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Three Caribbean atolls: Turneffe Islands, Lighthouse Reef, and Glover's Reef, British Honduras

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D. R. Stoddart

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THE PACIFIC SCIENCE BOARD
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Preliminary Results of Field-work carried out during

THE CAMBRIDGE EXPEDITION TO BRITISH HONDURAS 1959-60
December 1959 to July 1960

and

THE BRITISH HONDURAS CORAL REEFS AND ISLANDS EXPEDITION 1961
May 1961 to July 1961
(Sponsored by Coastal Studies Institute, Louisiana State University, and Office of Naval Research, Washington)

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 fourteen years.

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I. INTRODUCTION

In his "Checklist of Atolls", Bryan (1953) listed a total of 27 atoll-like structures in the Caribbean, three of which are located off the coast of British Honduras (cf. Cloud, 1957, 1010-1011). The Turneffe Islands he considered "not sufficiently surveyed to determine form"; Lighthouse Reef he described as "atoll-like, 5 cays"; and Glover's Reef as "sunken atoll-like, 5 small cays". Until recently this survey represented the total of our knowledge of these atolls, perhaps the least well-known and probably the finest structures of their type in the Caribbean Sea.

Location

Location of the atolls on published charts derives from surveys of the period 1820-1830, and no attempt is made to show details of form or topography. Figure 1 shows the atolls as surveyed by Captain Richard Owen, from a manuscript map (H57) dated October 1830 in the possession of the Hydrographic Department, Admiralty; in many respects it is more detailed than subsequently published charts, which are based on it. Figure 2 attempts to combine published charts of the location of the atolls with maps of detailed form derived from air photographs. These airphoto maps are reduced from the large scale maps included with this paper in the accounts of each individual atoll. It will be seen that Lighthouse Reef as shown on figure 2 corresponds well with representations on charts; Turneffe Islands correspond in gross form, but much lagoon detail is added; while Glover's Reef, though broadly similar on figures 1 and 2, differs considerably in figure 2 from published charts.

The following survey of the location of the atolls is derived from published charts. The coast of British Honduras is fringed by a submerged coastal shelf edged by a well-developed barrier reef. In the latitude of Belize (17°30'N), the shelf lagoon is 8 miles wide. Beyond the barrier in this latitude, a channel 11 miles wide separates the shelf from Turneffe. This channel varies in width from 5½ to 14 miles, being narrowest in the centre. Turneffe bank itself has a maximum length of 30.5 miles along its NNE-SSW axis; its greatest width, at the latitude of Soldier Cay, is 10 miles, and the average width 5-6 miles. It covers approximately 205 square miles, and its co-ordinates, from charts, are:

North extremity (drying reef)	17°38'00"N
South extremity (Cay Bokel)	17°09'00"N
Eastern extremity (northeast corner)	87°44'30"W
Western extremity (west side)	87°57'30"W

Lighthouse Reef is situated east of Turneffe, from which it is separated by a channel 11½ to 18 miles wide; again the channel narrows towards the middle and widens at its ends. The distance between Cay Bokel (south end of Turneffe) and Hat Cay (south end of Lighthouse

Reef) 19 miles. The maximum length of Lighthouse Reef along its NNE-SSW axis is 22 miles, and its width varies from 2 to 4 3/4 miles. The approximate area is 78.5 square miles, and its co-ordinates, from charts, are:

North extremity (Sandbore Cay)	17°28'30"N
South extremity (reef)	17°07'00"N
Eastern extremity (northeast reef)	87°27'00"W
Western extremity (southwest reef)	87°36'30"W

Glover's Reef is located 15 miles SSE of the south end of Turneffe, and 13½ miles SSW of the south end of Lighthouse Reef. Like Turneffe it is separated from the coastal shelf and barrier reef by a channel 13½-17 miles wide, narrowest at its northern end, between Glover's Reef and Cay Glory. Glover's Reef is aligned NNE-SSW, following the trend of the southern barrier reef. South of Glover's Reef, the barrier reef swings eastwards, forming the pronounced elbow at Gladden Spit, and then westwards to form the bight between Glover's Reef and the barrier. The channel thus formed on the south side of Glover's Reef, between it and the barrier, is 13½ miles wide. The bank has a greatest length along its main axis of 16 miles, and averages 5-6½ miles in width. Its area is some 82 square miles. Co-ordinates from charts are:

North extremity (northeast reef)	16°55'30"N
South extremity (southern reef-entrance)	16°42'00"N
Eastern extremity (northeast corner)	87°41'30"W
Western extremity (southwest corner)	87°52'00"W

Approaches

All three banks are steep-to, and must be approached with caution, though Turneffe is normally visible with the naked eye at a distance of 6-7 miles (from sea-level). There are two lighthouses on Turneffe: one on Mauger Cay near the north end, a tower 64 feet high, location 17°36'30"N, 87°46'00"W; the other is on Cay Bokel, at the southern extremity of the reef, location 17°09'30"N, 87°54'00"W. Cay Bokel light is not visible from the NNW and NE because of intervening mangrove.

Lighthouse Reef also has two lights: one, 70 feet high, on Sandbore Cay at the north end, 17°28'00"N, 87°29'00"W; the other, 80 feet high, on Half Moon Cay, near the southern end, 17°12'00"N, 87°31'00"W. Both are partly obscured by cays to the east and southeast. There are no lights on Glover's Reef, but the lights on the other atolls are highly dependable.

There is good anchorage in depths of 9 fathoms near Cay Bokel, at the south end of Turneffe, and also in the southern entrance of Glover's Reef. There are no satisfactory anchorages for large vessels at Lighthouse Reef, with the possible exception of the bay lying west and south of Half Moon Cay. Further details on lights and anchorages are given by the West Indies Pilot, Vol. 1, 11th edition, 1956, p. 459-462.

Discovery

There are no pre-Columbian historical remains on either Lighthouse Reef or Glover's Reef, though Maya shell-middens are reported from the Calabash Cays area and Northern Bogue on Turneffe (Romney and others. 1959, fig. 10). It is not impossible that the Mayas did visit the two outer atolls on occasion in canoes, since they appear to have carried on a sea trade between Yucatan and the Bay Islands (Chamberlain, 1953), and in fact this is suggested by the Turneffe middens, located at the eastern exits of the Turneffe lagoons still used by fishermen making for Lighthouse Reef. There is, however, no evidence of permanent settlement similar to that found on some cays within the British Honduras barrier reef.

