the jetties and also undermining and unroofing of a large new house on the northeast shore. On the low-lying east and northeast shores a thin new carpet of fresh sand has been deposited near the beach. On the higher west shore, retreat has involved cliffing, together with sand stripping and root exposure over a narrow zone immediately inland from the cliff. This is succeeded by an irregular zone of freshly deposited sand, through which the older vegetation protrudes. The total width of the erosion and deposition zone from the cliff edge varies up to 55 yards, but is generally 20-30 yards. Near the site of the old jetty on the west side there is a large stranded iron barge of unknown origin.

The most important vegetational effect has been the uprooting of coconuts, often leaving surface depressions filled with water. These holes are generally less than 3 feet deep, but may be 2-3 yards in diameter. Direction of tree fall is fairly constant, mainly 50-60°, but in places 25-30°. There is a widespread patchy vegetation between the fallen trees of Stachytarpheta jamaicensis, Euphorbia, Sesuvium portulacastrum, Cyperus planifolius, and grasses, together with a little Batis maritima and Borrichia arborescens. Perhaps 70% of the trees are down.

On the eastern sand ridge the picture is very similar. Shoreline retreat has been minor, but nearshore mangroves are all defoliated. Sophora and Suriana are no longer to be seen, but there is a fairly continuous cover of Borrichia arborescens, with Ernodea littoralis, Stemodia maritima, Euphorbia, Cyperus and grasses. Near the shore the direction of tree fall seems affected by wave action, varying from 340-010° near the mangrove edge, away from the shore, the direction is more constant at 60-70°.

The small amount of damage at Long Cay clearly results from the fact that winds were west and southwest at this point, and heaviest wave and wind action occurred along the mangrove coasts of the island. These were not mapped, and there is no means of telling in detail how they have changed; it is doubtful whether there has been any significant shoreline alteration.

Hat Cay

Hat Cay is the southernmost island on Lighthouse Reef, about 1¾ miles south of Long Cay. It is sandy, with maximum dimensions of 55 x 70 yards, and the surface does not rise more than 2 feet above sea level. Much of the vegetation consisted of mangroves (Avicennia, Rhizophora, Conocarpus), with some Borrichia, Suriana, Sesuvium, Hymenocallis and Sporobolus (ARB 87, 81, Figure 36). The cay was not revisited after the hurricane, but was photographed from the air. The encircling mangrove still stands but is completely defoliated. Much of the interior vegetation has disappeared, exposing bare sand. There has not, however, been any significant change in the size or shape of the cay. This is rather surprising in view of its exposed situation and the dominance of southwesterly hurricane winds.

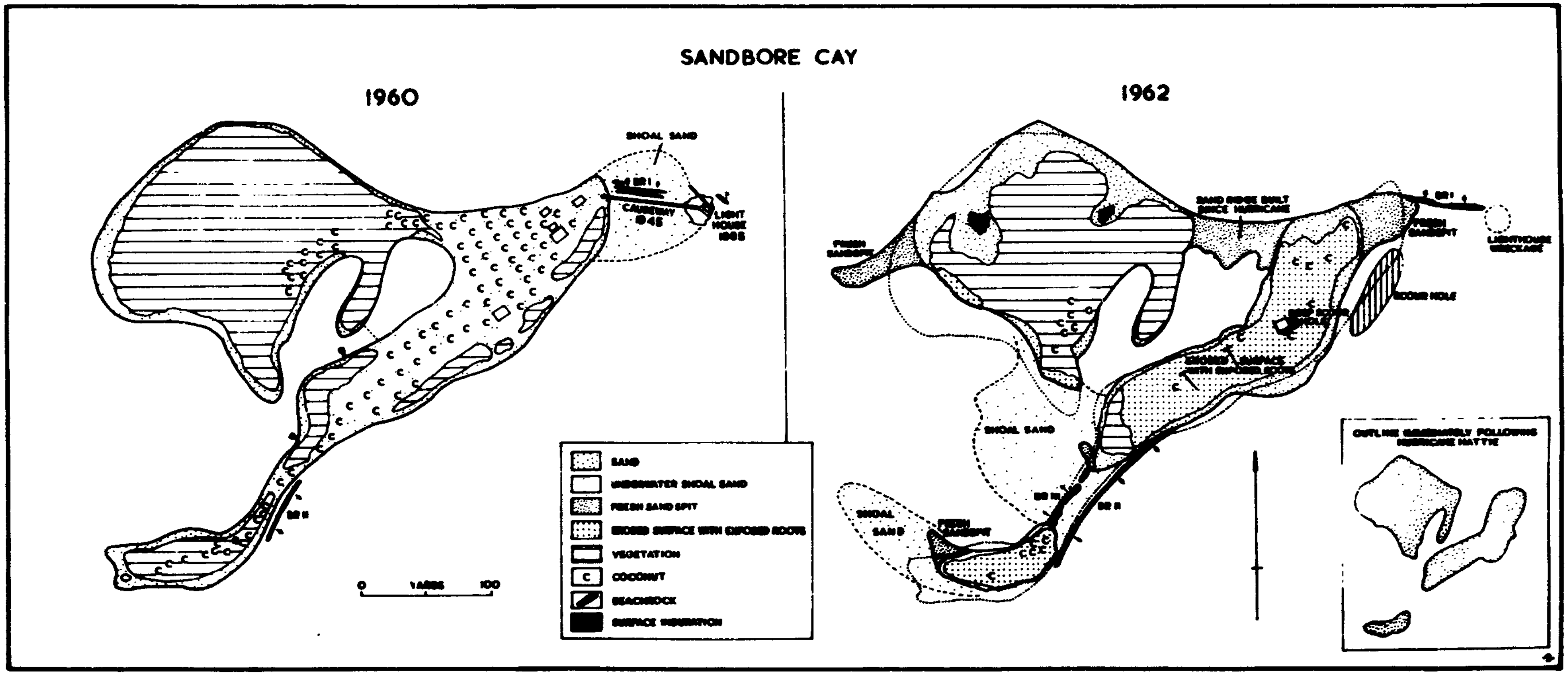

SANDBORE CAY
1960
1962
SHOAL SAND
CAUSEWAY 1945
LIGHT HOUSE 1935
SAND
UNDERWATER SHOAL SAND
FRESH SAND SPIT
ERODED SURFACE WITH EXPOSED ROOTS
VEGETATION
COCONUT
BEACHROCK
SURFACE INDURATION
0 YARDS 100
SAND RIDGE BUILT SINCE HURRICANE
FRESH SANDSPIT
LIGHTHOUSE WRECKAGE
SCOUR HOLE
ERODED SURFACE WITH EXPOSED ROOTS
SHOAL SAND
FRESH SANDSPIT
OUTLINE IMMEDIATELY FOLLOWING HURRICANE HATTIE

FIG. 56

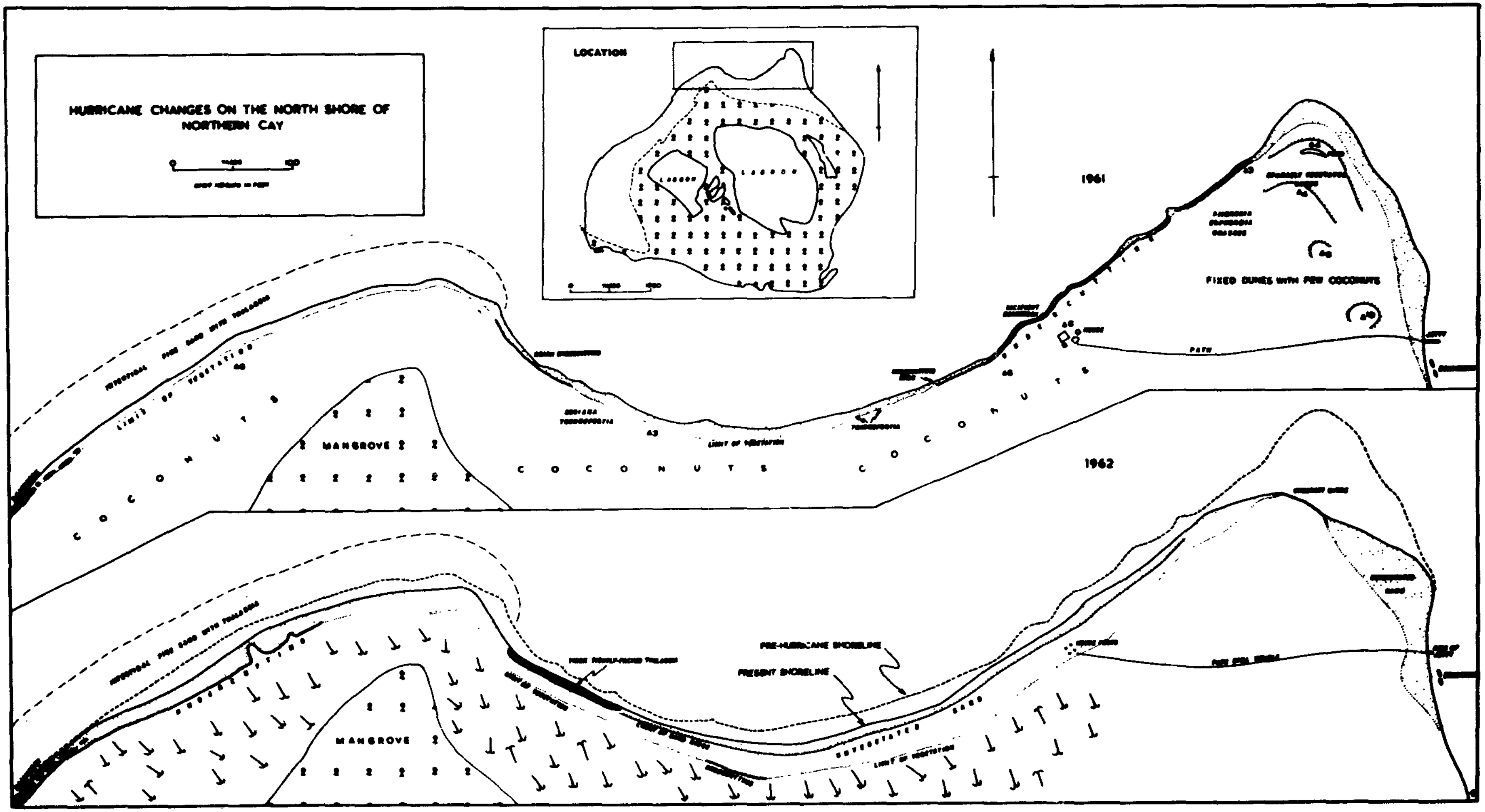
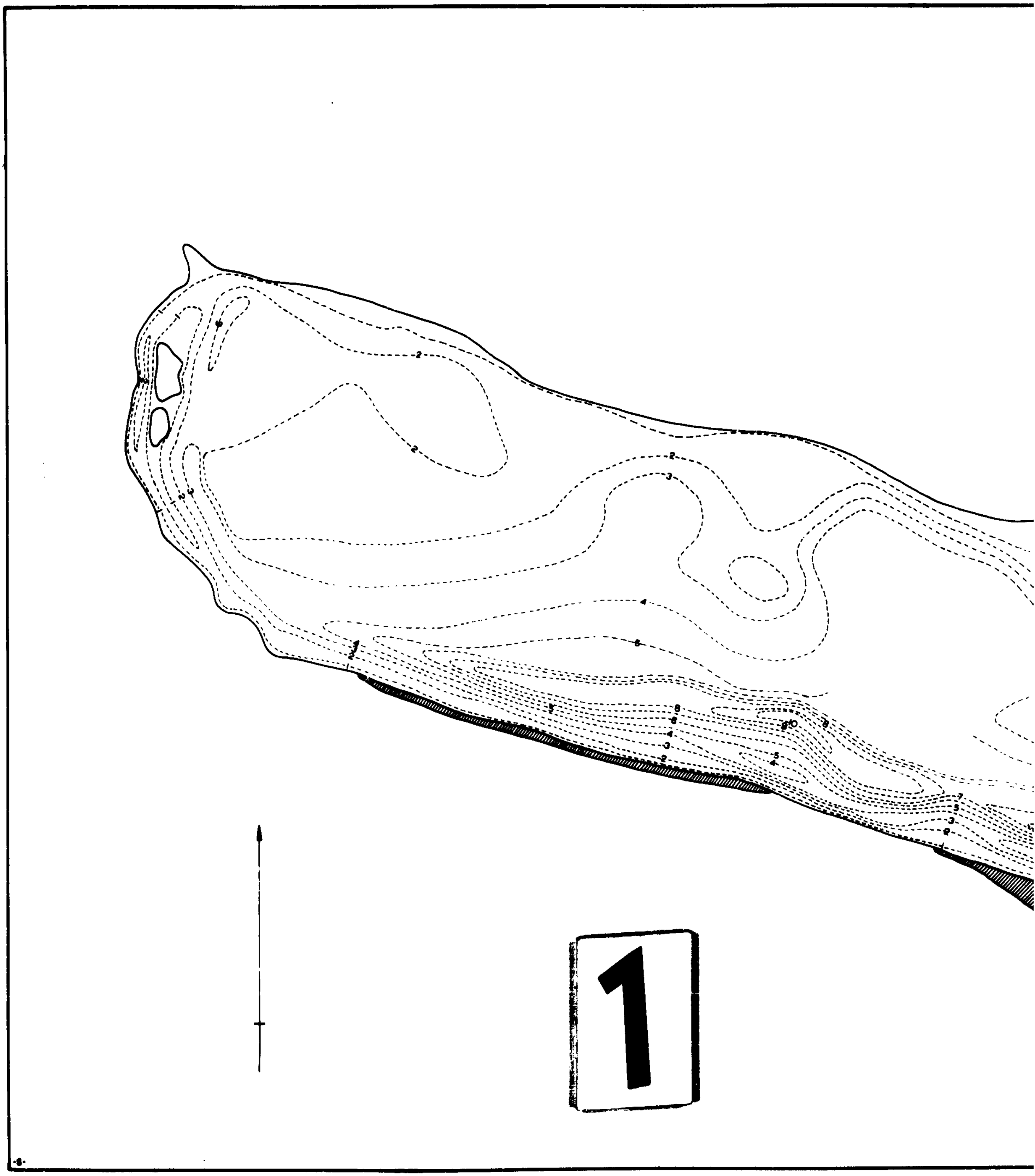

HURRICANE CHANGES ON THE NORTH SHORE OF NORTHERN CAY
LOCATION
1961
1962
FIXED DUNES WITH FEW COCONUTS
PATH
LIMIT OF VEGETATION
COCONUTS
MANGROVE
PRE-HURRICANE SHORELINE
PRESENT SHORELINE
UNVEGETATED SAND

FIG. 57


1

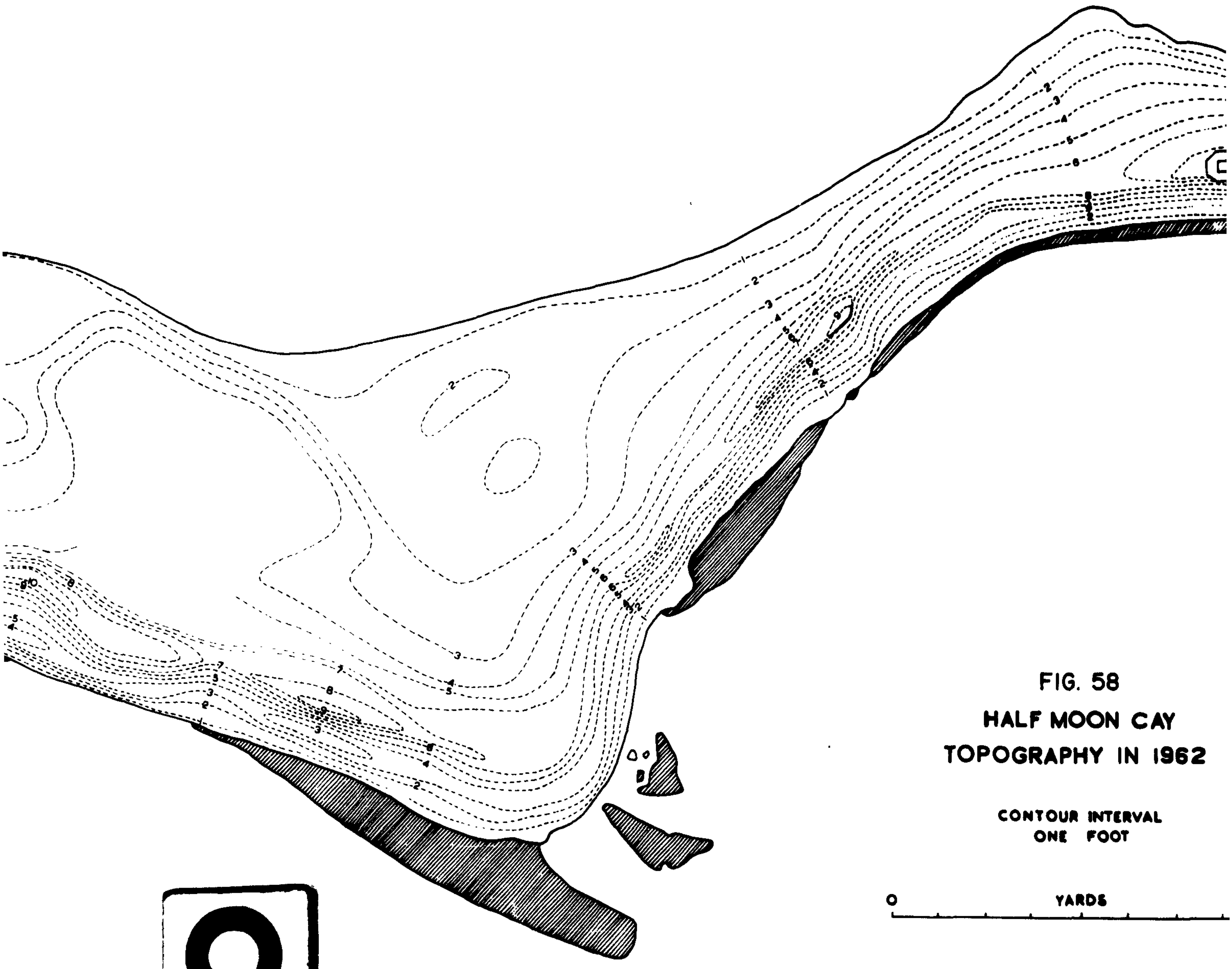


FIG. 58
HALF MOON CAY
TOPOGRAPHY IN 1962

CONTOUR INTERVAL
ONE FOOT

2

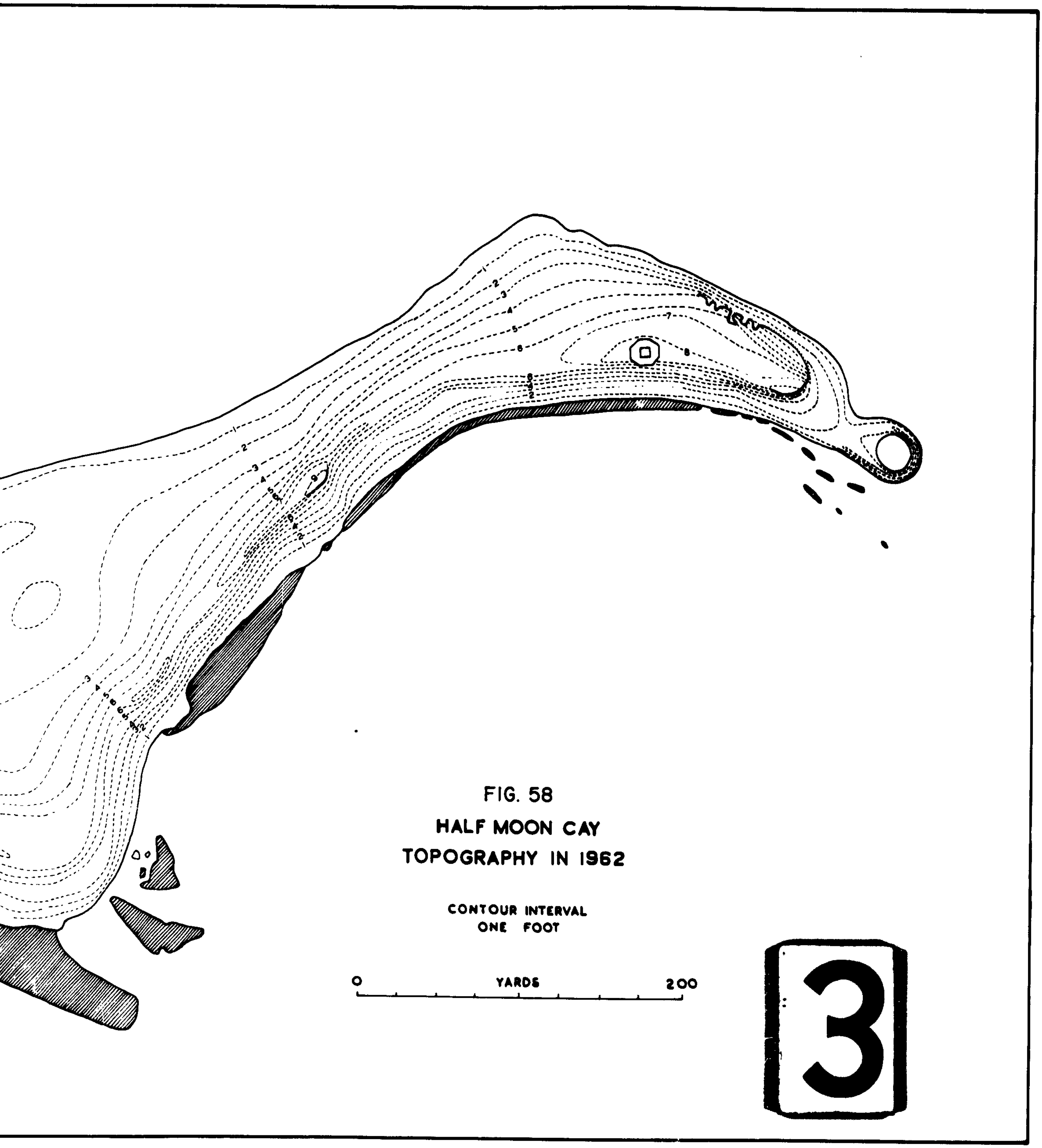
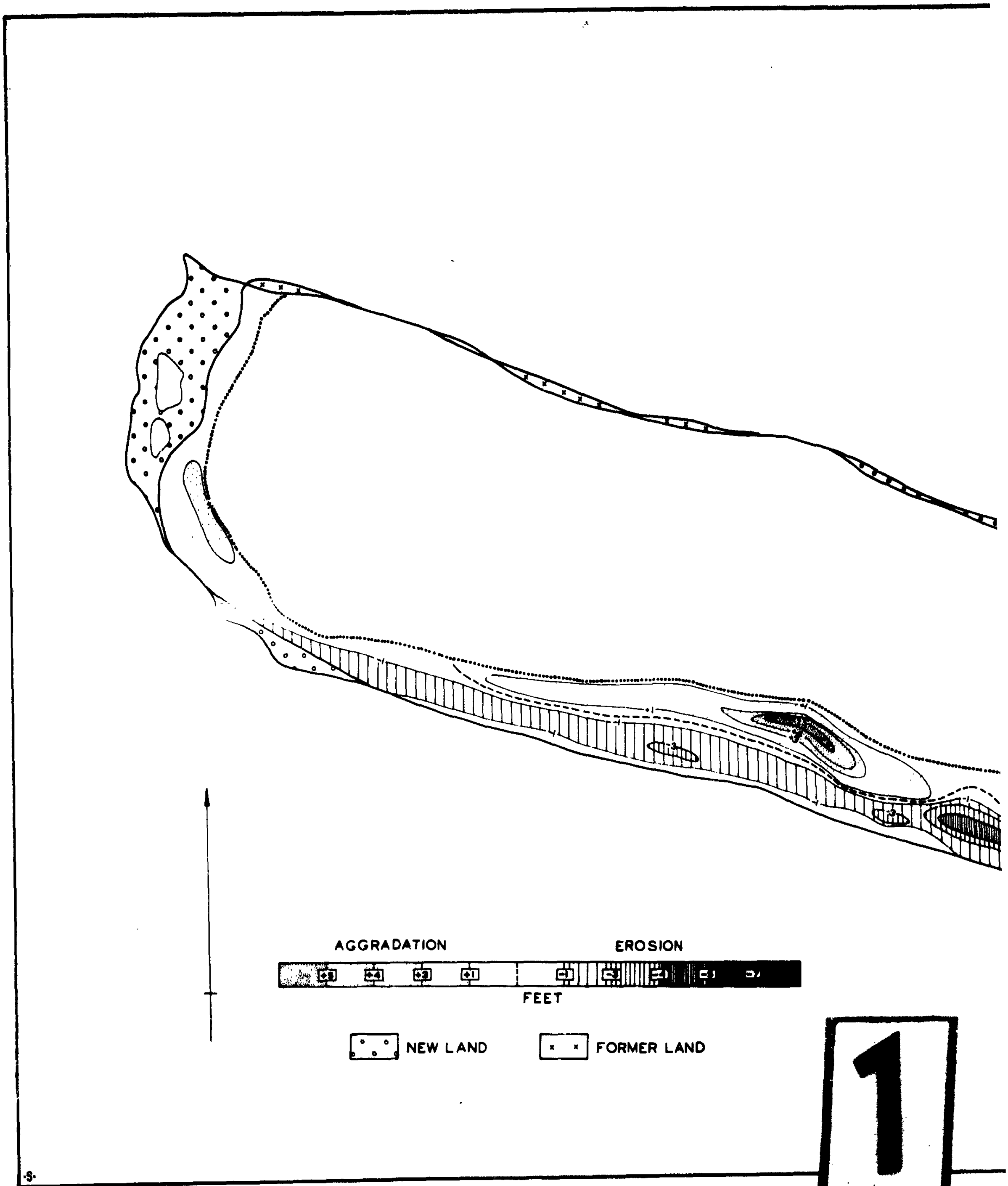