The east coast of the Yucatan Peninsula between Bahia Chetumal and Golfo Dulce was first explored by Francisco de Montejo in 1528 and his lieutenant Davila in 1532-3 (Chamberlain,1948, 1953). No permanent Spanish settlement seems to have been established on this coast between Salamanca de Bacalar and the Sarstoon River (Humphreys,1961), but the coastline and reefs must have become well-known to Spanish navigators travelling between Honduras, northern Yucatan and Cuba in the sixteenth and seventeenth centuries. English logwood cutters began to gather on the Belize River during and after the period 1640-1660, and this led to an international tension not conducive to the sharing of hydrographic information. There seems little doubt that Spanish knowledge of the coast and reefs was treated as a military secret, and their maps remained unpublished in Seville. The fashion for the published charts seems to have been set by Herrera's Description del destricto del Audiencia de Nueva Espana of 1601-15 (Vindel, 1955, 69-70), in which a number of coastal islands are named, from south to north, off the coast of what is now British Honduras: Ilbob, Lamanay, Pantoja, Quitasueno, and El Triangulo. On De Laet's map of 1625 (Comision de Limites, 1928), these appear as Ylbob, Lamanay, Zaratan, Pantoja, and Quitazuenho: with the possible exception of Lamanay (Turneffe?) none can be certainly identified today. These names regularly appear on the charts of Blaeu, Vooght, Visscher, Morden and others until c. 1720, and at least one map with these names appeared as late as 1793 (Baret-Elwe, 1793).

Nautical knowledge has by this time far outstripped the cartographers. The words 'Terre Neuf' (Turneffe) first appear (in addition to Lamanay and Zaratan) on a chart by Vooght in 1698. Manuscript maps reproduced by Calderon Quijano (1944) from the Seville archives show a Spanish understanding of the topography of the three atolls not approached in England until the nineteenth century. The Plano de la Costa Oriental de Yucatan of 1749, though poorly reproduced, shows the three atolls in their correct relations, with the cays on Lighthouse and Glover's Reefs clearly marked; Turneffe appears as 'Terra Nef'. The Plano de la Costa de Honduras of 1756 shows 'Terra Nef', 'Quattro Cayos' (Lighthouse Reef), and 'Longorif' (Glover's Reef), these last two names appearing on charts for the first time. The use of the name 'Long Reef' for Glover's Reef seems to have been general in the early eighteenth century, and Winzerling (1946) suggests that the name 'Glover' derives from a pirate of that name who made the atoll his own, though little else is known about him. The present name was used on the first Admiralty charts, and the old name has been forgotten. Quattro Cayos, Four Cays, or Eastern Reef was used for Lighthouse Reef until the Half Moon Cay lighthouse was built in 1821 (Honduras Almanack,1830). On both these manuscript charts the Turneffe lagoon is filled with shapeless islands, and the same is true for Glover's Reef on the 1756 map. On an undated map of the same period, Mapa de el ceno de Honduras (Calderon Quijano, 1944, Plate 17), however, the distribution of land on Turneffe is shown with an exactitude and clarity not achieved again for over 150 years; it may be compared with recent English official maps (e.g. in Romney and others,1959), and shows more information on the interior of Turneffe, though on a small scale, than present nautical charts (cf. Admiralty chart 959, 1929).

The Spanish discoveries penetrated slowly into the English literature, though a Spanish map was used by Speer in the first edition of his West India Pilot (1766), and greatly improved in the second (1771). Speer was clearly well acquainted with the waters he described. For the first time in his work an individual cay is named on Turneffe (Quibiquel in 1776, Kay Boquel in 1771); Glover's Reef appears as Longorriff or Arrecife Largo with three un-named cays in 1766, and received its present name for the first time on a chart in 1771; with Lighthouse Reef or Quattro Cayos del Sur (1766) shows North Four Kays and South Four Kays (including Hat Kay) in 1771. Nevertheless, Speer's map is crude compared with the extraordinary charts of the Gulf of Honduras prepared by Thomas Jefferys (died 1771) and published in 1775, 1792 and 1800. According to the editors of the 1775 West India Atlas, "The English charts, both manuscript and printed, are more numerous than the Spanish materials. On the continent they have chiefly been of use to determine the bay of Honduras, the Mosquito-Shore, and Florida. We had so considerable a quantity of manuscripts...upon the Bay of Honduras, properly so called, ...that there is nothing more to be wished for in the exactness of this map" (Jefferys, 1775, p. iii).

On the first Jefferys map of 1775, Turneff is marked, with Key Bokel in the south; in 1792 and 1800 Cayo de Muger or Mauger Key was added in the north. Glover's Reef appears in 1775 as Arrecife Largo, Glovers Reef or Long Reef; The Two Spots are marked at its northern end, and five un-named cays in the south; and there is little change in later editions. Lighthouse Reef is termed Four Keys Reef in 1792 and 1800. In the earliest map, Jefferys includes North Two Keys, with The Bushy Spot (modern Northern Two Cays and Sandbore Cay), and in the Southern Four Cays on this atoll he names North Key (Saddle Cay), Easternmost Key (Half Moon Cay), Halfmoon Key (Long Cay), and Hat Key. The misnaming of Half Moon Cay continues in the 1792 and 1800 editions.

Jefferys' maps remained the best available until the detailed survey of the east coast of Yucatan by the British Admiralty in the late 1820s and early 1830s. This was begun by Anthony de Mayne, HMS Kangaroo, with a survey of Belize harbour in 1828, which remains in manuscript. Commander Richard Owen and Commander Edward Barnett produced a preliminary survey of the whole coast in 1830 (Admiralty ms charts H57), and this still remains the basis of current charts of the atolls. Barnett went on to map Banco Chinchorro atoll in detail in 1839, and this chart was published in 1850, and Owen continued work on the coastal shelf and barrier reef, but paid no more attention to the three British Honduras atolls.

Subsequent surveyors, including the most recent (HMSS Vidal, Capt. E. G. Irving, 1957), have all been restricted to the coastal shelf and Belize harbour. Thus the representations of the atolls on present charts date entirely (with the exception of the west coast of Turneffe opposite Belize, and of recent charts of Glover's Reef) to Owen's sketch surveys of over a century ago. Glover's Reef on current Admiralty charts is said to be derived from small-scale American charts, and comparison with Owen's 1830 manuscript, and with the air photo plot, shows that the change was not for the better.

Scientific studies on the atolls

Owen carried no naturalist on his ship, and published accounts of his work are sparse (Owen, 1838; Bird Allen, 1841). Darwin includes information from Allen in his Structure and Distribution of Coral Reefs (1842), but the letters from Allen to Darwin describing the reefs cannot now be found. Few naturalists, apart from ornithologists (Salvin, 1894; Schmidt, 1941; Verner, 1957), have since visited the area. Sapper crossed Turneffe and visited Long Cay, Lighthouse Reef, in 1894-96 (Sapper, 1899, map 1), but does not seem to have published any description. Ower, a Government geologist, touches briefly on the reefs in several papers (1927, 1928); Dixon, also a Government geologist, visited Turneffe with the British Honduras Land Use Survey Team (Dixon, 1956; Romney and others, 1959), but gives no general account of the atolls. Vermeer (1959) also visited Half Moon Cay and Long Cay on Lighthouse Reef in 1957 as part of a reconnaissance study of the cays of British Honduras sponsored by the Office of Naval Research, Washington. Neither Alexander Agassiz (1894) nor T. Wayland Vaughan (1919), though often referring to the east coasts reefs of Yucatan in support of their own theories, ever visited the area. No geologist or zoologist (with the exception of the ornithologist Salvin and a lizard-collecting expedition referred to by Schmidt (1941)) ever seems to have visited Glover's Reef.