FIG. 58
HALF MOON CAY
TOPOGRAPHY IN 1962



1

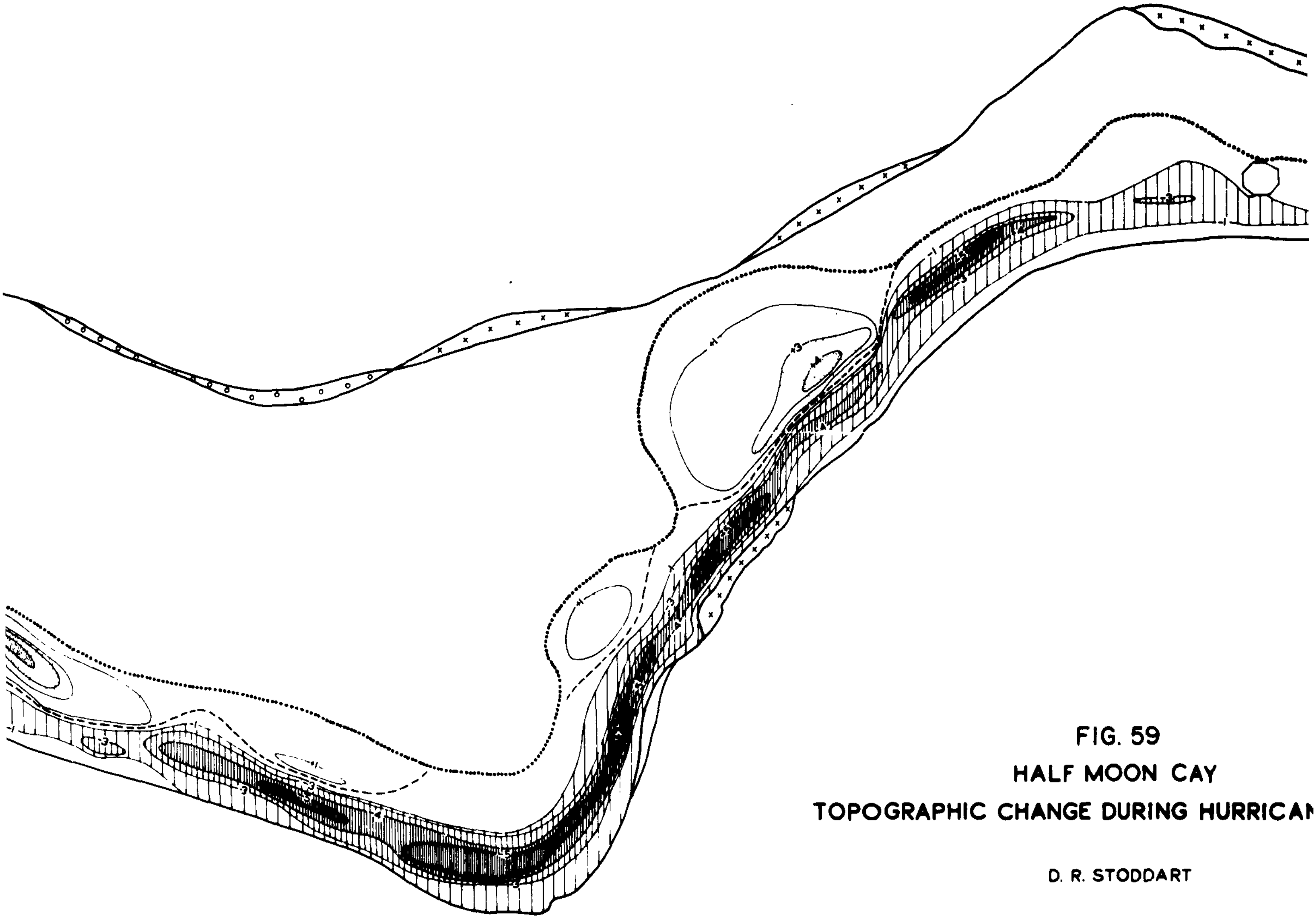


FIG. 59

HALF MOON CAY

TOPOGRAPHIC CHANGE DURING HURRICAN

D. R. STODDART

0 YARDS 2

2

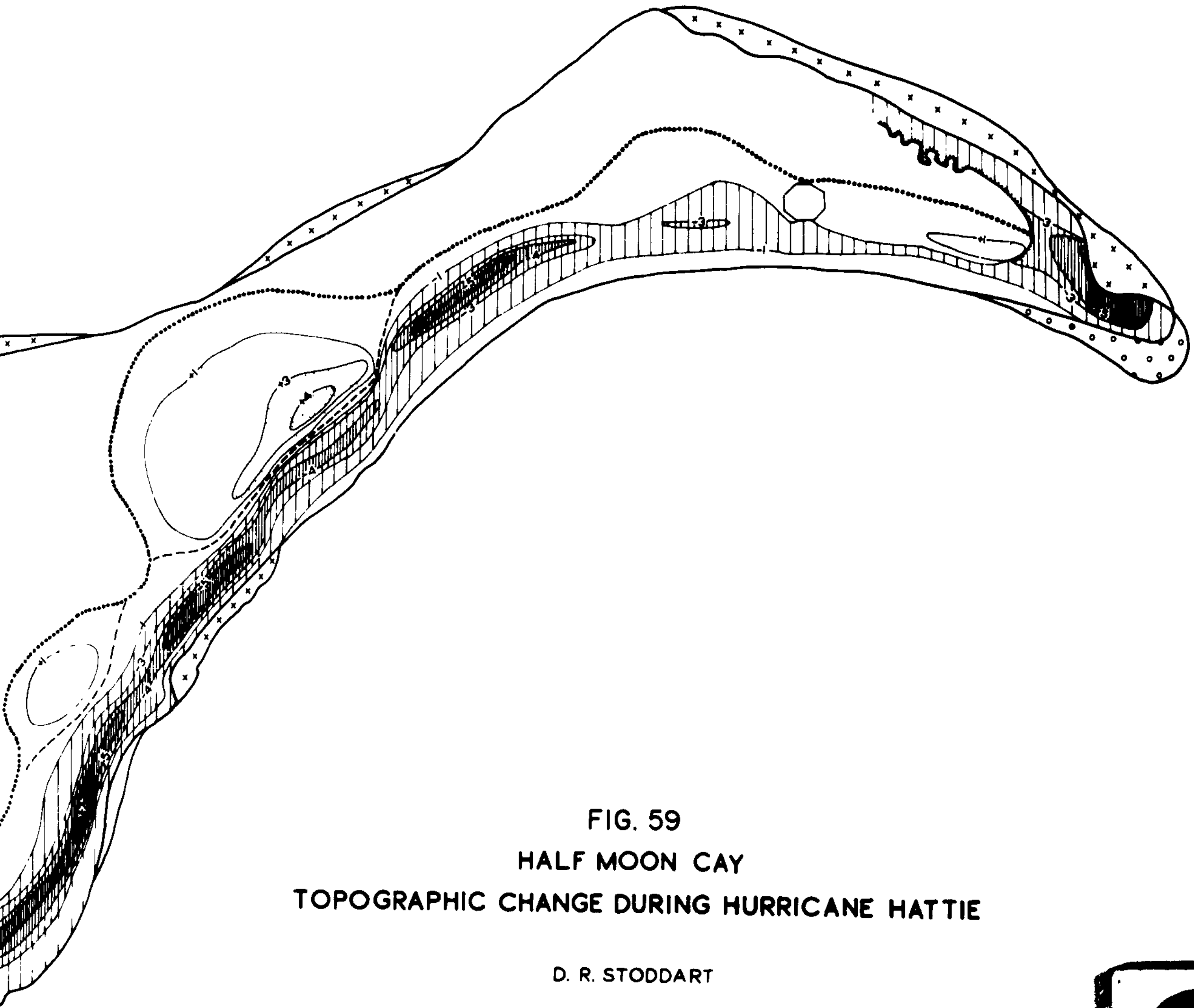
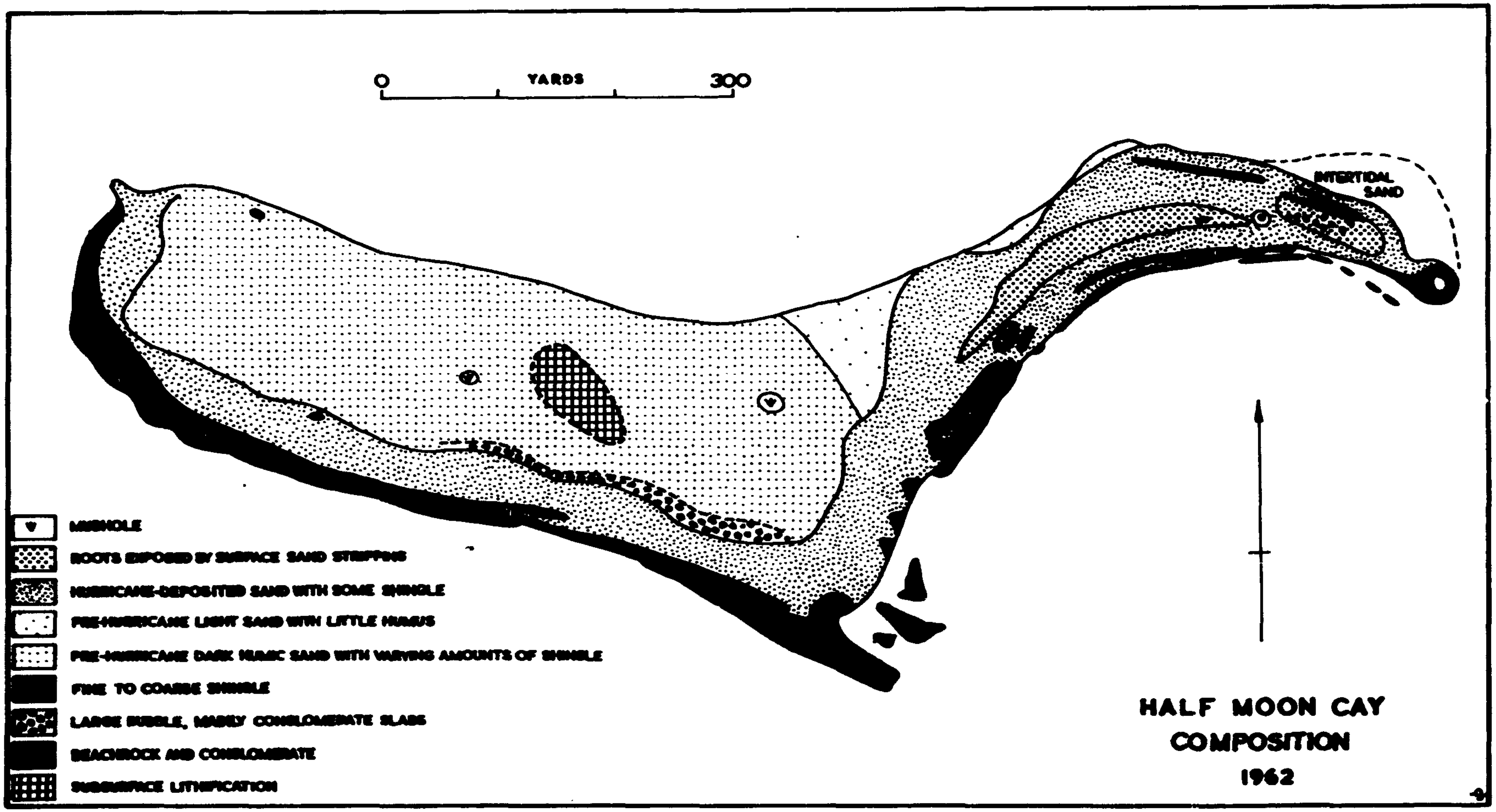


FIG. 59
HALF MOON CAY
TOPOGRAPHIC CHANGE DURING HURRICANE HATTIE

D. R. STODDART

3



0
YARDS
300
INTERTIDAL SAND
ROOTS EXPOSED BY SURFACE SAND STRIPPING
HURRICANE-DEPOSITED SAND WITH SOME SHINGLE
PRE-HURRICANE LIGHT SAND WITH LITTLE HUMUS
PRE-HURRICANE DARK HUMIC SAND WITH VARYING AMOUNTS OF SHINGLE
FINE TO COARSE SHINGLE
LARGE RUBBLE, MAINLY CONGLOMERATE SLABS
BEACHROCK AND CONGLOMERATE
SUBSURFACE LITHIFICATION
HALF MOON CAY
COMPOSITION
1962

FIG. 60

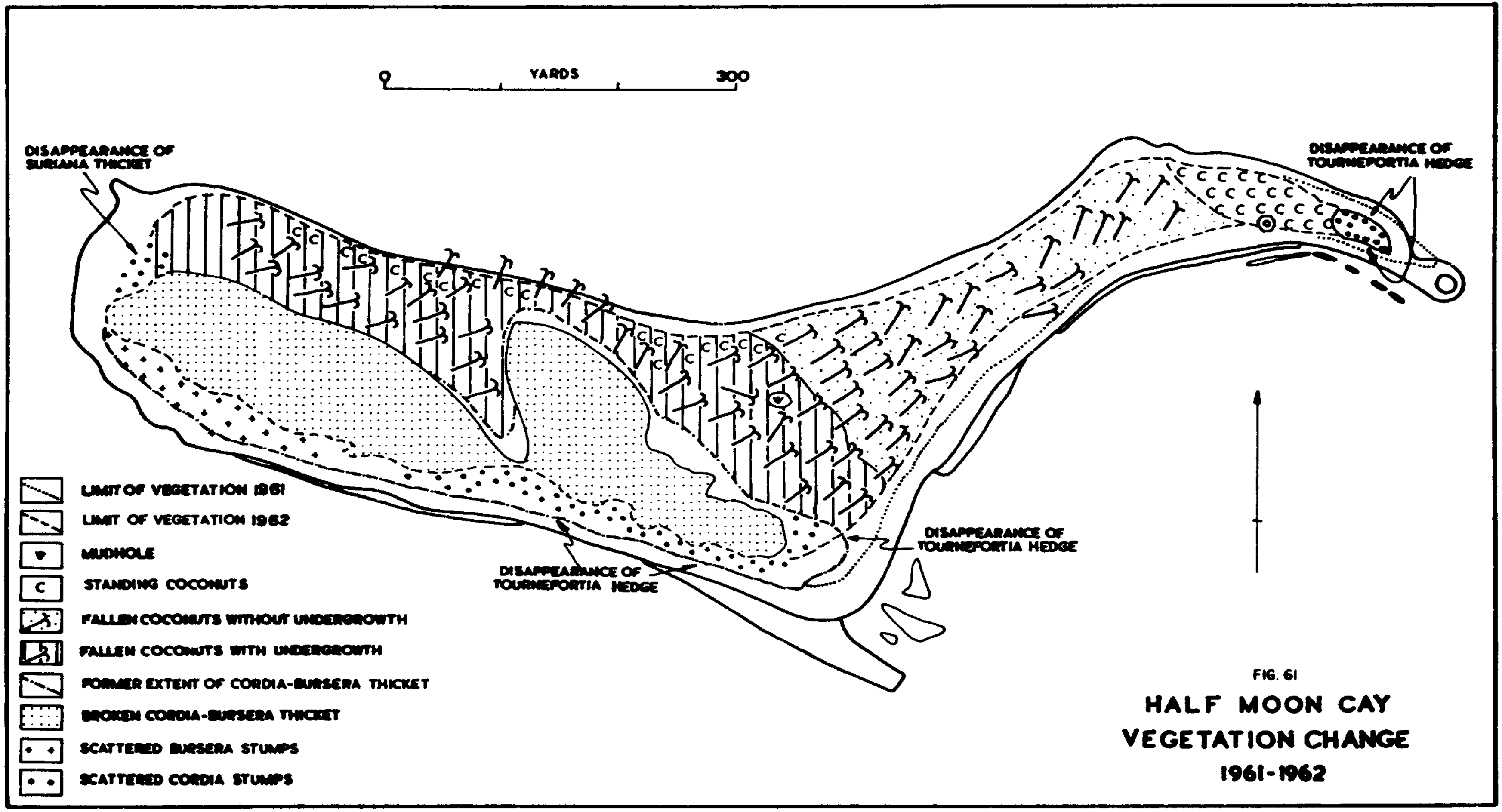


FIG. 61

HALF MOON CAY
VEGETATION CHANGE
1961-1962

VIII. SUMMARY OF PHYSIOGRAPHIC EFFECTS

In the concluding chapters of this report the main physiographic, vegetational and economic changes on reef islands resulting from Hurricane Hattie will be briefly and systematically outlined. References are given to cays which well display the topics discussed, but no extended comparison is made with the few studies of hurricane effects in other parts of the world.

Zonation of Damage

From the detailed descriptions and maps of cays in Chapters 4-7, three main principles concerning physiographic change during the hurricane emerge. These are: first, damage is distinctively zoned away from the storm centre; second, damage is greater on small than on large, and on narrow than on wide islands, at any given distance from the centre; and third, damage is more intense on islands stripped of natural vegetation, or where vegetation has been much altered by man. Discussion of this third point will be found in Chapters 9 and 11.

The zonation of damage is shown in Figure 62, which is necessarily generalised. The zone of maximum or catastrophic damage extends for 15-20 miles north and south of the hurricane track. North of the storm centre winds were northwesterly, veering north and east during the passage of the storm; seas were generally north and easterly, with local northwesterly seas in the northern barrier reef lagoon (Figures 5-10 and 13). South of the storm track winds were westerly, backing south and southeast as the storm passed. Over the greater part of this area, sea level rose considerably, reaching a maximum of at least 15 feet above normal to the immediate north of the storm track (Figure 12-13), and winds throughout the zone probably reached sustained speeds of up to 150 mph. A number of small cays disappeared in this zone (Cay Glory, Paunch Cay, Cay Bokel, St. George's East Cay and others); some were completely stripped of larger plants (Sergeant's, Goff's and English Cays); the physiography was in all cases much altered, mainly by marginal erosion, stripping of surface sand, and channel-cutting; and great damage was caused to human habitations, lighthouses and jetties. Mangrove was completely defoliated, lost branches and was in places uprooted (Drowned Cays, Turneffe Islands).

North and south of this central area is a second zone, 15 miles or more wide, subject to less extreme though still very violent wind and wave conditions, but largely unaffected by the storm surge, except to an undetermined extent north of the storm track, as at Cay Caulker. Physiographic changes in this zone were generally minor, being restricted to shoreline retreat and cliffing, and minor nearshore erosion and deposition, but vegetation, especially coconut trees, suffered heavy damage. In places, as at Cay Caulker, where the vegetation had been partly cleared before the storm, waves were able to cross the cay and excavate scour holes and channels. Otherwise as at Tobacco, South Water and Chapel Cays the dominant effect was tree fall. Mangrove in this zone escaped defoliation in the centre of large islands, and in early 1962 was already beginning to recover leaves on the sides of islands in the lee of hurricane winds and waves.

A third zone includes the cays between Placencia and Gladden Spit, central barrier reef lagoon, where the main hurricane winds blew from the south with restricted fetch across water 15-25 fathoms deep. On most of these islands the vegetational effects were insignificant, but all had sand or shingle deposited on their south and east shores (as at Trapp's, Laughing Bird, Scipio and Colson Cays). Vegetation damage was only considerable on Bugle Cay, which had been cleared for coconuts: considerable shoreline retreat accompanied the destruction of the vegetation. This zone lies 30-40 miles south of the hurricane track; it is not duplicated to the north in British Honduran waters, where the barrier reef lagoon is very shallow and the cays few in number; to this extent it appears to depend on local conditions.

Finally, the cays of Glover's Reef and the southern barrier reef and lagoon suffered no vegetational and little or no physiographic damage, apart from insignificant shoreline readjustments (as at Long Cay North, Glover's Reef), which may or may not have resulted from the hurricane itself. The cays of Glover's Reef lie only 40 miles south of the storm track and the small degree of damage may result from the fact that dominant water movements were parallel in direction to the southeast reef of the atoll, on which the cays stand. At Punta Gorda, sustained gale force winds were insufficient to cause defoliation of mangrove or physiographic changes to the cays off Punta Ycacos. The zone of no damage is not found on the British Honduras Coast north of the hurricane track, except in the northern part of the Bay of Chetumal, and on the mainland Yucatan coast north of Boca Bacalar Chico, but these areas were not investigated.

Erosional Effects

Underwater

1. Damage to reef. Destruction of living corals was greatest on the barrier reef immediately north of the storm track, where up to 80% of reef corals disappeared, presumably transported by wave action into deeper water. The extent of reef damage has been fully discussed in Chapter 3 and Figure 14 and will not be repeated here. In terms of the zonation of cay damage, maximum reef damage occurred in Zone I, depending largely on exposure to waves, and to a lesser extent in Zones II and III; only in Zone III, where damage was moderate, was any large amount of reef material thrown above high tide level. Reef damage in Zone IV was negligible.

2. Submarine Slumping. The only example of submarine slumping discovered was that at Crickozeen Creek, on the west side of Turneffe Islands, between the mangrove rim and the edge of the bank, where physiographic evidence indicates rotational movement of a sector of bottom sediment (Chapter 6). It is not clear why such slumping should be so restricted in occurrence, nor what factors caused slumping at this one point.

3. Erosion of scour holes and channels. No significant change was caused to underwater topography by the hurricane; even where large scale destruction of reef corals occurred, this only extended to the removal

of a thin living veneer of reef material from the surface of reef patches. The patches themselves, and the reef flats, survive with very little change. Where such shoal areas are covered with Thalassia, it is a simple matter to observe the distribution of scour holes and channels cut through the vegetation mat. Such features can be seen at Goff's and Big Calabash Cays; they are shallow and unimportant features, with steep and overhanging sides, and it is clear that the vegetation has prevented further erosion. One is not justified in assuming that where the vegetation mat does not exist, erosion has been general, on the same scale as the cutting of the scour holes and channels; it may be that local weaknesses in the Thalassia mat have simply concentrated erosion at these points. Comparison of air photographs before and after the storm, even in areas where reef damage was extremely severe, reveals very little change indeed in shallow-water vegetation patterns (e.g. on the east side of Turneffe, at Calabash Cays and Cockroach Cays). Channel cutting has only been considerable where water movement has been restricted by islands, as between the mangrove cays of the Drowned Cays, barrier reef, or through the narrow creeks on the west side of Turneffe Islands. The overdeepened channels may be dozens of yards long and several fathoms deep, with steep and overhanging sides and meandering courses within the general meandering pattern of the creeks themselves. Where not so constricted, channels are v-shaped in plan and generally cut into the lagoon-edge of reef-flats; none have cut back more than a few yards into the reef-flat surface, and their depth is restricted. Constricted channels are now occupied by fast tidal streams, which probably limit infilling; unconstricted channels generally contain fairly still water, and may be expected to fill in fairly rapidly. Unconstricted channels are minor features; all large channels, such as those near the edge of the coastal shelf between Cays Chapel, Caulker and Ambergris, are in fact little- or un-altered pre-hurricane features.

Subaerial

1. Destruction of cays. A number of cays disappeared altogether in Zone I, including Paunch Cay, St. George's East Cay, Cay Glory, Cay Bokel, Big Calabash East II Cay, Blackbird Cay, some of the Cockroach Cays, and Saddle Cay. All of these except Paunch Cay were vegetated, though in the case of Cay Glory the vegetation only consisted of low-lying grasses, prostrate plants and a very young coconut; others had mature trees, including tall mangroves and coconuts. Most were low-lying; all except St. George's East Cay were predominantly sandy, with a little nearshore rubble, and all were small. St. George's East, a shingle cay, was the largest island to disappear: before the hurricane it was 120 yards long.

2. Marginal Erosion. Retreat of cay shorelines has taken place in Zones I, II and III. All material above sea level and for several inches below it has been eroded away, in a zone up to 20 yards in width, generally greatest near the hurricane centre and on the side of the cay facing main hurricane winds (east to the north of storm centre, southwest to the south). This has left a vertical cliff, usually 1-2 feet high, capped by a mat of coconut roots from which all sand has been flushed. In places this cliffed shoreline is fairly straight; often the presence of near-shore coconut boles holding up promontories has given it an intricate

outline. Occasionally one finds pillar-like remnants of the old cay standing outside the present cliffline, as at Soldier and Big Calabash Cays; these too are steep-sided and capped with coconut roots.

3. Destruction of unconsolidated spits. This was probably universal throughout Zones I - III, but by early 1962 fresh spits of similar general form had in most cases regrown at or near the old location, as at English Cay.

4. Channel-cutting. Cutting of channels through cay surfaces was limited to Zone I, in the area covered by the high sea surge, and to cays with coconut or other thin ground vegetation. Scouring of deep channels occurred at St. George's Cay, and shallower channels at Mauger and Sandbore Cays, all across narrow necks of land. Incipient channels were seen at Half Moon Cay and Deadman V Cay, extending headward from the lee side of cays, and at Cay Caulker, where roadways transverse to the seaward shore were overdeepened in the village.

5. Scour holes in cay surfaces. Erosion of scour holes by overtopping waters was widespread in Zones I - III. They were generally developed at the margin of some obstacle to water flow, such as buildings (Sandbore Cay) or the upturned boles of trees, using as a nucleus the holes left by roots. Holes at Cay Caulker are elongate and not apparently related to any obstacle. At Half Moon Cay scour holes were seen in the lee of shingle ridges deposited by the hurricane itself. Scour holes have also been seen along the lee shores of cays, where overtopping waters reached the lagoon (Cay Chapel, Cay Caulker).

6. Stripping of surface sand. Where cays were overtopped by the storm surge in Zone I or had their margins submerged by heavy wave action in Zones II - III, stripping of loose surface sand was almost universal, though generally confined to a narrow marginal strip up to 30 yards wide, immediately inland from the undercut cliffline. Decrease in elevation was generally less than 1 foot, but this involved the removal of all or most surface sand and soil, revealing long coconut roots and occasionally orange Thrinax roots. These are sometimes combed in the direction of water movement, as at Deadman V and Big Calabash Cays. Frequently in Zone I the coconut roots form a surface mat several inches thick, devoid of sand though littered with fresh debris; in Zones II-III, however, the exposed root mat is much thinner and rests on tightly packed sand, as at South Water Cay.

7. Erosion of consolidated deposits. Beachrock has been remarkably successful in resisting erosion, especially underwater. However, at Half Moon Cay, where the conglomerate platform is much pitted and eroded, wave smoothing is apparent on the surface, where several large projecting blocks have been torn away. In the southeast bay the outer margin of the beachrock has suffered considerable damage; large plates were broken off and thrown onto the shore or uptilted in the water against the unbroken beachrock. The only consolidated deposits to disappear were incipient beachrocks of small extent, such as a beachrock seen in 1961 near the north point of Northern Cay. Clearing of algal mats on beachrock also revealed much fracturing, which may have existed before the hurricane.

8. Uprooting of coconut trees in Zones I - II could leave holes in the cay surface up to 3 yards in diameter and 3 feet in depth, which were liable to scouring by waves near the shore. These holes may reach the water table, and many are now filled with water, giving surface a pock-marked appearance, as at Long Cay, Lighthouse Reef.

9. Finally, cliffing and undercutting of sand areas could take place well above sea level during violent wave activity, as on the southeast sand ridge at Half Moon Cay, where undercutting and ridge retreat has formed a vertical cliff 4 feet high just below the ridge crest and 20 yards from the sea.

Depositional Effects

Underwater

1. Deltas and deposition cones of sand at the mouths of scour channels between cays, as at Drowned Cays, and at the leeward end of creeks, as on the west side of Turneffe, are found in Zones I - II.

2. Deposition cones are also found at the leeward ends of scour channels cut through cay surfaces. They are beautifully developed at St. George's Cay, Zone I.

3. Shoaling in nearshore areas, by deposition of material eroded from cay surfaces, especially sand. This is well seen in the Sandbore Cay lagoon, Zone I.

4. Scattering of large blocks on reef flats. In view of the great destruction of reefs it is surprising that so-called 'negro-heads' or reef-blocks throw up onto reef-flats during the storm are almost non-existent. Immediately after the storm it is said that more small reef debris was visible above sea level, at least on the northern barrier reef, but by early 1962 most of this had disappeared. Only at Big Calabash Cay, Turneffe, and Cary Cay, central barrier reef lagoon, are any large blocks now stranded on reef-flats.

5. Deposition of rubble carpets. This is much more widespread in Zones I - III, though the amount of deposition is still small compared with Jaluit. Carpets are best developed along the old reef crest, where they rise to within a few inches of the surface, occasionally emerging as low ridges, and terminating lagoonward in steep faces. They are best seen along the barrier reef, as at Cay Glory and Carrie Bow Cay, and on the Turneffe east reefs. In places the shingle lacks this well-defined ridge form and is spread in a thinner, wider carpet, with imbricate palmata slabs, as at Goff's Cay.

6. Ephemeral reef-crest shingle ridges consist only of the emergent portions of these carpets. None are more than 3 feet in height and most only a few yards long. Immediately after the hurricane they may have been more extensive than when seen in early 1962. The ridges at Soldier Cay, Carrie Bow Cay and Skiff Sand are probably in the process of destruction.

7. Presumably the great amount of reef material destroyed in Zone I has been swept into deeper water on the seaward and lagoonward slopes of reefs; much of it may lie at depths of 50 feet or more. Much vegetable material has also been dumped in deeper water: in the northern barrier reef lagoon trees are seen on the lagoon floor and even emerge above the surface at distances of several miles from cays. No investigations were made of conditions on lagoon floors or in deeper water.

Subaerial

Submarine depositional features are of minor importance, and with the exception of the St. George's Cay deltas, none are spectacular. Subaerial depositional features are physiographically significant, more so in some areas than in others. They are not well developed in Zone I on the barrier reef, but are found in the same zone on the east side of Turneffe; they reach their most typical development in Zone III, where erosional effects are minimal. Part of the difference in Zone I lies in vegetation: on the barrier reef the cays were low, small and coconut-covered. With the coconuts swept away, and submerged by the storm surge, the island itself would present little obstacle to the passage of sediment. On the atolls, however, most of the cays were densely vegetated and most of the vegetation remained in place during the storm, acting as a barrier to sediment movement and resulting in the piling-up of debris. To illustrate this one may contrast the mainly depositional effects at Cockroach II (Pelican) Cay, covered with Bursera-Cordia bush; and the different picture at Cockroach Cay itself, covered with easily-destroyed coconuts, where most surface sand was stripped, no shingle ridges were built, and deposition was limited to accumulation of sand in the leeward bay. There is a similar contrast between deposition on the Cordia-Bursera covered south shore of Half Moon Cay, and erosion on the coconut-covered southwest shore. Finally, in Zone III one may contrast the widespread deposition on densely vegetated islands such as Colson, Scipio, Owen, Trapp's and other cays, and the considerable erosion on Bugle Cay, which had been cleared for coconuts. Subaerial deposition takes the following forms:

1. Littering of heavily eroded surfaces with coarse coral rubble, often of small calibre, as at Cockroach Cay and Sandbore Cay, Zones I and II.

2. Accumulation of coral shingle and sand against vegetation barriers: this occurs at Cockroach II and Half Moon Cays (where debris is piled up to a height of 10 feet above sea level), and on several of the central barrier reef cays, such as Owen and Laughing Bird Cays.

3. Deposition of wider, thinner carpets, generally of sand, on the cay surface, especially inland from the marginal erosion zone already described, in Zones II and III. This feature is typically seen at South Water, Trapp's, Scipio and Colson Cays. The carpet may be up to 30 yards wide, wedging out seaward and thickening landward, terminating on the landward side in a steep face, often arcuate in plan. The sand buries the old cay surface, which may retain its vegetation and soils, to depths of up to 2 feet. Even where the sand is deepest the taller vegetation may protrude through it and survive (especially Thrinax); where thinner, Hymenocallis is often still visible and living. Such carpets were seen at Placencia

in 1961 on the day they were deposited by Hurricane Anna. Burial of old soil horizons by carpets, mostly of rubble, was described at Jaluit after Typhoon Ophelia (Blumenstock, editor, 1961); in British Honduras rubble carpets are distinctly rare, except where they form parts of ridges piled against vegetation barriers, as at Cockroach Cays.

4. Deposition of shingle ridges round the old cay shore, which may itself have suffered erosion. Again, these are typically developed in Zone III, where the ridges may or may not adjoin the old shore for all their length. In places the main ridge may lie some yards to seaward, enclosing a low-lying shingle carpet or open water between it and the eroded shore (Colson, Scipio, Trapp's Cays). In this case the calibre of the material is coarsest in the ridge, and much finer in the enclosed zone. These offshore ridges may pass laterally into ridges built against and on the shore itself.

5. Extension of leeward shores by sand deposition. This was noted by mapping at Cockroach Cay and Deadman I Cay along the greater part of the leeward shore; minor extensions of shorelines by deposition was also noted at Half Moon Cay and elsewhere.

Incidental Physiographic Effects

The most important incidental physiographic effect on cay physiography was the increase in number of outcrops of cemented sands. These have been described individually in this report, and in general terms in ARB 87, 106-109. They may be grouped as follows:

Intertidal beachrock

The name 'beachrock' is here restricted to the narrow strips of cemented beachsands, which generally dip seawards, following the line of the shore, are of very limited vertical extent, and are characteristically found on retreating beaches or on reef-flats marking the sites of former shorelines. In British Honduras beachrock and beachsands contain much *Halimeda* and encrusting red foraminifera. New exposures resulting from Hurricane Hattie were of three types: (a) old relict beachrock covered with later sediments has been re-exposed, as at Goff's Cay, Carrie Bow Cay, and partially at Paunch and Curlew Cays. (b) Incipient beachrock noted in 1960-61 has been revealed by shore retreat and stands away from present shore as true relict beachrock; this is well shown on the lee shore of South Water Cay and the south shore of Sandbore Cay. (c) In other areas shore retreat has revealed beachrock the existence of which was not previously suspected. This is well shown on the lagoon shore of Sandbore Cay, and in the peculiar islandward-dipping beachrock on the seaward shore of Carrie Bow Cay. None of this beachrock stands above or below its intertidal location; its position reveals horizontal shifts in shoreline location only. At Carrie Bow Cay, two lines of fresh beachrock have been revealed marking the position of a former ephemeral sand-spit, which in 1960 was subject to overtopping by waves: it is difficult to see how fresh groundwater could have played any part in the formation of this rock, in the manner Russell (1962) has described. Most of the new intertidal beachrock varies considerably in degree of cementation, but all consists of typical beachsands. The reverse-dipping beachrock at Carrie Bow Cay is well-cemented, that marking the ephemeral spit is very soft. Many of the softer exposures, especially on seaward shores, may not survive against wave attack for a sufficiently long period for the secondary cementation which Russell indicates is necessary for complete lithification. No fresh beachrock anywhere in British Honduras approaches the toughness of long-exposed examples, such as that at Half Moon Cay. Examination of hand samples shows that freshly exposed beachrock consists of loosely bonded particles in a very friable cement, with many open spaces; whereas in older beachrock the grains are tightly cemented into a solid mass with few interstices, except where the grains are large, dominantly Halimeda, where interstices still remain open.

While it is true that beachrock exposures are only associated with retreating beaches, as Seymour Sewell (1935, 511) and Stanley Gardiner (1930, 16) recognised, the British Honduras data shows quite clearly that massive beachrock may form on stable, and even aggrading shores, as on the interior lagoon beach of Sandbore Cay. In this instance, the thickness of beachrock on the stable lagoon shore much exceeds that on the eroding seaward shore. Beachrock clearly forms beneath beaches, not at the surface; where incipient beachrock outcrops at the foot of beaches, it may be traced inland beneath beach sands, in the same way in British Honduras as mapped by Russell elsewhere in the Caribbean. The cause of reverse dip in beachrock is unknown: its occurrence at Carrie Bow Cay and Southwest Cay II, Glover's Reef (ARB 87, 97), suggests that it may be a more widespread phenomenon than previously recognised. Widespread evidence of retreat of cays across reef flats suggests that reversed beachrock may have been formed on lagoon beaches and exposed on seaward shores as the cay retreated completely across it; but such an interpretation needs more substantial evidence. The role of beachrock as a stabilising element in cay physiography has often been stressed: thus Steers (1937, 12) writes that "the formation of beachrock on any coral islet off the Queensland coast is a stabilising factor, and the permanency of an islet probably depends more on this factor than on any other". The presence of many exposures of relict beachrock off present cay shores shows that this protection is at best imperfect; during Hurricane Hattie no instance was seen where the presence of beachrock restricted shore retreat, when compared with nearby areas lacking beachrock. By contrast, well-developed and undisturbed natural vegetation appeared much more effective in cay preservation.

Cay Sandstone

Cementation of cay sands above sea level was described by Kuenen (1933, 86-88) and Seymour Sewell (1935, 502-512), but on account of its less distinctive characteristics and infrequent exposure it has not often been described. Moresby (1835, 159), Seymour Sewell (1935, 502-512) and Stanley Gardiner (1907) noted it in the Maldive Islands, where Gardiner termed it "tuffe"; Kuenen also noted it in the East Indies (1933; 1950, 434-435). Following Hurricane Hattie, there is little doubt that rock exposures on the British Honduras cays formerly interpreted as possible raised beachrocks are in fact cay sandstones. Such rocks are best exposed at Harry Jones Point and Big Cay Bokel, Turneffe. The rock has an almost horizontal upper surface, but may dip laterally along the beach with variation in the height of the cay surface itself. The upper surface is smooth when fresh, but becomes blackened, pitted and eroded on exposure to the atmosphere. Undermining after exposure along the shore may lead to the breaking off of slabs of rock, which then lie on the shore at the angle of the beach, and where thin may be confused with intertidal beachrock. This is well seen at Northern Cay, Lighthouse Reef. Typically, cay sandstone lacks the large unbroken Halimeda grains, large fresh red Homotrema, and distinctive vertical size-grading of intertidal beachrock. Its constituents are finer, and the cementation in fresh samples is superficial and poor. After exposure it appears that a secondary cementation takes place, analogous to that which Russell demonstrates for intertidal beachrock (1962), resulting in a tough, ringing rock; this was in fact noted long ago by Moresby (1835, 400).

Cay sandstone is normally exposed by retreating shores; at Cay Chapel it has been revealed by stripping of surface sand across the front slope of a beach ridge. Here it forms an inclined plate, dipping seaward though well above sea level, and still very friable. After four months of exposure the surface was etched into hole-and-ridge patterns often associated with wind erosion in deserts (Cotton, 1942). Nearby, the same rock is seen in a beach scarp, covered with 12 inches of uncemented sand and soil, with vegetation. Similar though weaker cementation was seen at Cay Caulker, in overdeepened roads transverse to the seaward beach. Nowhere was cay sandstone seen to be overlain with more than 3 feet of uncemented sand. It is presumably associated with percolation of rainwater to the water-table, and was not seen on any cay without a known fresh-water lens.