Present study

This paper is based on several visits to the atolls in the course of two expeditions. Turneffe was visited twice and Lighthouse Reef once, in early 1960, in the course of the Cambridge Expedition to British Honduras 1959-60, led by J. E. Thorpe (CEBH, 1960; Carr and Thorpe, 1961). My main study on this occasion was the study of the form and development of the sand cays on the British Honduras reefs as a whole. Thirteen cays were mapped on Turneffe, and three on Lighthouse Reef. In the light of results obtained on this expedition a second visit was seen to be necessary, and it is a pleasure to acknowledge the help of the Office of Naval Research, Washington, and the Coastal Studies Institute, Louisiana State University, in making this possible. I am grateful to Miss Evelyn L. Pruitt, Head, Geography Branch, Office of Naval Research, for much encouragement with the 1961 expedition. During this second expedition (British Honduras Coral Reefs and Islands Expedition 1961) I was again concerned with mapping cays on both the atolls and the barrier reef. Glover's Reef and Lighthouse Reef were each visited twice, and Turneffe once, and another 9 cays mapped on them, but an effort was also made to collect information relating to the atolls generally. In particular, the reef transects described in Section IV were made on the second expedition. The routes followed on these excursions are shown on figure 3.

On the first expedition I had the field assistance of J. D. Poxon, B. A., Selwyn College, Cambridge, who also navigated our yacht Tortuga, and on the second one of S. P. Murray, of Louisiana State University; their help has been invaluable. I would also like to thank Professor J. A. Steers, of Cambridge, under whose direction this work has been carried out, and Professor R. J. Russell, of Baton Rouge; Dr. F. R. Fosberg, who kindly identified my plants; and Dr. Fosberg, Dr. Cyril Dixon (Geological Survey, British Guiana) and Dr. D. A. Vermeer (University of California), for discussion of many points.

It is impossible to make individual acknowledgment of all the help received on these expeditions from many other sources, but mention must be made of the assistance from the then Governor of British Honduras, Sir Colin Thornley, the Chief Secretary and Executive Council, and the Comptroller of Customs, Mr. David Bradley, for customs exemption and other help; from the British Museum (Natural History) in the supply of plant-collecting materials; from Marine Electronics Ltd., London, for supply of an echo-sounder; and from the many commercial organisations and individuals, detailed elsewhere, for their help with equipment, general supplies and finance. This work has been supported since 1959 by a grant from the Department of Scientific and Industrial Research, London, held at the Department of Geography, Cambridge, England.

Miss Pruitt kindly made available, through Coastal Studies Institute, the air photographs on which figures 27 and 37 are based. I am indebted to Admiral E. G. Irving, Hydrographer to the Navy, Hydrographic Department, Admiralty, London, for permission to base figures 1, 14 and 32 on unpublished Admiralty manuscripts, and for giving me access to the Hydrographic Department Archives at Cricklewood.

Dimensions of Pacific and Caribbean Atolls compared

Atoll	Length miles	Breadth miles	Area square miles	Maximum depth fathoms	Land area square miles	
Bikini	26	15	243	32	3.4	(1)
Rongelap	33	20	396	35	3.2	(1)
Eniwetok	25	20	360	35	2.5	(1)
Rongerik	11	11	57	26	0.53	(1)
Kapingamarangi	8	6.3	31.7	43	0.4	(2)
Raroia	27.5	8.75	156	30	8.2	(3)
Turneffe	30.5	10	205	3.5	48	(4)
Lighthouse Reef	22	4.7	78.5	5*	3	(4)
Glover's Reef	16	6.5	82	24	0.3	(4)

* Depth of blue hole: 78 fathoms

Sources: 1. Emery, Tracey and Ladd, 1954.
2. Wiens, 1956.
3. Newell, 1956.
4. This paper

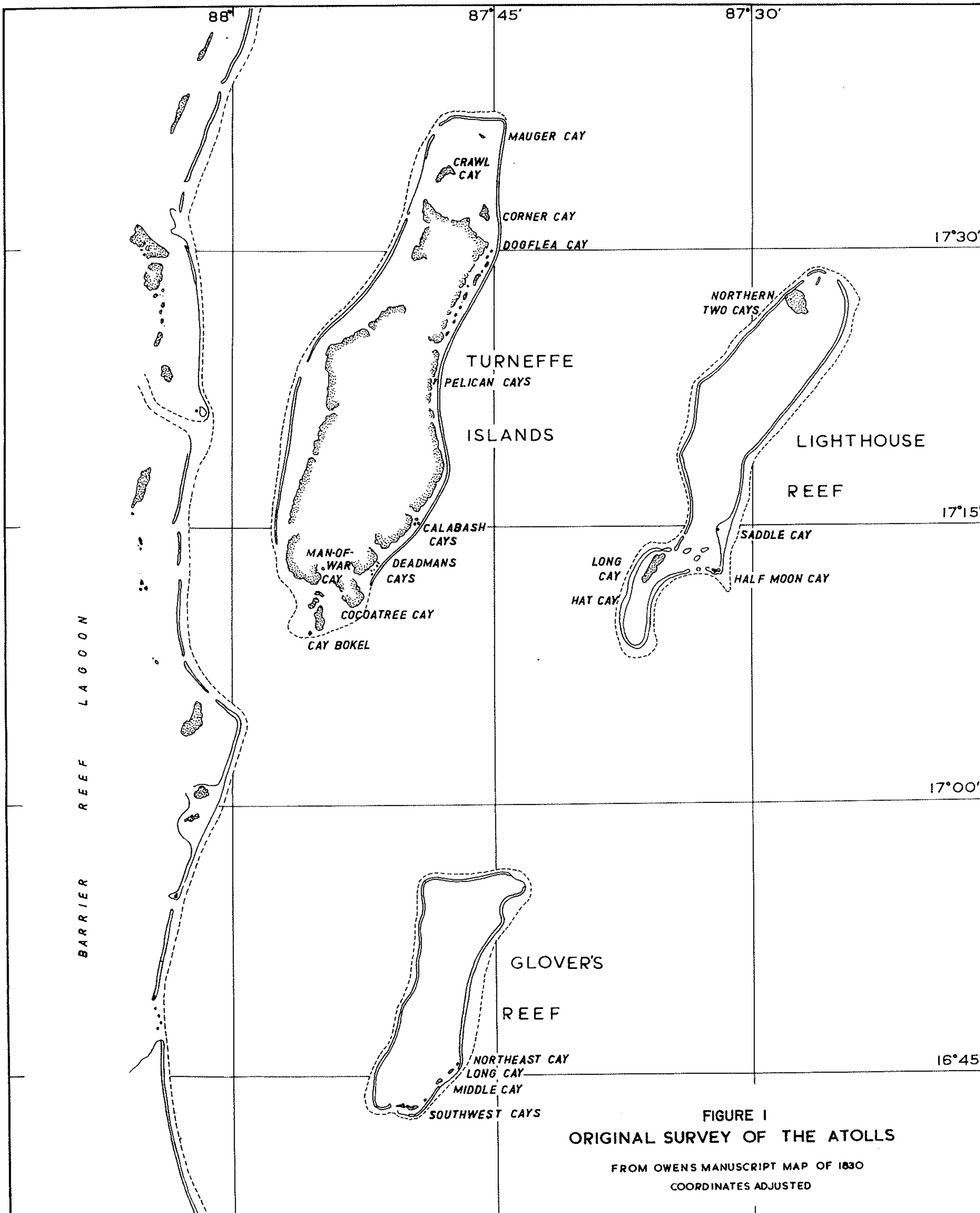


FIGURE I
ORIGINAL SURVEY OF THE ATOLLS

FROM OWENS MANUSCRIPT MAP OF 1830
COORDINATES ADJUSTED

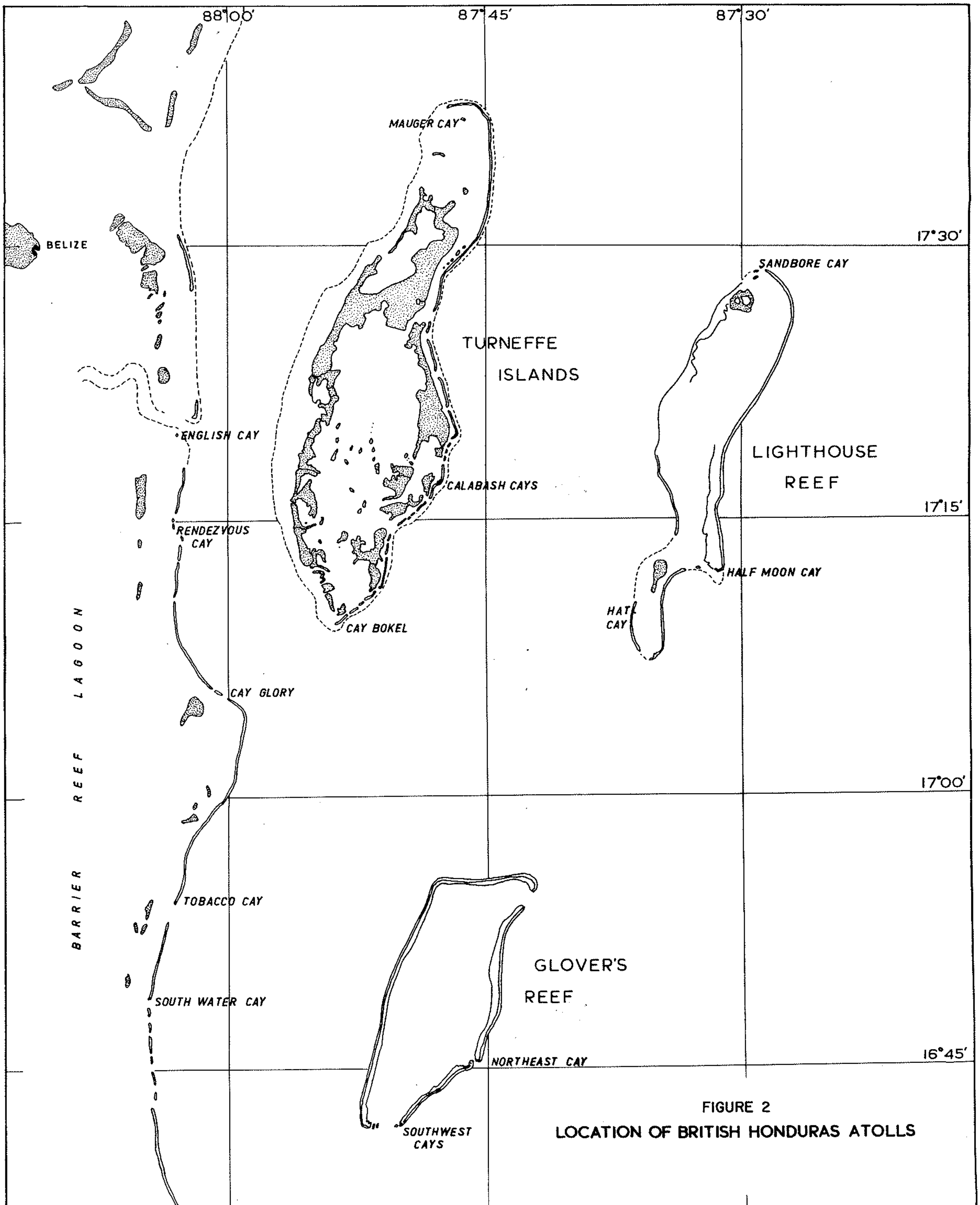


FIGURE 2
LOCATION OF BRITISH HONDURAS ATOLLS

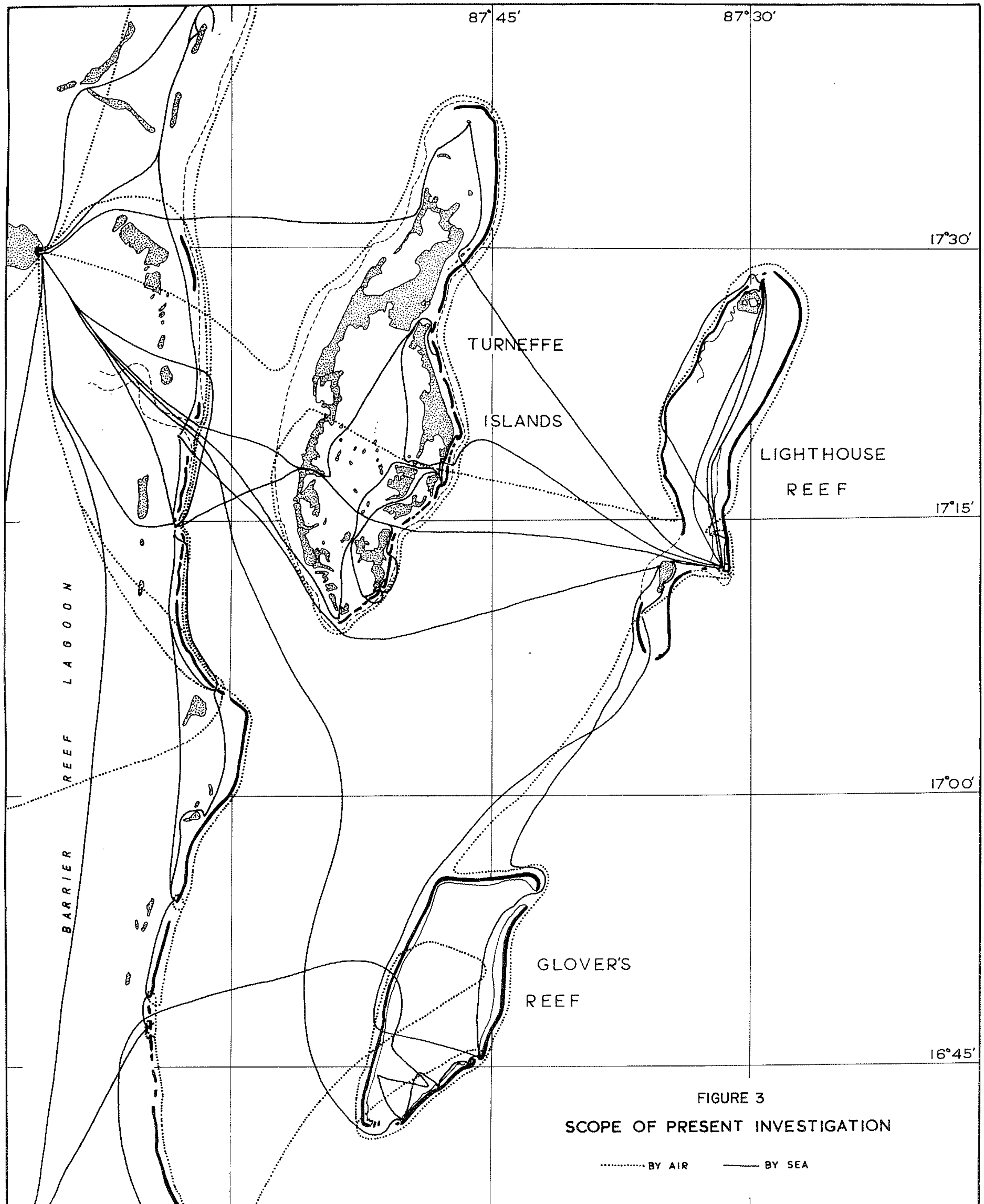


FIGURE 3
SCOPE OF PRESENT INVESTIGATION

II. GROSS FORM AND STRUCTURE OF THE OFFSHORE AREA

Submarine topography of the east coast of Yucatan

The most striking feature of the offshore topography is the marked linear orientation of surface and submarine features, and this finds some parallel in the more subdued fault-controlled lineation of drainage features in the northern limestone lowlands of British Honduras and adjacent Quintana Roo (Sapper 1899). Each of the four atolls near the base of the Yucatan Peninsula--Banco Chinchorro, Turneffe Islands, Lighthouse Reef and Glover's Reef-- is aligned with its long axis trending NNE-SSW, and this is true also of Cozumel Island and the submerged Arrowsmith Bank farther north on the same coast. Available soundings are rather sparse in the area between the banks and the barrier reef, but they are sufficient to show that these apparent surface lineations are only the superficial expression of major submarine topographic features on a greater scale than any land relief on the adjacent coastlands. Figure 4 is a compilation map showing submarine contours, based on maps of the Quintana Roo coast published by Edwards (1957 and of British Honduras by Vermeer (1959). It is possible to disagree with many of the details of this map, but the gross pattern revealed is probably correct.

The whole of the east coast is bordered by two "platforms": an "upper platform" with its outer edge at approximately 2400 feet (400 fathoms), and a "lower platform", with its outer edge at approximately 6,000 feet (1,000 fathoms). A third platform, the coastal shelf, may be traced north of the Yucatan Peninsula, as a vast shallow extension of the Yucatan limestone lowland, and also in the southeast of the peninsula, off the British Honduras coast, where it is fringed by the barrier reef. Arrowsmith Bank, Cozumel Island and Turneffe are located on the edge of the "upper platform", and Banco Chinchorro rises from a spur extending eastwards from the main shelf at about the same height. No banks rise from the "lower platform" except in the south, where it supports Lighthouse Reef and Glover's Reef. In this southern section the two platforms come together, and off the southern barrier reef of British Honduras there is a single fall from sea-level to over 6000 feet depth.

Several escarpments, forming part of this "upper platform-lower platform" system may be traced off the atolls of British Honduras. For convenience, they are named here the Outer Escarpment, Turneffe Escarpment, Chetumal Escarpment, and Chinchorro Escarpment.