The recency of the cementation, and formation at the present altitude are beyond dispute. At Harry Jones, cay sandstone contains Maya pottery. Most newly exposed surfaces contain coconut roots within the rock matrix. At the inner edge of the exposed area, these roots may be followed up into overlying undisturbed sand. Further, cementation beneath cay surfaces is less advanced than on exposed areas: this is well shown by a scour hole cut through the cay surface into underlying cay sandstone at Northern Cay, Lighthouse Reef (Figure 63). Here a weak horizon of cementation was exposed on all sides of the scour hole, with uncemented sands both above and below. Outcrops of cemented material, too restricted to determine form, as at South Water Cay, are here interpreted as cay sandstones, rather than resort to hypotheses of warping or eustatic fluctuations of sea level. It should be noted that this re-interpretation of the Harry Jones exposure removes what evidence there was for movements of this kind at Turneffe Islands (ARB 87, 109-111): no feature of these cays now requires any recent high stand of the sea in explanation of it.

Promenade Rock

This name is used here for the cemented material comprising a restricted topographic feature, the promenade, described by Steers initially from the Great Barrier Reef Islands (1929, 252-256; 1937, 27, 119) and in greater detail for the Morant Cays, Jamaica (1940a, 39-40: 1940b, 309). At Morant Cays Steers found platforms with eroded, horizontal upper surfaces, showing no apparent dip, 12-18 inches above sea level, composed of beach sands and similar to true beachrock. The rock surface appeared to be recemented and was much harder than the interior. Promenades always occurred on the windward sides of cays. The similarity of these promenades with the conglomerate platform at Half Moon Cay has been previously noted (ARB 87, 107). During Hurricane Hattie, low-lying platforms of cemented sand and rubble were exposed by severe shoreline retreat at Deadman I and II Cays, Turneffe, where previously only a small patch of supposedly incipient beachrock had been seen. These resemble the Half Moon Cay exposures in everything except degree of cementation. It appears that cementation of sands, shingle and rubble must take place beneath cays at and slightly above sea level, and that this cemented material has been exposed by erosion. The cementation is sufficient to preserve the form of the promenade, but not for the collection of specimens. As in the case of beachrock and cay sandstone, it seems likely that secondary cementation occurs once the promenade is exposed, to transform it into solid resistant rock. Whether the Deadman exposures will survive long enough for the secondary cementation to take place has yet to be seen. As in the case of cay sandstone the important conclusion is that promenades form beneath cays at their present elevations: and that they are not indicators of relative change in land or sea level. This explanation does not preclude the possibility that elevation or depression has occurred, through tectonic or eustatic causes; but it does mean that without other evidence, promenades and cay sandstone exposures are not in themselves sufficient indicators of such movements.

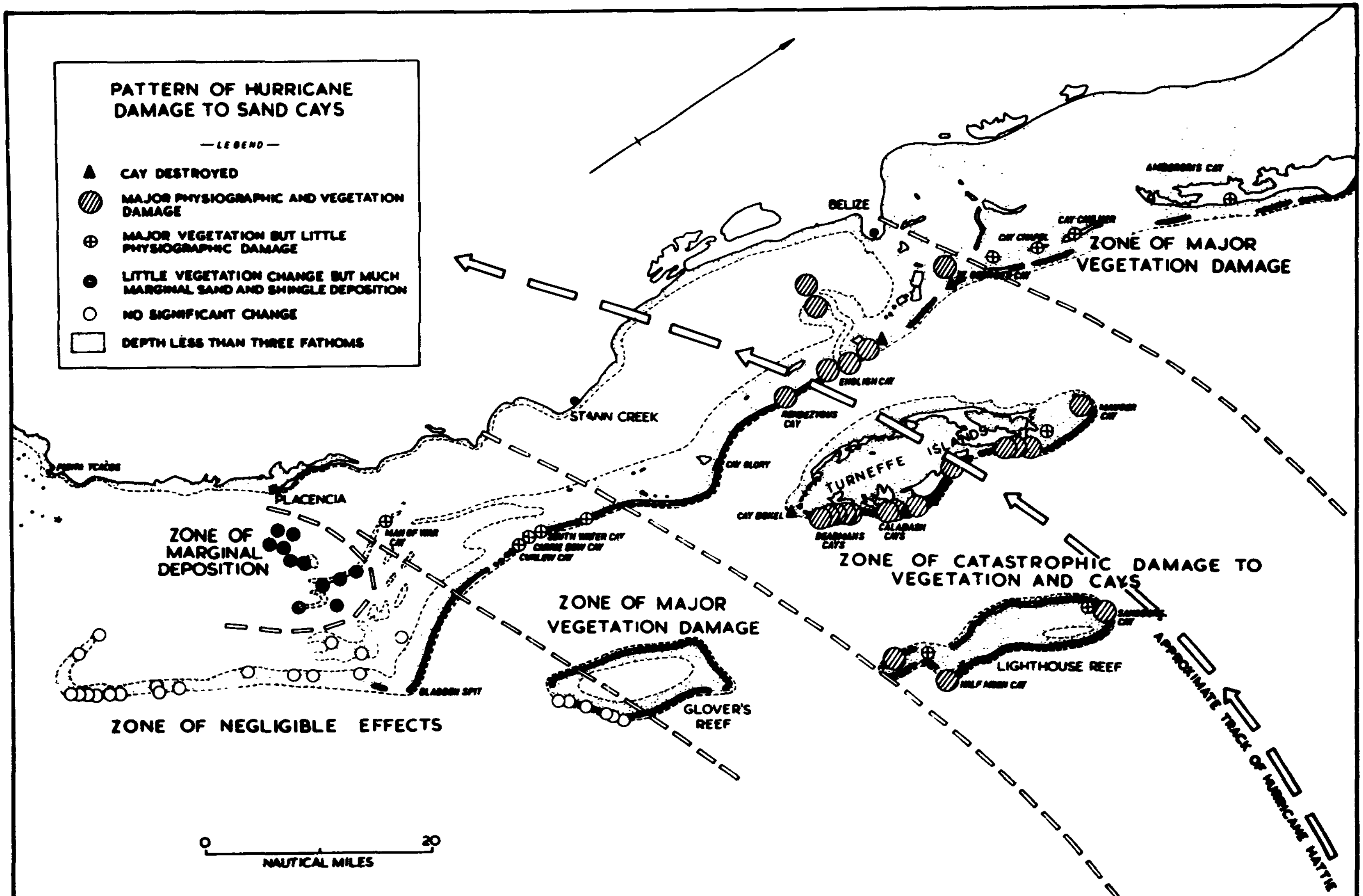
Shingle Rock

At Cockroach Cay II the exposure of a very coarse shingle rock, cemented by a brownish cement, has been described in Chapter 6. The cement appears superficially similar to that in the central part of Half Moon Cay, and in the two fresh exposures of the same rock on that island. At Cockroach II the present topographic form of the shingle rock is similar to that of the Cay Chapel cay sandstone: it lies on the face of the beach ridge, is restricted in area with very steep sides, and dips seawards. The main point of difference is in the brown cement. In this connection it is interesting to note that both islands where this occurs have substantial areas of Cordia-Bursera bush.

Other Rock

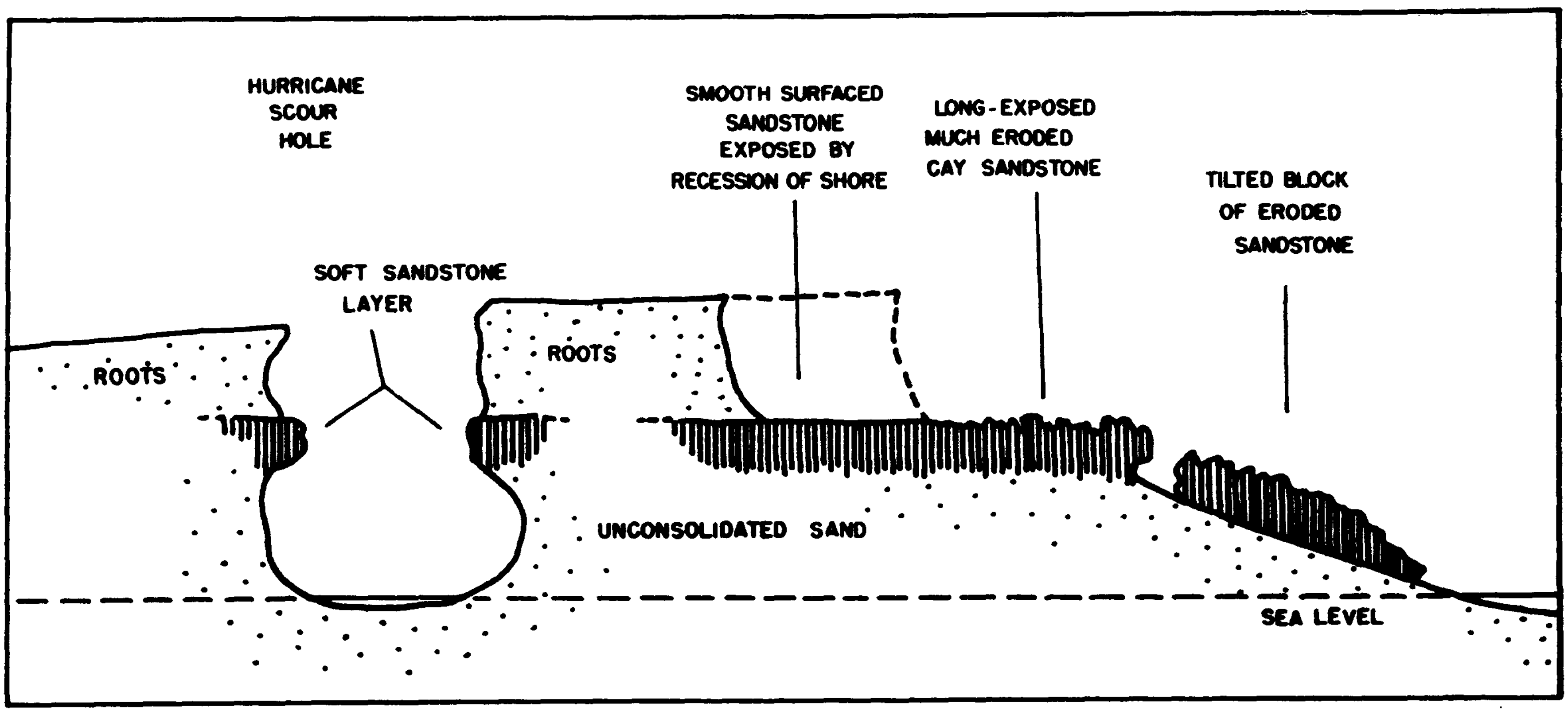
Finally, surface incrustation of sands, perhaps resulting from inundation by salt water during the hurricane, has been described at Sandbore Cay, Lighthouse Reef. This is very friable and thin, and there is no evidence that lithification will proceed sufficiently to form a significant topographic feature.

Apart from the Cockroach II shingle rock and the interior cementation at Half Moon Cay, cemented materials on cays appear to consist of cay sandstone, promenade rock, intertidal beachrock, and a few other exposures which may be intermediate between these groups. Seymour Sewell was "by no means fully convinced" (1935, 501) of the distinction between cay sandstone and beachrock. Cay sandstone formation is apparently associated with fresh water percolation (Kuenen, 1950, 434-5); and Russell (1962) has recently assembled evidence to show that primary cementation in beachrock formation is also associated with the presence of a freshwater lens. While there are many examples, some cited in this report, where it is difficult if not impossible to accept the role of freshwater in beachrock formation, chiefly on locational grounds, it is pertinent to enquire, if Russell is correct in the cases he describes, what the essential differences are between intertidal beachrock and other rocks associated with fresh water but developed well above high tide level. If there is, in fact, no essential difference, then the usefulness of beachrock as a reliable indicator of changes of level must be very much reduced, in spite of the fact the field exposures of the two types of rock are characteristically completely different.



PATTERN OF HURRICANE DAMAGE TO SAND CAYS
— LEGEND —
CAY DESTROYED
MAJOR PHYSIOGRAPHIC AND VEGETATION DAMAGE
MAJOR VEGETATION BUT LITTLE PHYSIOGRAPHIC DAMAGE
LITTLE VEGETATION CHANGE BUT MUCH MARGINAL SAND AND SHINGLE DEPOSITION
NO SIGNIFICANT CHANGE
DEPTH LESS THAN THREE FATHOMS
BELIZE
ZONE OF MAJOR VEGETATION DAMAGE
ENGLISH CAY
STANN CREEK
TURNEFFE ISLANDS
CALABASH CAYS
PLACENCIA
ZONE OF MARGINAL DEPOSITION
ZONE OF CATASTROPHIC DAMAGE TO VEGETATION AND CAYS
ZONE OF MAJOR VEGETATION DAMAGE
LIGHTHOUSE REEF
HALF MOON CAY
GLOVER'S REEF
ZONE OF NEGLIGIBLE EFFECTS
APPROXIMATE TRACK OF HURRICANE HATTIE
0
20
NAUTICAL MILES

FIG. 62



Section of Cay sandstone at Northern Cay

FIG. 63

IX. VEGETATIONAL EFFECTS OF THE HURRICANE

Vegetation Types and Zonation of Damage

Damage to vegetation at any place during the hurricane depended on the local storm conditions (largely a function of distance and direction from the storm centre); whether the vegetation was affected by direct submergence and wave action or by the wind alone; the type of the vegetation; the species involved; and the nature of the substrate. The main vegetation types of the British Honduras cays correspond quite closely with those described for the Florida Keys by Davis (1942) and the Jamaican cays by Asprey and Robbins (1953). We may briefly differentiate the following types:

1. Beach vegetation, locally differentiated according to substrate and exposure.
2. Interior vegetation on cleared sand cays.
3. Marginal vegetation, forming a low thicket at the top of the beach, between the beach vegetation and the interior woodland or palm thicket; differentiated according to substrate and aspect.
4. Woodland, mainly Cordia-Bursera thicket.
5. Palmetto woodland, mainly Thrinax.
6. Coconut plantations, with or without undergrowth. Other introduced plants are grouped as Type 6a.
7. Acrostichum marsh.
8. Rhizophora marsh.
9. Avicennia woodland.
10. Interior vegetation on dryland areas of sand-mangrove cays.
11. Submarine vegetation.

1. Beach vegetation

This typically consists of prostrate vines, low herbs and some grasses (Sauer, 1959). Species include Ipomoea pes-caprae, Sesuvium portulacastrum, Euphorbia mesembrianthemifolia, Cakile lanceolata, Vigna luteola, Sporobolus virginicus. Damage largely depended on the degree of hurricane modification of the substrate itself, and to a lesser extent on direct effects on plants. Thus if a beach has been shifted landward and vertically eroded, the vegetation on it will obviously have been destroyed. Near-shore vegetation on exposed beaches in Zones I - III was therefore damaged, the destruction extending right across the island in the case of some cays in Zone I. Where inundation occurred without beach erosion, the best survivors are the grasses; other plants such as Ipomoea and Sesuvium seem to have been swept away by wave action.

2. Interior vegetation

Except where artificially cleared, most cay surfaces beneath coconuts are covered with a low mat of herbs, grasses, etc., often in distinct zones. Species include Stachytarpheta jamaicensis, Ipomoea pes-caprae, Canavalia rosea, Euphorbia mesembrianthemifolia, E. blodgettii, Cyperus planifolius, Fimbristylis cymosa, Wedelia trilobata; grasses such as Eragrostis, Sporobolus and Andropogon; bushes such as Ernodea littoralis, Erithalis fruticosa and Rivina humilis; and the lily Hymenocallis littoralis. Near the margins, especially of small cays in Zone I, damage resembles that to beach vegetation: sand-stripping and deposition of sand and shingle may destroy or damage vegetation over a peripheral zone up to 60 yards wide, but generally less than 20 yards wide in Zones II - III. In Zones II - III the interiors of cays were not submerged by the storm surge and the ground vegetation suffered no considerable change. Clearly, therefore, the relative amount of marginal destruction and lack of change in the interior will depend on the size and shape of the cay concerned. Burial near cay margins appeared to kill all plants except trees and the lily Hymenocallis, which often protrudes through sand carpets.