The Outer Escarpment extends along the southern barrier reef from Sapodilla Cays to Gladden Spit, and thence northeastwards along the east sides of Glover's and Lighthouse Reefs. Off the barrier reef the scarp is straight and steep: within 3½ miles of Ranguana Entrance the sea floor lies at a depth of 4800 feet. Twelve soundings along this section of the barrier reef, 2-4 miles seaward from it, average 4020 feet. North of Gladden Spit the soundings off the barrier reef decrease considerably, indicating the presence of a shelf or col between Gladden Spit and Glover's Reef at depths of 900-1100 feet. The scarp crest in fact continues along the east side of Glover's Reef, giving depths of 1800-3300 feet within 1-2 miles of the reef-edge, and along the east side of Lighthouse Reef, giving depths of 6600 feet within 3 miles of the reef-edge. Between the barrier and Glover's Reef, and between Glover's and Lighthouse Reefs, the sea is less than 1,000 feet deep. Clearly, the barrier reef and the two atolls lie on the crest of a submarine scarp trending NE-SW, and at least 120 miles long. The average gradient of the scarp slope is between 1 in 3 and 1 in 4.

The "upper platform" between Glover's Reef and the barrier reef lies at a depth of 900-1100 feet. It appears to deepen northeastwards, and to pass into a pronounced trough extending in a northeasterly direction between Turneffe and Lighthouse Reef. Between the barrier and Turneffe, on the other hand, the "upper platform" continues northwards at depths of 900-1,000 feet, forming a channel 6-10 miles wide. Soundings between Turneffe and Lighthouse Reef are very meagre, but it seems that the east side of Turneffe is bounded by a submarine slope similar to that bounding the east sides of Glover's and Lighthouse Reefs, but on a smaller scale. Twelve soundings $1\frac{1}{2}$-4 miles from the west reefs of Lighthouse Reef average over 3,000 feet; a single sounding midway between Mauger Cay (north Turneffe) and Sandbore Cay (north Lighthouse Reef) is charted as 6090 feet. There is only one sounding off the east reefs of Turneffe (2 miles west of the northeast corner), of 2220 feet. It thus appears that the Turneffe Escarpment overlooks a basin with maximum depths of 6,000 feet, shoaling southwards, and passing northwards into the "lower platform". Lighthouse Reef seems to be situated on a long narrow spur, bounded on the west side by this basin, and on the east by the Outer Escarpment.

North of Turneffe and Lighthouse Reef there are no banks rising to the surface for over 60 miles. The sea floor falls regularly from the barrier and fringing reefs of the Yucatan coast to depths of up to 300 feet within 5 miles of the coast. There are no detailed charts for the east coast of Yucatan north of Belize, but it is probable that this coast too is bounded by an escarpment (Chetumal Escarpment), gentler than the others, controlling the linear nature of the coast and reefs northwards at least as far as Bahia del Espiritu Santo, where it is intersected by transverse faults from the west.

Chinchorro Bank is also bounded on the east side by a steep slope (Chinchorro Escarpment), and the same is true of Cozumel Island and Arrowsmith Bank.

Fault origin of the escarpments

The presence of these steep submarine gradients was noticed by Ower, who attributed them to offshore faulting and published a map of the southern reef area (1928, 497) showing two sets of submarine fault-lines. One set, aligned NNE-SSW, with downthrow to the southeast, corresponded to the "Outer Escarpment" delimiting the southern barrier reef and Glover's Reef, and to the "Turneffe Escarpment". These were deduced from soundings on charts, and Ower recognised the gross similarity in direction and downthrow with the faults of the northern lowlands of British Honduras.

A second set of faults was recognised transverse to the first (striking E-W and SE-NW), with downthrow to north or south. The main dryland analogy to this system which he mapped is the E-W Northern Boundary Fault of the Maya Mountains, a horst of Paleozoic rocks surrounded on all sides by Mesozoic and Tertiary limestones and other rocks. In the offshore area, the location of the transverse faults shown on Ower's map seems purely conjectural, with little relation to bottom topography; they seem to have been inserted to explain the rise of the outer atolls from their respective scarp-crests. Study of Admiralty charts in 1959 led to the conclusion that there is in fact one major set of faults controlling submarine topography, trending NNE-SSW, and giving rise to the Outer Escarpment, Turneffe Escarpment, and probably also the Chetumal and Chinchorro Escarpments (Stoddart, 1960). It was subsequently found that this interpretation had been worked out in detail by Edwards for Quintana Roo (1957) and by Vermeer for the coast of British Honduras (1959, 20-25). No other interpretation for the submarine topography seems possible with present knowledge. It is unlikely that the escarpments are constructional reef forms for several reasons. Thus the Outer Escarpment can be traced not only along modern reefs, but occurs as a submerged feature, not rimmed with reef, between the two outer atolls, and this same scarp also bounds the coastal shelf south of the southern end of the barrier reef, where it again lacks a reef-rim. Further, the Chetumal Escarpment seems to delimit for over 200 miles a coast built of non-reef limestones, along which the barrier reef is weakly and discontinuously developed, and this indicates that the reef itself is of minor importance in determining present bottom topography.

The picture which emerges, therefore, is one of a number of NNE-SSW fault-lines, arranged en echelon along the British Honduras coast, giving rise to major submarine escarpments, with average gradients of 1 in 3 to 1 in 5. The maximum gradient charted appears to be a fall in depth of over 1 mile in a distance of two miles from the surface reef, on the east side of Lighthouse Reef. The atolls are seen to be oval-shaped reefs, 13-35 miles long, rising several hundred feet above the surface of the fault-bounded platform on whose edge they stand. The offshore topography consists of a number of submarine steps, each bounded by an east-facing escarpment, each bearing at some place along its crest a reef-mass rising to sea-level (fig. 5).

Submarine scarps and regional tectonics

If the submarine topography of the northern Caribbean basin (Parr's "Cayman Sea") is viewed as a whole, the faulting deduced from chart evidence becomes comprehensible. The dominant feature of the basin is the Bartlett Trough (fig. 6) or Cayman Deep, a narrow trench extending across it for nearly 1,000 miles. The northern rim of the trough may be traced in the faulted Sierra Maestra of Southern Cuba, through the Cayman and Misteriosa Banks, and probably into the Maya Mountains of southern British Honduras (Taber, 1928; Matley, 1924). The southern rim of the trough is formed by the island of Jamaica, the Pedro, Rosalind and Nicaraguan Banks, and the mountains of the Republic of Honduras. The Trough reaches a maximum depth of over 23,000 feet. It appears to pass westwards into the Lake Izabal-Rio Dulce lowlands of Guatemala, and according to Walper (1960) may be followed as a fracture zone into the Alta Verapaz.

Dixon gives grounds for believing that movement was initiated along the Bartlett axis in pre-Cretaceous times, but the maximum dislocation took place in the late Tertiary, probably reaching a peak in the Pliocene (Schuchert, 1935). The extensive raised reefs, elevated shore terraces, and Plio-Pleistocene marine deposits of Cuba (Agassiz, 1894; Taber, 1934) and to a lesser extent Jamaica, indicate that movement on a large scale continued into the Pleistocene and may still be continuing. Little detailed work on the tectonic history of the Trough has been done since Taber (1922, 1931) outlined its main features, though recently it has been suggested that rather than being a simple normal rift, the Bartlett axis is a major zone of wrench- or transcurrent-faulting, along which considerable lateral movement occurred (Moody and Hill, 1956; Hess and Maxwell, 1953).

The reef-capped coastal features of British Honduras can thus be seen in a wider context as relatively minor dislocations along the north side of the Trough, where it abuts against the Central American mainland. Vertical movements of thousands of feet have taken place along this zone of weakness since late-Tertiary times (Schuchert, 1935), and the British Honduras faulting may have taken place in Pliocene times, even continuing into the early Pleistocene. This sets a very approximate limit to the age of the coastal reef formations. The rocks involved in the fracturing are not known, since no solid rocks outcrop anywhere on the atolls. They may have been Cretaceous-Eocene limestones similar to those blanketing the western part of the Maya Mountains, and which in northern British Honduras were subjected to dislocations of similar trend to those of the offshore areas. This layer of limestones probably overlies Paleozoic rocks at an unknown depth. Whether the main body of each atoll above the platform on which it rests consists of reef limestones or of older limestones (as Ower's suggested transverse faults may indicate) remains one of the many problems associated with these reefs.

Growing interest of oil companies in the offshore area will probably add greatly to our knowledge of the structure of the coast and reefs, through seismic exploration and deep borings.