3. Marginal vegetation

This rather unsatisfactory name is applied to a typical vegetation of bushes 3-6 feet tall at the top of the beach, forming a transition zone between the beach vegetation and interior woodland or coconuts. Constituent species differ with substrate and aspect: Tournefortia gnaphalodes is typical on exposed shores, especially on shingle, Suriana maritima on more protected shores, especially on sand. Other bushes, often stunted, include Coccoloba uvifera, Borrichia arborescens and Conocarpus erectus, with Sporobolus, Hymenocallis and other low beach and interior plants. In Zone I, where the rise in sea level and violence of wave action both reached a maximum, this vegetation type has disappeared. Re-location of beaches has destroyed all mature Tournefortia and Suriana on Lighthouse Reef, Turneffe Islands and the northern barrier reef. Sophora tomentosa has also disappeared in this zone. Damage in Zones II and III was much less, but even at South Water Cay, where beaches suffered little change, Tournefortia and Suriana have markedly decreased through wave action.

4. Woodland

This group includes the remnants of a presumably once more extensive cover of woodland and thicket on the cays, the greater part of which has been removed for coconuts since the European occupation. It typically consists at Half Moon and Cockroach Cays of dense, often spray-swept thickets of Bursera simaruba and Cordia sebestena, forming a canopy at a height of 20-30 feet. On Half Moon Cay at least there is little or no ground vegetation beneath the thicket. Coccoloba is found round the margins and Ficus and Neea towards the interior of the thicket. In Zone I damage to this thicket was of two types: direct wave damage round the margins and wind damage in the interior. The first, which often involved erosion and deposition of beach material, led to uprooting of trees or stripping of sand and soil from their roots. Consistently in these circumstances Bursera remained in the position of growth better than Cordia; Coccoloba was also seen uprooted, though generally still in situ. Near-shore trees not uprooted generally lost all their leaves and most branches, and many are now only twisted and broken stumps. At the limit of wave action on larger islands trees were buried by shingle, as at Half Moon and Cockroach Cays. The interior part of the woodland which escaped wave action also lost all or most leaves and many branches; as a result I estimate that the height of the canopy at Half Moon Cay decreased by at least 50% as a result. Larger trees such as Ficus were uprooted and overturned. However, in early 1962 leaves were returning to those trees affected only by wind action, in contrast to those which suffered inundation and wave attack. In Zones II and III it is difficult to evaluate hurricane effects on woodland as a whole, apart from individual species, because of its poor development. Judging by individual species, damage in Zone III was negligible.

5. Palmetto woodland

This is a localised type, characterised by stands of Thrinax parviflora similar to those on the Jamaican coast (Asprey and Robbins, 1953, 373). It is confined, at least in pure stands, to seaward shores, and is only well developed in Zone III. Even in nearshore locations most palmettoes survived, even where partly buried by sand and shingle deposits. Thrinax appears more resistant than Cocos to wave and wind action.

6. Coconut plantation

This is the dominant vegetation on sand cays, coconuts having been observed on Lighthouse Reef in 1720 (ARB 87, 63-64), noted on Glover's Reef in 1804 (Henderson, 1812), and being widespread on the barrier reef as early as the second half of the eighteenth century. Coconuts were totally destroyed where cays were washed away during the hurricane, and wherever shorelines were relocated. Post-hurricane shores in Zones I - III are generally lined by fallen trees, giving rise to a miniature cape-and-bay outline. Away from the effects of wave action, wind felled approximately 75% of all trees in Zone I and at least 50% over most of Zone II. Direction of tree fall is shown in Figure 64, which shows a good correlation with the direction of first hurricane-force winds (cf. Figures 6-10); note however that many of these observed directions are influenced by wave action. It seems likely that most tree-fall occurred during these first hurricane-force winds, rather than - as Wiens suggests (Blumenstock, editor, 1961, 21) - during most intense hurricane winds.

In British Honduras these often seem to have followed the storm centre, and would have given directions of fall the opposite of those observed. In Zone I tree fall occurred either by uprooting or snapping above ground level; many trees stood but lost their crowns. In Zones II - III uprooting was most evident along shorelines. Damage to coconuts in Zone II appears to decrease more rapidly north of the storm track than south of it. Thus, while many trees were felled at Cay Chapel, fewer came down at Cay Caulker, where even young trees survive at the edge of the seaward beach; damage was very slight at Ambergris Cay. Cay Caulker is the same distance north of the storm track (25 miles) as Tobacco and South Water Cays are to the south; at the latter islands, 70-80% of the coconuts fell, perhaps partly reflecting the reportedly stronger southerly winds. Many nuts were strewn over non-inundated surfaces, but had not germinated in early 1962. Vegetation under coconuts suffered little damage away from storm surge areas. Most species still survive (see type 2).

6a. Introduced plants

Introduced plants are generally associated with human settlement. Terminalia catappa is one of the most widespread, and survived in Zone II even in nearshore locations; it was not seen before the hurricane in Zone I. Musa paradisiaca was destroyed at Cay Caulker and at coastal settlements near Mango Creek, both in Zone II. Tall pines and a mango tree were overturned at Cay Caulker.

7. Acrostichum marsh

This is limited to the cays of the central barrier reef lagoon and the southern barrier reef (Zones III, IV); it appears to have suffered no ill-effects except where locally buried by sand or shingle near shorelines. Acrostichum inland from Belize (Zone I) is still living.

8. Rhizophora marsh

The major part of mangrove and mangrove-sand cays consists of Rhizophora, which is also found in small quantities round the shores of some sand cays. In Zone I both nearshore and interior Rhizophora was exposed to inundation and severe wave action; elsewhere interior Rhizophora was affected by wind alone. Throughout Zone I mangrove was completely defoliated, damage being greatest on windward shores and on small islands. In the interior parts of the Turneffe mangrove defoliation was less severe, and trees had regained some leaves by early 1962. This suggests that inundation and direct wave action play a large part in leaf stripping and perhaps in killing individual trees. On smaller islands, and on the Turneffe mangrove areas, the beginnings of leaf re-growth on the leeward sides of cays (i.e. west side to the north and east side to the south of the storm track) was noted in April-May 1962 at points north of St. George's Cay; and at Southern Long and Cross Cays. These points are respectively 12 miles north and south of the storm track. Within this zone, about 25 miles wide, defoliation was total on small cays, and none at this time showed signs of regeneration. Individual plants were liable to defoliation as far south as Laughing Bird Cay, nearly 40 miles south of the hurricane centre, but a high proportion of mangroves escaped defoliation at distances of 30-40 miles from the centre. After the hurricane, mangrove cays in the most devastated area had a distinctly reddish appearance from the air, and destruction of the leafy canopy revealed large areas of standing water and bare mud, particularly in the Drowned Cays and islands northwest of Belize. Individual Rhizophora trees showed extraordinary stability, typified by the survival of a dead Rhizophora ring at Big Calabash Cay II and Blackbird Cay, where the enclosed island disappeared under wave attack. Seedlings, on the other hand, disappeared in large numbers, and had not re-appeared in early 1962. The details of mangrove cay topography, especially shoreline form seen in plan, are virtually unaltered by the hurricane, as air photographs demonstrate.

9. Avicennia woodland

This is insufficiently developed on the cays affected by the hurricane to merit separate comment. Like Rhizophora it suffered defoliation in Zones I - II, and in exposed situations was liable to overturning, loss of branches and reduction to a stump.

10. Interior vegetation on cleared mangrove cays

Many mangrove cays have small dryland areas with coconuts and ground vegetation, as at Mauger Cay, Weewee, South Rendezvous Cay and Cat Cay. Typical plants include Batis maritima, Cyperus planifolius, Chloris petraea, Euphorbia sp., Conocarpus, Coccoloba, and Thespesia populnea. Except where inundated by the storm surge, and apart from overturning of coconuts and other tall trees, damage to this vegetation was slight, and comparable to Type 2, Interior vegetation of sand cays. Where inundated, as at Three Corner Cay and Mauger Cay, large shrubs were liable to uprooting and all plants to destruction by surface sand scouring and channel-cutting.

11. Submarine Vegetation

No systematic observations were made on submarine vegetation. Throughout Zone I larger algae, including Halimeda, disappeared from beachrock and other rocky surfaces near sea level. Thalassia leaves appear to have been stripped by wave action in places, and piled on beaches, as at Northern Cay, Lighthouse Reef, but apart from scattered channel-cutting and hole-scouring, the turf mat was not disturbed.

Summary of Vegetational Effects

Factors leading to vegetation damage thus include:

(a) inundation, limited to a narrow zone north of the storm track and to lower margins of cays;

(b) direct wave action on marginal vegetation and across the entire area of small cays;

(c) effect of water-born boulders and other debris;

(d) horizontal erosion of beaches, greatest in Zone I, also in Zones II - III;

(e) surface stripping of sand, with consequent removal of vegetation and exposure of roots: Zones I - III;

(f) burying by fresh deposits of shingle and sand, common in marginal areas of densely vegetated islands in Zone I and all islands in Zones II - III;

(g) effect of wind in uprooting, snapping off and decapitating trees, especially coconuts, and defoliating mangrove;

(h) effect of wind-driven rain and sea-water.

To some extent these factors are affected by local physiographic and vegetational conditions. Thus, beaches covered by dense vegetation such as Cordia-Bursera thicket are more resistant to erosion than bare beaches: deposition occurs round the margins but most of the thicket remains in the position of growth. Several examples have been noted. Further, the larger the cay, and the further from its shores, the less the damage to vegetation, except in the case of coconuts, which are highly susceptible to wind damage. The probability of catastrophic physiographic damage and hence of vegetation destruction is greater the less dense the vegetation, the lower and smaller the cay, the higher the storm surge, and the greater the wave action.

Vegetation damage takes the following forms:

(a) uprooting, particularly of coconuts, taller trees such as Coccoloba, and shallow-rooted bushes;

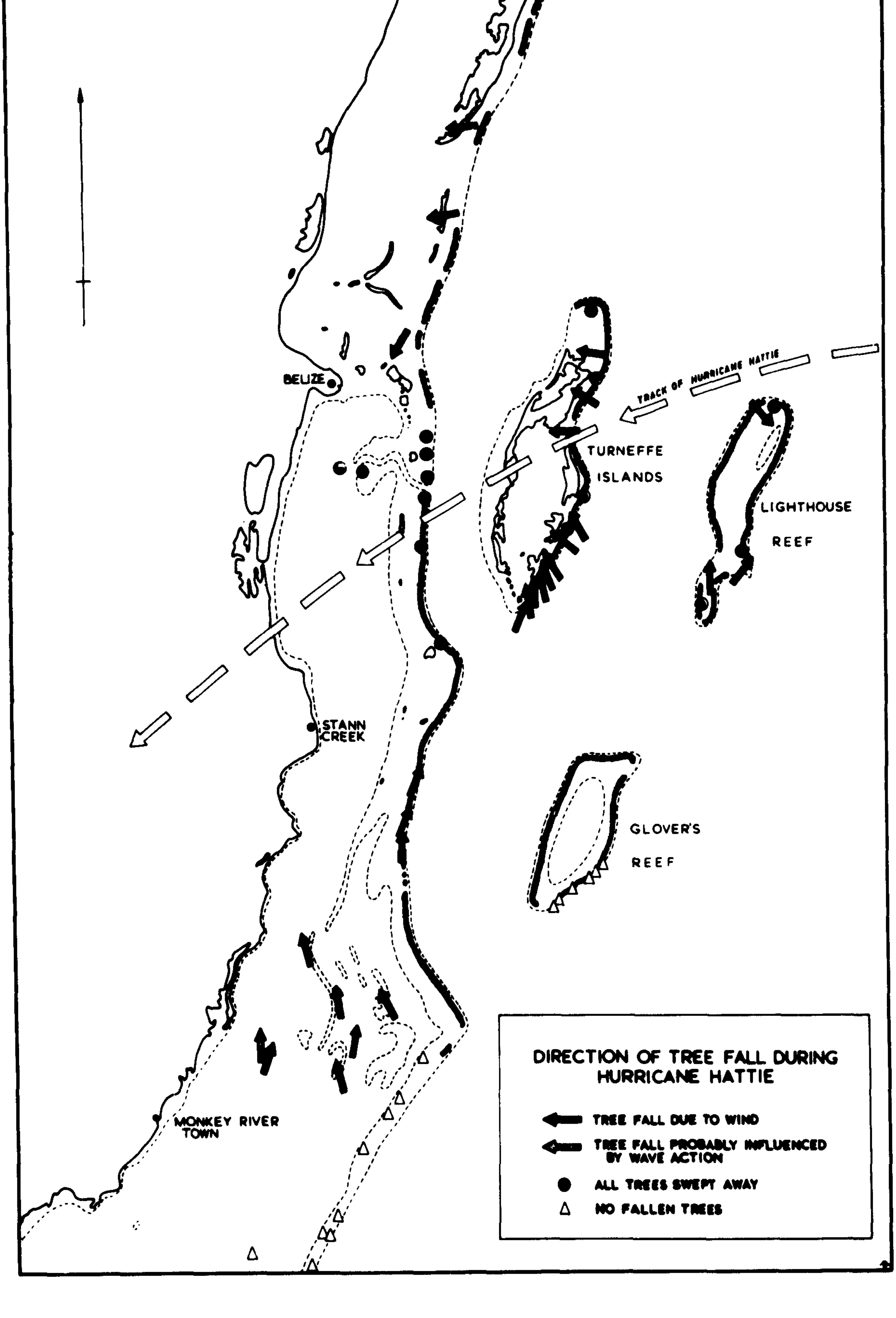
(b) removal of branches and twigs, as in Cordia and Bursera;

(c) removal of leaves, most obvious in Rhizophora, but seen also in Cordia, Bursera and many other plants;

(d) decapitation, confined to coconuts.

All these are superficial physical effects. No account can be given here of such matters as salt-spray soaking, increased groundwater salinity, and possible delayed mortality of injured trees, all of which would require detailed study. To sum up: the most striking vegetational changes associated with Hurricane Hattie were the widespread felling of coconut palms; the widespread defoliation of Rhizophora and other mangrove; and the destruction of beach and marginal vegetation, often through movement of the substrate, involving the complete disappearance over a 30-mile wide area of such characteristic cay species as Tournefortia gnaphalodes and Suriana maritima. These general conclusions relating damage at any point not only to species and vegetation type but to relative degree of wind, wave and surge action, correspond well with those of Fosberg (in Blumenstock, editor, 1961, 51-55) and Sauer (1962). Since no attempt was made before or after the hurricane to make complete enumerations of species on any island, with the possible exception of Half Moon Cay, there is no point in including a detailed species-by-species discussion; for notes on individual species see the cay descriptions in preceding chapters. Fosberg (ibid. 54) noted that _Terminalia catappa_ did not well resist wind damage, but in British Honduras it appeared to survive better than most trees. For a discussion of post-hurricane colonisation by plants, and the significance of differing effects on differing vegetation types in the wider question of cay evolution, see Chapter 11.

FIG. 64


BELIZE
TRACK OF HURRICANE HATTIE
TURNEFFE ISLANDS
LIGHTHOUSE REEF
STANN CREEK
GLOVER'S REEF
MONKEY RIVER TOWN
DIRECTION OF TREE FALL DURING HURRICANE HATTIE
TREE FALL DUE TO WIND
TREE FALL PROBABLY INFLUENCED BY WAVE ACTION
ALL TREES SWEPT AWAY
NO FALLEN TREES

X. HUMAN AND ECONOMIC RESULTS OF THE HURRICANE

Settlement

Apart from the villages at Ambergris Cay (San Pedro) and Cay Caulker, both with a population of about 300, including a large proportion of Spanish-speakers, settlement on the cays is scattered and generally temporary. Before the hurricane there were fairly permanent settlements on St. George's Cay, a holiday centre; on a few widely scattered privately-owned islands (Tobacco Cay, South Water Cay, Carrie Bow Cay, Northeast Sapodilla Cay, Wild Cane Cay, Frenchman's Cay, on the barrier reef; Northern and Long Cays on Lighthouse Reef; Long and Southwest Cays on Glover's Reef); and on islands with lighthouses, on most of which Government maintained a keeper. Apart from the two villages and St. George's Cay, population of the cays probably did not exceed 150 persons at any time.