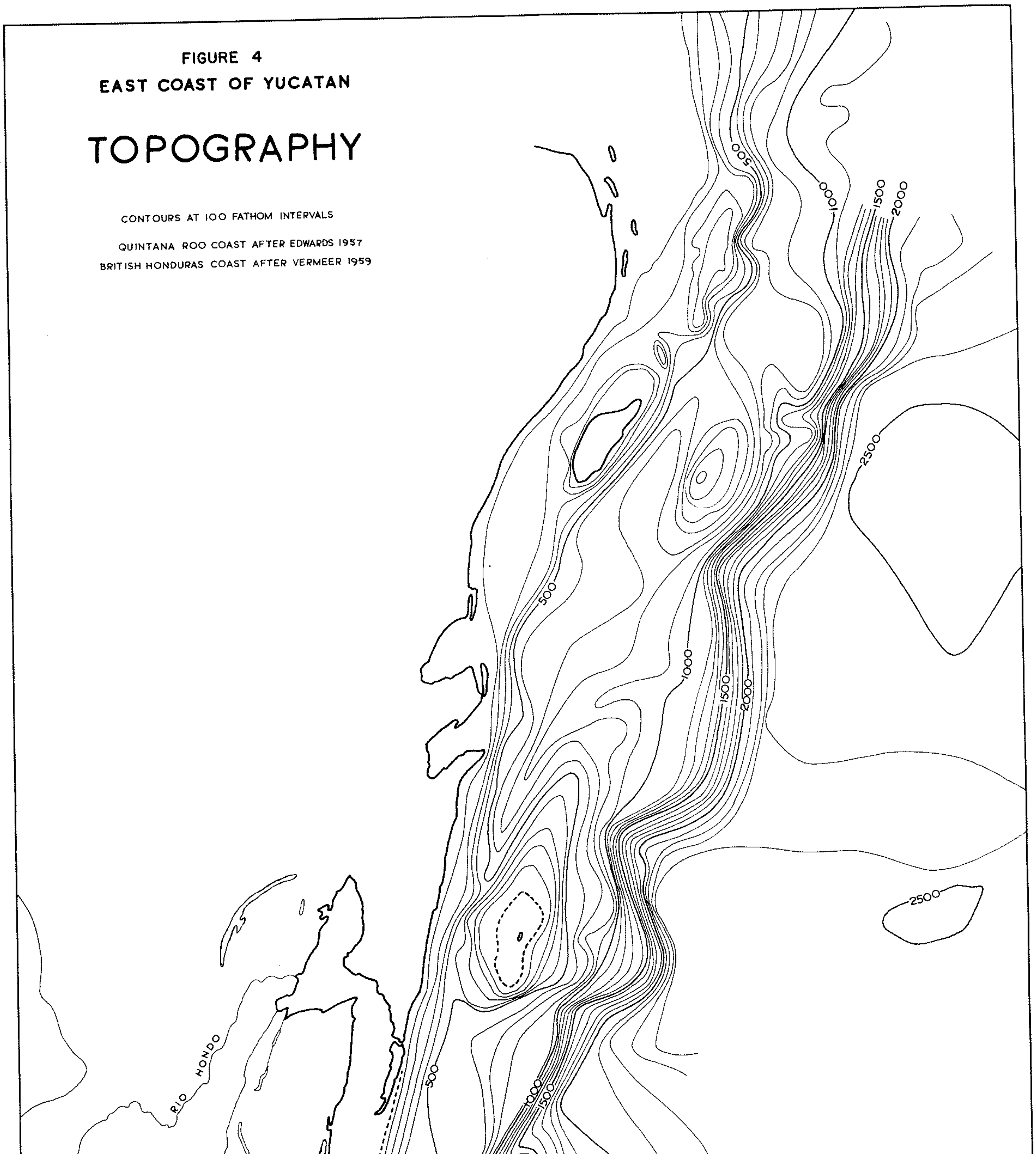


FIGURE 4
EAST COAST OF YUCATAN

TOPOGRAPHY

CONTOURS AT 100 FATHOM INTERVALS

QUINTANA ROO COAST AFTER EDWARDS 1957

BRITISH HONDURAS COAST AFTER VERMEER 1959

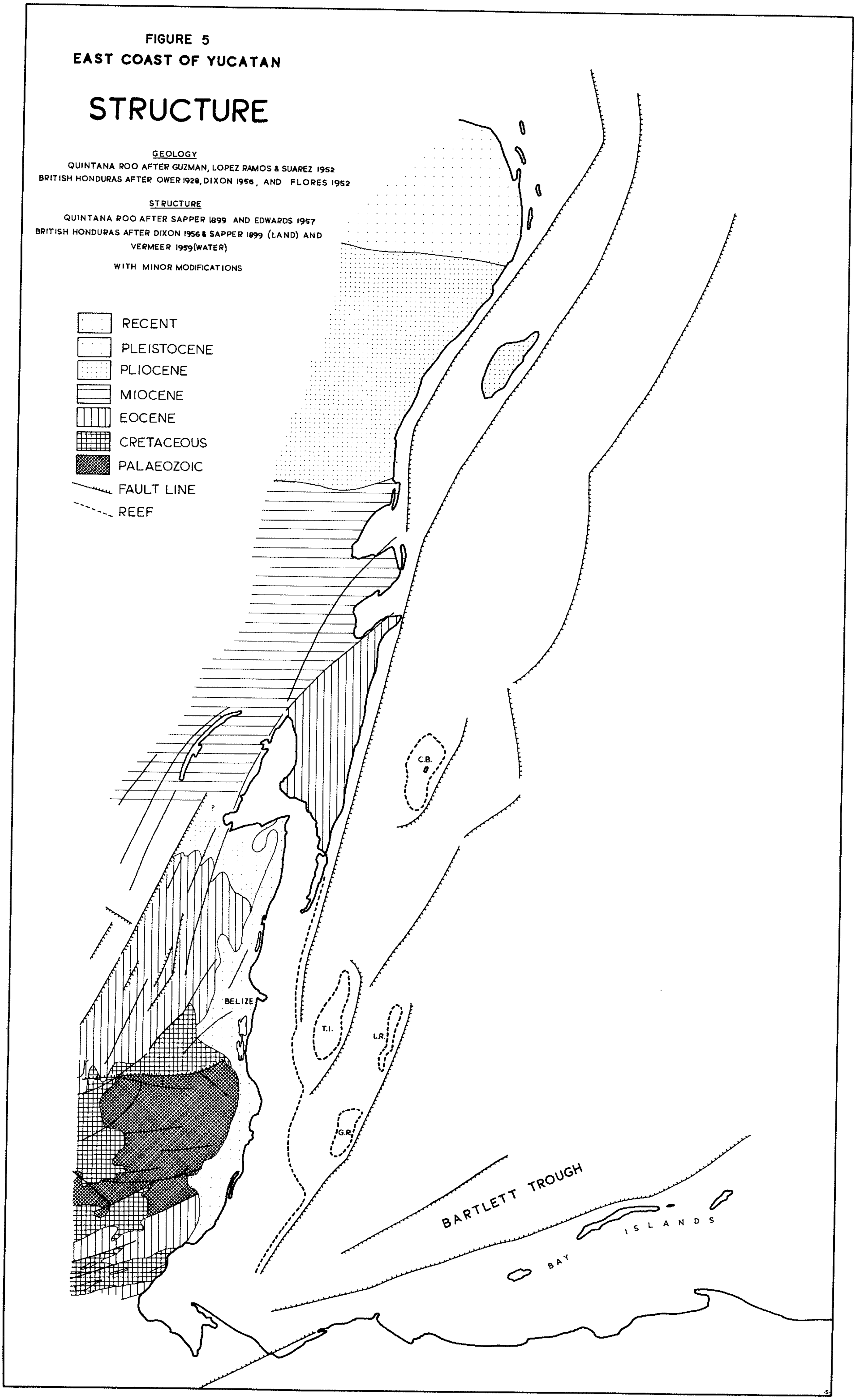
FIGURE 5
EAST COAST OF YUCATAN

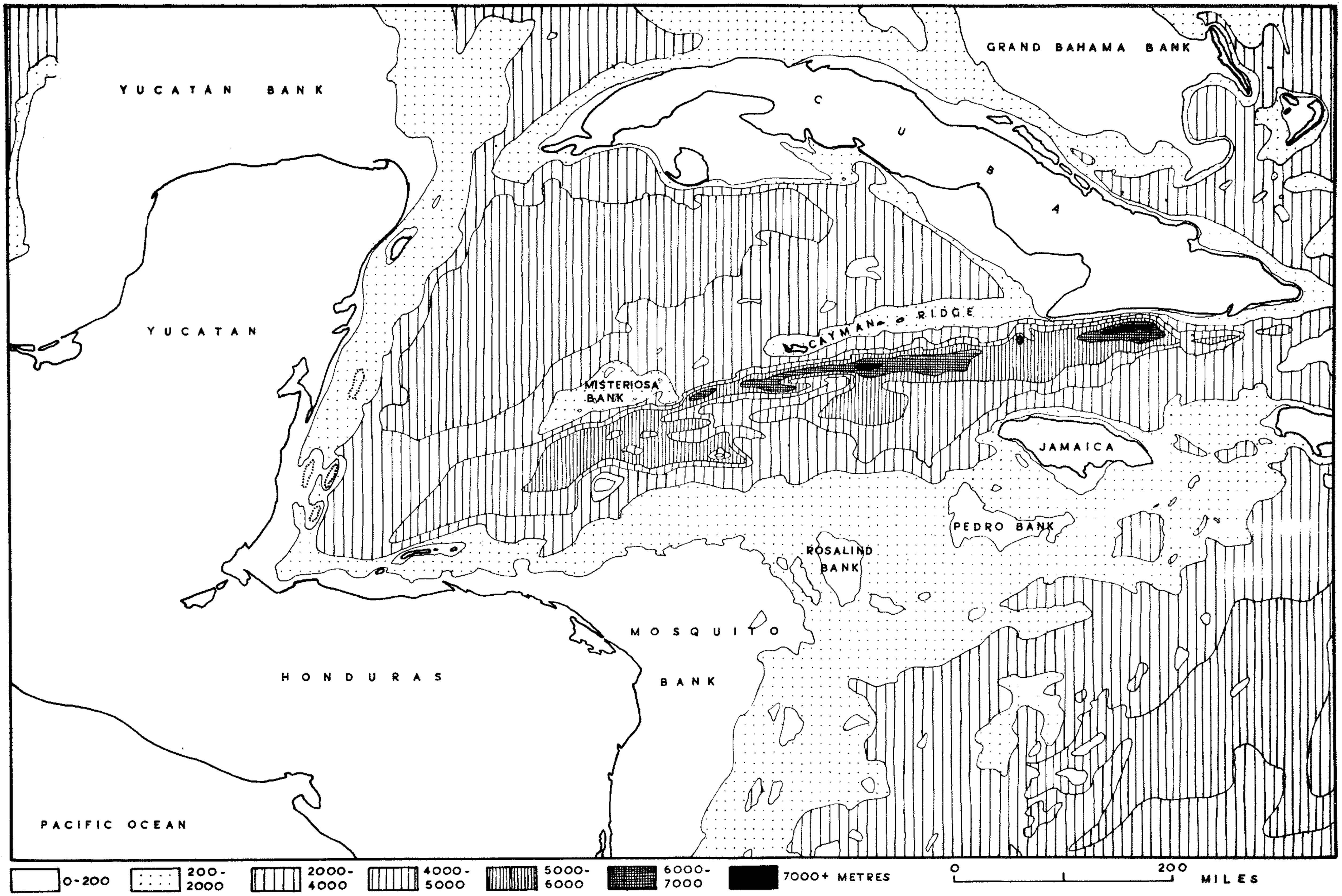
STRUCTURE

GEOLOGY
QUINTANA ROO AFTER GUZMAN, LOPEZ RAMOS & SUAREZ 1952
BRITISH HONDURAS AFTER OWER 1928, DIXON 1956, AND FLORES 1952

STRUCTURE
QUINTANA ROO AFTER SAPPER 1899 AND EDWARDS 1957
BRITISH HONDURAS AFTER DIXON 1956 & SAPPER 1899 (LAND) AND VERMEER 1959 (WATER)

WITH MINOR MODIFICATIONS





THE BARTLETT TROUGH
FIGURE 6

III. CLIMATE, SEA CURRENTS, TIDES

In this section several factors of the environment of the atolls will be discussed, but it must be borne in mind that records have never been kept on any of them for more than very restricted periods, in spite of permanently maintained lighthouse stations on Turneffe and Lighthouse Reef, and that for statistics we must rely on data from coastal stations. With the exception of the work of Parr in the Gulf of Honduras generally, and of University of Texas workers on the British Honduras coastal shelf, there do not appear to have been any marine surveys by oceanographic vessels near the atolls.

Climate

An account of the climate of British Honduras is given by Romney and others (1959, 15-22), and of Yucatan by Page (1933, 409-422), Edwards (1957, 61), and briefly by Trewartha (1961, 70-71). Even on mainland stations data are grossly inadequate: in Quintana Roo only 2 stations have records of 20 years or more, while of all recording stations in British Honduras, only 2 record more than daily rainfall.

Taking the Yucatan peninsula as a whole, rainfall increases from north to south, and is greater along the east coast than in the interior, as shown by the following figures:

Progreso	19	inches
Merida	36	
Valladolid	47	
Cozumel	66.6	
Chetumal	49.5	
Corozal	51.9	
Belize	69.6	
Stann Creek	117.3	
Punta Gorda	166.85	

Turneffe and Lighthouse Reef lie between the latitudes of Belize and Stann Creek. By analogy with coastal conditions rainfall on the atolls should be between 70 and 120 inches; it is, however, unlikely to be so high. The atolls are low, the land area small, and the dry season long, so that the rainfall probably does not exceed an average of 70 inches for any atoll. The dry season extends from March to the end of May, and can lead to severe water shortage on the cays, which rely on rainwater butts rather than groundwater for their supply. The seasonal pattern of rainfall at Belize, which is probably comparable to the atolls, is as follows (1941-1950, Romney and others, 1959, 16):