Hurricane effects on settlement were greatest in Zone I. On Sandbore Cay the lighthouse was destroyed, and this, Northern and Long Cays are no longer inhabited: only Half Moon Cay on this reef is still settled. On Turneffe, the Mauger Cay light stood but the island was made uninhabitable; hence in early 1962 the light was also out of action. The Cay Bokel light was destroyed, together with the island. Other settlements destroyed include the major coconut clearing centre at Calabash Cays; Soldier Cay and Cockroach Cay. Turneffe now has no permanent inhabitants, in contrast to the 7-8 small settlements before the hurricane. On the barrier reef, English Cay light stood, and though all houses were washed away the cay was re-occupied for navigational reasons almost immediately and houses were rebuilt. The Robinson Point light also stood: here the houses were also destroyed, but since the light is automatic the island has not been re-occupied. Bugle Cay light stood and the cay is still occupied. There was no change at Hunting Cay. Other settlements disappeared at Sergeant's, Spanish and Rendezvous Cays, and almost so at St. George's Cay. The barrier reef islands are now virtually uninhabited between Cay Caulker and Tobacco Cay. Forty-five persons lost their lives during the storm (Table I).

These remarks apply to fairly permanent settlements in houses. Much of the cay population, however, is literally a floating one: fishermen from coastal settlements visit the reefs for several days at a time, sheltering in their boats near islands at night. In some cases they construct palm-thatch huts for short stays, and exceptionally at Cay Glory built a number of houses on stilts on the shallow reef flat for use during the grouper season. This mainland-based visiting continues, particularly in the case of Caribs from Stann Creek and nearby villages, who continue to visit Weewee, South Rendezvous and other cays. The resumption of permanent settlement on the more devastated cays will presumably await their re-vegetation, which may take several years.

Economy

The most widespread economic resource on the cays before the hurricane was coconuts, which suffered heavy damage in Zones I - II, precisely those areas, close to Belize, where they had previously been most heavily exploited. Coconuts planted now could begin yielding after 1970; but it seems unlikely that either public or private capital will be free for coconut investment in view of demands on the mainland and the now-acknowledged vulnerability of the crop. A rehabilitation programme was put into operation following Hurricane Janet in 1955: "the futility (of this) was clearly demonstrated" after Hurricane Hattie, according to a report on agricultural damage by Wilson, Jolly and Chopin (1961). In 1962 coconuts in Belize and other coastal settlements were scarce and expensive, and nuts imported from Ruatan, Bay Islands, found a ready sale.

The complete destruction of boat-building yards at Robinson Point Cay and cessation of boat-building at Cay Caulker have been noted. Small-scale private boat-building continues at Half Moon Cay, but nowhere else. It seems unlikely that boat-building will be resumed on the islands on a commercial basis, and the industry will become even more localised in Belize. The only industries carried out on the cays now are small-scale: "corning" of fish for the Belize market, and domestic production of coconut oil for cooking.

Fauna

No systematic observations were made on land fauna. The pigs at Cay Bokel and Calabash Cays, Turneffe, disappeared during the storm, but those at Half Moon Cay took refuge in woodland and survived. Numbers of chickens disappeared on inhabited cays in Zone I. No observations were made on the survival of rats, Iguana, Ctenosaura, Anolis and other lizards on the cays on which they were found. Conditions after the hurricane were certainly ideal for rats, with much broken vegetation debris. Effects on birds seem to have been negligible. During the passage of the eye, Captain Eustace of the Tactician noted that "hundreds of birds, alive and dead, were clustered round the funnel, among them a few parrots, who were probably speechless"; these parrots must have been blown from the mainland by northwesterly winds, as parrots have only been seen on one island, Placencia Cay, near the mainland. Ospreys were widely nesting on damaged cays in early 1962, and Fregata magnificens in large numbers on Man-of-War Cay, central barrier reef lagoon. As noted in Chapter 7, the nesting period of the red footed booby, Sula sula sula, may have been delayed by several weeks as a result of the storm, though there may be an alternative explanation. After the hurricane one was impressed by the absence of birds from many damaged islands, especially Pelicanus occidentalis and Fregata magnificens from the heavily damaged islands of the northern barrier reef. It is possible that they moved southwards to the undamaged cays in Zone IV. In spite of the increase in area of standing water on many cays, no significant increase in the number of mosquitoes and other biting insects was noticed on any island.

XI. POST-HURRICANE ADJUSTMENTS AND PROSPECT

This final chapter briefly summarises changes in physiography and vegetation between Hurricane Hattie, 30-31 October, 1961, and the time of the re-survey 4-7 months later, notes probable future adjustments in the light of experience at Jaluit Atoll, Marshall Islands, and comments briefly on the ecological implications of the spread of coconuts into this reef area in post-Columbian time and the possible change in dominant hurricane effects which has resulted from it.

Topography

Destruction of the reef in Zones I - II removed an effective baffle which had previously limited wave activity on cay shores. Now waves suffer less bottom retardation at the reef edge, and larger waves reach cay shores. Several fishermen commented on this, which has resulted in a general steepening of cay shores and increasing roughness of anchorages. At the same time, reef destruction has led to the supply of increasing amounts of debris, now predominantly shingle and rubble, but ultimately as this is comminuted, of sand-size material also. This accounts for the rapid regrowth of temporary spits, as at English Cay, and the appearance of unvegetated sandbores, either where no cays had previously been seen (Jack's Cay and the small sandbore north of Goff's Cay) or where cays had long since disappeared (Slasher Sandbore). Where cays had disappeared during the hurricane, construction of embryonic sand cays which do not yet reach the surface has begun, as at Paunch Cay (built of shingle) and Cay Glory (built of sand). Shallow channels cut in cays at water level are in places filling up (northern channel at Sandbore Cay), though at St. George's Cay rapid tidal currents appear sufficient to keep at least four of the channels permanently open. The combined effect of increased wave action, increased debris supply and apparently increased sedimentation will presumably come to an end with the regrowth of reef corals and a return to pre-hurricane conditions. Complete recovery in the more devastated areas may take two decades or more (cf. Stephenson, Endean and Bennett, 1958).

Conversely, as at Jaluit, there is some evidence that constructional shingle features on reef-flats are unstable structures, at least on windward shores. In 1962 shingle ridges round some cays were being destroyed by the flushing out of sand and fine shingle, leaving a lag of coarser rubble. At Jaluit, over a period of three years, large reef-flat ridges on windward shores were pushed toward the island, leaving low rubble tracts or even bare reef flat, though leeward ridges suffered little change (Blumenstock, Fosberg and Johnson, 1961, 619). Topographic features least liable to change are depositional sand and shingle forms above the reach of wave action: these include ridges and carpets of sand and shingle piled on the old cay surface up to heights of 10 feet above sea level. Material in these ridges, which are being colonised by vegetation, may be broken down by weathering, but only further storm action can remove them as topographic features. Scour holes on cay surfaces are liable to slow filling with vegetation debris and wind-blown sand. Presumably areas where surface sand and soil have been completely stripped will also be recolonised by plants, and new soil formed over a period of years.

Vegetation

The main vegetation changes since the hurricane have been the colonisation of fresh sand and shingle areas by plants. On the completely devastated island of the northern barrier reef the chief coloniser was undoubtedly Portulaca oleracea, followed by Euphorbia mesembrianthemifolia and Sesuvium portulacastrum. Other colonisers include Cyperus planifolius, Fimbristylis cymosa, Ipomoea pes-caprae and Cakile lanceolata. Elsewhere in Zone I Portulaca was much less important, and on still-vegetated islands fresh sand carpets were being rapidly colonised by Ipomoea and Sesuvium, rather than Portulaca. Several islands, chiefly on the atolls, showed a considerable increase in Cenchrus, which had previously been kept in check by human interference. Following the destruction of the coconut canopy at Half Moon Cay, Wedelia trilobata seemed less widespread. In spite of the complete destruction during the storm of Tournefortia in Zones I - II, small seedlings were sprouting on most devastated islands in 1962, and may survive to maturity.

Recent spread of coconuts and changing hurricane effects

The great destruction of coconuts and lack of incentive to clear the debris and replant may possibly lead to some reversion to natural conditions on the cays. There is in fact considerable evidence that heaviest devastation on cays occurred precisely where human interference with natural vegetation and clearing for coconuts had progressed furthest. Many examples are given in this report of adjacent islands or even sections of islands where deposition occurred in thickly vegetated areas and erosion in sections cleared for coconuts or houses. If now the coconuts are not replanted, and the cays are allowed or even encouraged to develop a cover of Cordia, Bursera, Thrinax and dense shrubby undergrowth, then in future hurricanes, part at least of the vegetation cover may survive in the position of growth and form a nucleus for sand and shingle deposition, as at Half Moon, Cockroach II and elsewhere in 1961. In this way hurricanes might augment rather than decrease or even destroy reef islands. Complete clearance for coconuts and houses, particularly on seaward shores, as had taken place before 1961 at St. George's, Sergeant's and Rendezvous Cays, is an open invitation to catastrophic damage, and since it is no longer possible to regard hurricanes on this coast as very infrequent phenomena (cf. Appendix 1), the destruction of land, vegetation, property and life under such circumstances is only a matter of time. Cay owners and inhabitants, therefore, must choose between immediate amenity and long-term stability.

In this perspective, it seems at least probable that the known diminution in numbers of reef islands in historic time, as shown by the early charts of Speer and Jeffreys, and particularly by the detailed 1830 survey of Owen, has resulted largely from the increased destructive tendencies of hurricanes since the introduction and spread of the coconut by man in post-Columbian times, and specifically since about 1800. In their natural states, cays, to survive at all, must represent a delicate balance between forces of accretion and forces of degradation (Spender, 1937, 141): they must be in a state of dynamic equilibrium with their environment. In this equilibrium, vegetation, stabilising and protecting the cay, must play a major part. The catastrophic changes brought about by Hattie and other recent hurricanes are largely the result of the disturbance of this natural equilibrium by clearing of the original vegetation. Thus, under present vegetation conditions, steep high shingle ridges are relict historical features dating from dense-vegetation days: such ridges today can only be built on those cays with a dense vegetation cover. Reef islands themselves are rapidly becoming transitory features.

Destruction of reef islands has been noted on a world wide scale by Stanley Gardiner, Kuenen and others. This interpretation, of increased efficiency of storm erosion and decrease in aggradation following clearing of natural vegetation, thus provides a key, more immediate than that of eustatic fluctuations of sea-level, not only to the great decrease in numbers of cays in historic time, but to the absence of islands in location where one would expect islands to form. Steers has noted that the difficulty in explaining the growth of cays is not so much to account for their formation but for their frequent absence, and that same dilemma has been noted in British Honduras (Stoddart, 1962a, 164). Hurricane action, following vegetational disturbance, may provide the key to this and other problems: man, not nature, appears as the culprit.

Conclusion

Hurricane Hattie presented an excellent opportunity to study hurricane action on reefs by comparison of "before and after" maps. For the same reason it would be of great interest to pursue this investigation, as at Jaluit, by a further re-survey in 1965. Changes in vegetation and adjustments to hurricane constructional and degradational features would form the theme of such a re-survey, which might well throw light on some of the admittedly speculative ideas put forward in this final chapter.

In 1962 one's main conclusion is that, terrifying as the hurricane was, its results were less catastrophic than might have been expected (even small sand cays escaped destruction), and that they would have been even less - and probably dominantly aggradational rather than destructional - had it not been for human interference with the cay environment. It is even questionable whether in the long-term view hurricanes should be considered as unusual and catastrophic events. Wolman and Miller's (1960) view, that it is the events of medium magnitude occurring every two or three years, which have the greatest geomorphologic significance, is based mainly on river studies and need not necessarily apply to coastal features. Let Charles Darwin have the last word. He, too, was impressed by the resistance of islands to the ocean waves at Cocos-Keeling: "Let the hurricane tear up its thousand huge fragments", he wrote in his Journal, "yet what will that tell against the accumulated labour of myriads of architects at work night and day, month after month?" (1839, 548).

XII. APPENDICES

1. Early British Honduras Hurricanes and their Effects

This appendix lists the major British Honduras hurricanes which have been recorded since 1787. Sources include the lists of West Indian hurricanes by Poey (1855, 1865), standard texts on hurricanes, especially Tannehill (1938), and studies of British Honduran history by Metzgen (1925), Burdon (1931-35), and Anderson (1958). The information in these works on earlier storms largely derives from the issues of the <u>Honduras Almanack</u> for 1829, 1830, 1832 and 1836. Other sources are indicated in the list. Efforts were made to obtain contemporary newspaper accounts for the period 1830-1900, but without success. The relevant periods are not covered by the Bancroft Library collection in California, and I have not been able to discover any other archive of early British Honduras newspapers. Newspaper accounts of storms in the period 1940-1960 were obtained from the holdings of the Jubilee Library, Baron Bliss Institute, Belize.

<u>List of Hurricanes</u>

<u>1787</u>, September 2nd. This is the first major hurricane on record. According to the Honduras Almanack (1829, 52), "This morning at 3 o'clock a hurricane came on which desolated the Settlement exceedingly, destroyed every home on it, but one; and considerable property; a number of lives were lost on this occasion, and many of the public papers. The shipping of the country went all ashore and were lost." Captain Allen adds that "a hurricane in 1787 caused the sea to rise at the entrance of the Belize River 7 or 8 feet, so as to overflow and destroy nearly the whole town. Great numbers of people were drowned" (1841, 83). Mr Lesley of the Bliss Institute kindly gave me the reference to a letter written by Major Richard Hoare to Admiral Alan Gardiner, dated St. George's Key, October 7, 1787, which gives an eyewitness account of the storm (Public Record Office, Admiralty Papers, i/243). Between 4 a.m. and 6 a.m. the wind blew at gale force, increasing to hurricane force at 8 a.m. and veering to south-east. By 10 a.m. the wind was still at hurricane force but was easterly. At about this time the low-lying areas were flooded by a wall of water 5-6 feet high. By 1 a.m. both the wind and the water had subsided. This hurricane was clearly comparable in intensity to Hurricane Hattie. For other brief references, see Nautical Magazine, 1848, 397, 453, 524.

<u>1813</u>, August 1st. Hurricane at Belize (on August 2nd according to Honduras Almanacks of 1826 and 1830). Smith refers to this storm as stripping leaves from the trees (1842, 732).

<u>1813</u>, August 25th. Hurricane, reference Nautical Magazine, 1842, 732. No details.

<u>1827</u>, August 19th. Hurricane at Belize; St. George's Cay flooded on August 20th (Almanack, 1829, 63). The storm "drove all the ships on shore at Belize" (Smith, 1842, 732).

1831, June 27th. Probably a minor hurricane, between Belize and Chetumal (Tannehill, 1938, 152), which also defoliated trees (Smith, 1842, 732).

1864, August 31st. Hurricane at Belize. The eye passed over the town itself and the sea rose 5 feet, causing widespread flooding (Tannehill, 1938, 236).

1893, June 6th. Severe damage done by a storm at Belize and in the southern districts (Metzgen, 1925, 20).

1902, June 20th. A minor hurricane in the Belize area (Tannehill, 1938, 164).

1915, October 15th. "Damage done by hurricane" (Metzgen, 1925, 21).

1916, September 1st. Minor hurricane in the Chetumal area (Tannehill, 1938, 183).

1918, August 25th. Minor hurricane in the Punta Gorda area.

1920, October 16th. "Hurricane struck northern part of the Colony, doing considerable damage. The sea at Corozal and Payo Obispo receded for several miles" (Metzgen, 1925, 28).

1931, September 10th. This hurricane was undoutedly one of the worst in recent history, though only popular accounts exist (Cain, 1933; Burdon, 1932). The first storm warning was received on September 8th. At dawn on September 10th light rain was falling, with heavier showers at intervals; by 9.30 a.m. the wind was estimated at 36 mph. It continued to increase during the morning from the north-west, until 1.15 p.m., when it was estimated at 60 mph, with pressure 28.10 inches. Between 1.35 and 2 p.m. there was a lull and the wind dropped. At 2.05 the wind returned suddenly from the north, according to Cain, with a velocity of 60 mph. It continued to increase to 72 mph at 2.15 p.m.; 96 mph at 2.30; 120 mph at 2.35; and 132 mph between 2.50 and 3 p.m. Buildings began to collapse shortly after 2.15 p.m. After 3 p.m. the wind began to fall rapidly, and about a quarter to four shifted round to the south-west. The town was flooded by a storm surge 5-15 feet high. Minimum reported pressure was 27.6 inches. Several hundred people were killed, though Cain's estimate of 2500 was probably exaggerated.

1934, June 5th and 8th. According to Tannehill (1938, 212-213), a tropical storm crossed the British Honduras coast north of Belize on June 5th, moved into Peten, swung south into the Montagu lowlands, out into the Gulf of Honduras near Puerto Barrios, and then travelled north along the barrier reef, again passing close to Belize on June 8th.

1942, November 8th. Twenty people were killed during a hurricane at Corozal.

1945, August 31st. A small hurricane brought rough seas and high tides during the afternoon; 4 persons were drowned at Calabash Cays.

highest winds were about 60 mph, and lowest reported pressure 29.23 inches, according to local press reports. This was one of the first hurricanes for which a series of advisories was received in Belize, but none were delivered to the authorities until September 3rd. As a result, a number of hurricane regulations were drawn up in time for

1945, October 4th. On October 3rd notice was received of a hurricane moving toward Belize at a speed of 7 knots, with winds of 85 mph over a 30-mile radius, and very rough seas. At 10.45 a.m., October 4th, it struck the Punta Gorda area, destroying 80% of the houses in that town and 70% of the houses in Monkey River. At Monkey River hurricane force north-westerly winds were blowing as early as 5.30 a.m. At 7.15 a.m. they backed to north, becoming more violent, and the sea level began to rise. By 8.30 the winds were north-easterly, and the water still rising. At 9.45 the winds reached a peak of violence as severe as at 7.15 a.m., and then began to abate. By 11.30 the hurricane has clearly passed, but Monkey River town was still covered with 18 inches of water. There was no lull at this place, but a 5 minute lull was observed at Erkenee's Point, and one of half-and-hour at Snake Cay and Punta Negra. According to the Daily Clarion of 6th October, Snake Cay was badly damaged.

1955, September 27th. Hurricane Janet largely destroyed Corozal and Chetumal. This has been described as "one of the fiercest hurricanes in history" (Dunn and Miller, 1960, 7; see 1-7, 74). Minimum recorded pressure at Chetumal, Quintana Roo, as the eye passed over was [illegible].00 inches, and wind speeds were well in excess of 120 mph; the Chetumal anemometer ceased recording at 150 mph. Damage estimated at £1 m.* was caused at Corozal in British Honduras. For a fuller account of this storm, see the U.S. Weather Bureau advisories, and Pagney (1957). It passed to the north of the British Honduras cays.

1960, July 15th. HurricaneAbby, a minor hurricane, struck Mango Creek, causing some shoreline readjustment and felling of coconut trees at Tobacco Cay. For details, see advisories.

1961, July 24th. Hurricane Anna, another minor storm, crossed the coast between Monkey River and Placencia during the early hours of the morning. The writer was at sea near Monkey River at the time, and visited the coastline that day. A number of trees were down at Placencia, which had been flooded. A carpet of fresh sand had been deposited on the north-east shore, over-lying uneroded grassland. Houses had suffered minor damage. Trees were also felled at Buttonwood Cay and at a nearby island near Gladden Spit. For meteorological details, see advisories.

1961, October 31st. Hurricane Hattie.

Frequency of hurricanes

These recorded hurricanes (there is no doubt that at least in the early period there were others not sufficiently severe to be noted) occurred in the following months:

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* $ 2,800,000.

June	July	August	September	October	November
4	2	5	4	4	1

Between 1830 and 1900 there were only 3 recorded storms, one of great violence compared with fourteen hurricanes in the slightly shorter period 1900-1962. These 14 storms included the very violent hurricanes of 1931, 1945, 1955 and 1961. Cry and Haggard (1962) have shown that the daily frequency of tropical storms and hurricanes in the North Atlantic area, 1901-1960, is greatest in August, September and October, reaching a peak in the first two weeks of September, and a secondary maximum in the middle of October. There are considerable differences in distribution of storms in different areas. Thus for the Atlantic coast of the United States there is no marked frequency maximum between June and October, whereas for the Atlantic Ocean south of 20°N and east of 55°W there is a very pronounced maximum in late August and September. In the western Caribbean, delimited by the Central American mainland between Cabo Catoche (Yucatan) and the Paraguana Peninsula (Venezuela), Haiti and Cuba, there is a preliminary maximum in June, followed by a quiet period in July, beginning to increase slowly in August and September, and building up to a maximum in mid-October (Cry and Haggard, 1962, 343). 63% of the 110 tropical cyclones and 70% of the 57 hurricanes have begun in this area between September 15th and November 15th.

British Honduras can thus reasonably expect at least one hurricane a decade, probably more, and more violent catastrophic storms at least once every thirty years, perhaps more often. These storms are most likely to occur in September or October. Placed against the background of the history of the cays, which presumably came into existence soon after the sea reached its present level, hurricanes are thus frequent phenomena.

2. Some Maya Pottery from Grand Bogue Point, Turneffe Islands, British Honduras

Euan W. MacKie
Hunterian Museum, University of Glasgow

Some thirty fragments of more or less weathered pottery were received for examination, all of which had been collected by Mr Stoddart from the surface at Grand Bogue Point (Figure 54). Although the majority of the pieces do not have precise parallels with material excavated from sites in the Cayo District of British Honduras, the area with which this writer has first-hand knowledge, there seem to be sufficient general similarities with other sites in the territory to permit an approximate placement of the collection in the overall ceramic sequence of this part of Maya Central America.

Two main classes of pottery are present (Figure 65): sherds with traces of a bright red slip, usually termed Red ware; and plain sherds. Some of these last may have lost their slip through weathering, but most seem to be fragments of plain, unslipped vessels. Red ware vessel types include shouldered dishes, (o) and (p); storage jars, (g) (h) (i) (q) (r); a bowl with carved decoration, (l); a probable lid, (n); a sherd with incised decoration, (k); a large fragment of a ring-base, (j); a slab-foot with incised decoration, (s); and a fragment of a perforated spout or hollow handle, (m). Plain vessels are mostly large storage jars, (a) (b) (c) (d) and (f), but include one (e) which might from its size be a weathered example of the black slipped storage jars commonly found at the Cayo District sites and termed fugitive black ware. Three fragments of solid pottery cylinders with one end rounded were present; these are usually assumed to be parts of incense burners (Borhegyi, 1959). Two struck flakes of flint were also included with the collection.

In the assessment of the chronological position of these sherds in the ancient Maya ceramic sequences the absence of polychrome painted pottery may be significant. The ultimate phase at such Classic period ceremonial sites as Uaxactun, Xunantunich and San José is distinguished by a marked decline in polychrome wares; however, recent work at the second site has demonstrated that a poor wooden hut may entirely lack painted wares at a time when they were abundant in the nearby ceremonial site (MacKie, in litt.) The absence of painted sherds may also indicate a pre-Classic or Early Classic age but the other indications listed below combine to favour a much later date.

The Red ware storage jars (h) and (r) have a profile with a sharp angle inside the neck which is closely similar to unslipped jars found in phases IV and V at San José (Thompson, 1939, Figures 66 and 76). Red ware vessels with ring-bases occur at San José from phase II onwards, but the forms most similar to (j), with a high almost vertical ring, occur in phases IV and V (Thompson, 1939, Figures 68 and 78). The two Red ware shouldered dishes (o) and (p) each exhibit a groove and a row of impressions along the shoulder, features quite well paralleled at San José in phases IV and V (Thompson, 1939, Figures

68, 69 and 80) and at Xunantunich in phases IIIb and IV (Thompson, 1942, Figure 47; MacKie, in litt.). The plain jar (c) has its counterparts at Xunantunich in phase IV (Thompson, 1942, Figure 6, s and t).

The carved Red ware bowl (l) and the Red ware sherd with incised decoration (k) also have general analogies in the Late Classic phases at San José and Xunantunich. Carved Red ware occurs at San José in phases IV and V (Thompson 1939, Figures 67 and 85) and at Xunantunich in phase IV (MacKie, in litt.), in which phase also appears some incised Red ware (Thompson, 1942, Figure 48). The closest parallel for the very large Red ware jar (q) seems to occur somewhat earlier, at San José in phases III and III/IV (Thompson,1939, Figure 59); and the slab-foot (s) also has generalised analogues in an earlier phase of the Late Classic, in periods IIIa and IIIb at Xunantunich (Thompson, 1942, Figures 15, 24, and 41; MacKie, in litt.).

The solid pottery rods (t), probably parts of incense burners (Borhegyi, 1959), are known to have been used for many centuries (Borhegyi, 1956), but they appear to increase in numbers in British Honduras ceremonial sites in Late Classic times (MacKie, in litt.).

Thus the majority of the analogies drawn between the Grand Bogue sherds and material from ceremonial sites elsewhere in British Honduras are consistent with their belonging to a stage in Late Classic or early post-Classic times, corresponding to phases IIIb and IV at Xunantunich and IV and V at San José. It might be expected that remains from areas peripheral to the nearest main centres of Maya Classic culture, Guatemala and western British Honduras, should belong to the period of maximum population expansion, and excavations at the ceremonial sites of Xunantunich and San José, and the settlement site at Barton Ramie on the Belize River (Thompson, 1939, 1942; MacKie, in litt.; Willey, Bullard and Glass, 1955) strongly suggest that the Maya population in the British Honduras area was at its maximum in Late Classic times.

It is now possible to give these later phases absolute dates in years with some accuracy. The extensive excavations at Uaxactun in Guatemala have provided a long ceramic sequence which can be tied to many of the dated stelae there, and which can also be correlated with the sequences at sites in British Honduras. Ceramic analogies suggest that the two final phases at San José, IV and V, correspond approximately to the last two at Xunantunich, IIIb and IV, and that both are roughly coeval with the last two phases at Uaxactun, Tepeu 2 and 3 (Thompson, 1942; MacKie, 1961,220). R. E. Smith (1955, 106) places Tepeu 2 and 3 in the 8th and 9th Centuries A. D. and the Grand Bogue sherds ought to be of similar age. However, Maya activity on some of the cays of British Honduras undoubtedly continued later, judging by the fine Plumbate pottery found on Wild Cane Cay (MacKie, in litt.). This widely traded pottery has been dated to the 11th and 12th centuries A. D. (Shepard, 1948, 115).

<u>Description of the sherds</u> (diameters indicated on Figure 65):

(a) plain light brown and orange, sand tempered; no trace of slip; horizontal striations inside and out.

(b) dark grey clay, light brown surfaces; horizontal striations; no trace of slip; sand tempered.

(c) friable light brown clay, sand tempered; horizontal striations on external surface; no trace of slip.

(d) light grey clay, and light brown mottled surfaces; sand tempered with horizontal striations; no trace of slip.

(e) fine light yellow-brown clay with orange core; sand tempered; no trace of slip.

(f) bright orange clay, darker mottled areas on surface; sand tempered; marked horizontal striations on interior; no trace of slip.

(g) light grey clay, cream surfaces; sand tempered; traces of bright red or orange slip; two faint horizontal grooves on exterior just below angle of rim.

(h) light grey clay, light brown surfaces; brownish slip inside and out, probably red originally; sand tempered; horizontal striations.

(i) dark grey clay, light brown surfaces; red slip; sand tempered; horizontal striations.

(j) ring-base; dark grey clay, cream surfaces, traces of red slip; sand tempered; horizontal striations underneath.

(k) light grey clay, light orange surfaces; red slip on exterior; sand tempered; incised decoration apparently done after application of slip, but weathered; part of a carinated vessel; sand tempered.

(l) light grey clay, cream surfaces; traces of red slip; sand tempered; decoration incised and carved out, probably after application of slip, but too weathered to be sure.

(m) light orange clay, sand tempered; red slip on all visible surfaces except inside tube; small hole, smooth-sided and probably made before firing.

(n) lid (?) Grey clay, light brown surfaces; sand tempered; ring at top applied separately and smoothed down; red slip on under surface, upper surface severly weathered; horizontal striations on under surface.

(o) light grey clay, orange surfaces; sand tempered; traces of red slip on both faces; upper groove at least made before application of slip.

(p) grey clay, light brown surfaces; slip on both faces, darker red than on (o); sand tempered; row of impressed marks at shoulder made with corner of instrument with rectangular end; hole drilled through, presumably for a repair.

(q) grey clay, light brown surfaces; sand tempered; horizontal striations; traces of dark red slip on exterior.

(r) similar to (h).

(s) light brown clay; faint traces of dark red slip on outer surface, more clearly on upper surface; tempered with many minute fragments of white material, possibly shells.

(t) light brown clay; sand tempered; no trace of slip.

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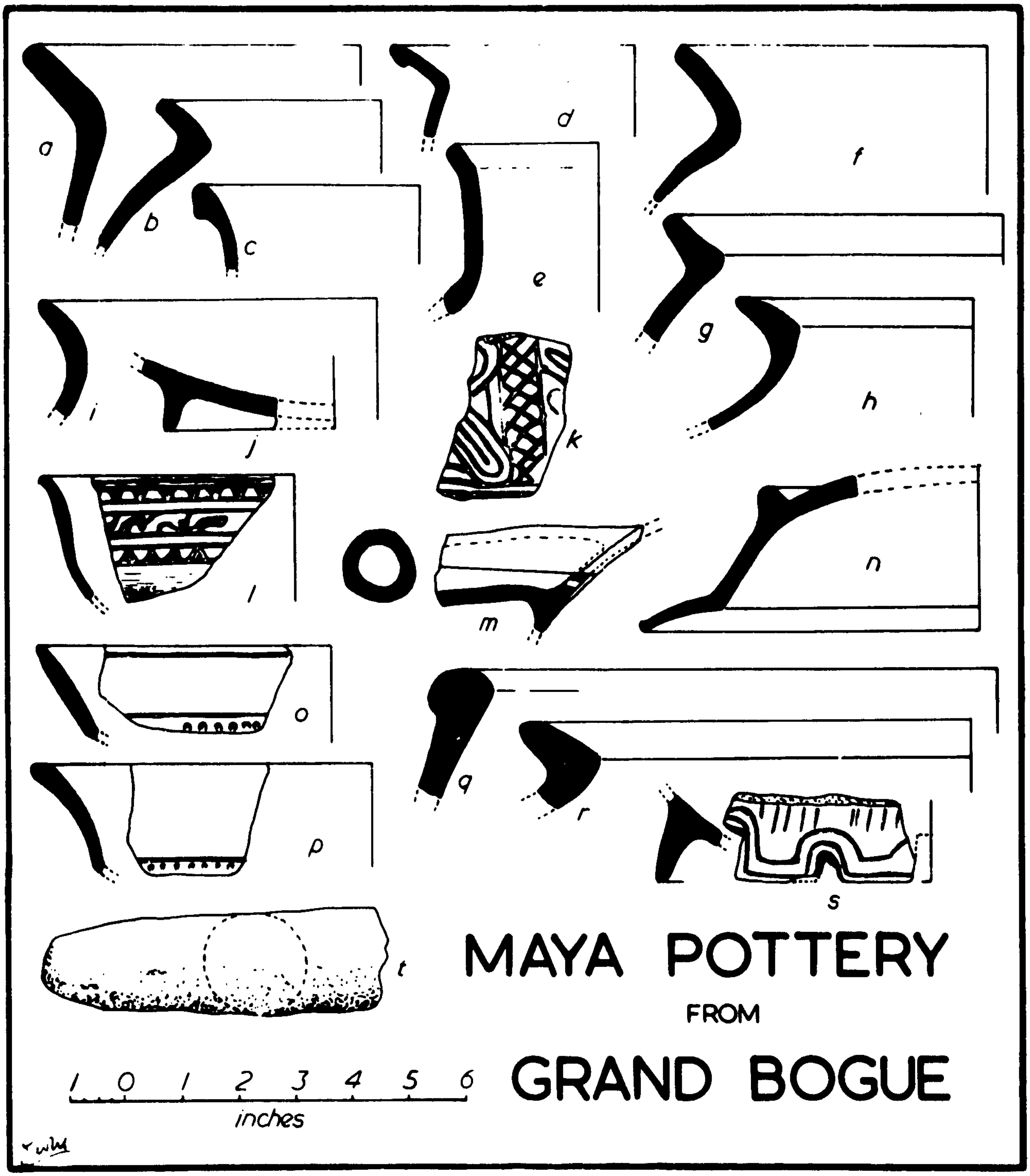
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MAYA POTTERY
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GRAND BOGUE
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FIG. 65

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