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Inches:	3.9	2.7	1.4	2.2	3.4	6.6	5.7	7.3	9.8	9.4	8.9	8.2	69.6

The only rainfall figures available for the atolls are those quoted by Smith (1941) for Calabash Cays, east side of Turneffe, for the summer months of 1937-1939; the variability is considerable:

	April	May	June	July	Total
1937	3.46	3.47	3.50	11.52	21.95
1938	3.10	2.18	4.64	2.00	11.92
1939	0.30	0.45	1.16	2.87*	4.78

(* - Man of War Cay; no data for Calabash Cays)

The winds in the atoll area blow steadily from the east for most of the year. At Belize, the only recording station, for the period 1917-1949, 56% of winds at 0600 hours came from the E and SE quadrants and 23% from the NW (means for the year); while at 1800 hours, 75% of winds came from the E and NE quadrants. The wind data, taken from the West Indies Pilot (I, 1956, 76) are summarised in the wind roses in figures 7-9. The importance of northwest winds in early morning reflects the importance of land-and-sea breezes at a coastal location; the extent of these offshore winds is very restricted, and may not even reach the barrier reef. They are probably negligible on the atolls. The constancy of the easterlies at Belize during the summer needs no stressing: at 1800 hours in June, July and August 100% of the observed winds come from the NE, E, and SE quadrants, the two former greatly predominating.

Two further features may be mentioned in connection with winds. The first and most important is the extension of the North American high pressure system southwards during the period November-February, occasionally extending to the end of March. This brings north winds, a sudden fall of 5-7° (and sometimes much more) in air temperature, low clouds, and frequently rain and stormy weather. The whole lasts for four or five days at a time, and is known as a "norther". These are felt on the atolls as much as at Belize. Secondly, there is some evidence in the lower part of the Gulf of Honduras, in the Punta Gorda-Puerto Barrios area, and along the southern barrier reef, of occasional strong southerly winds displacing the easterlies. There is no evidence, however, that these extend to the atolls.

During the months July to October the British Honduras coast is liable to tropical hurricanes, moving westwards from the Caribbean Sea. On occasion these are highly destructive: Belize has been destroyed more than once, most seriously in 1931 (Cain 1933), while Hurricane "Janet" did great damage to Corozal and Chetumal in 1955 (Pagney 1957). Poey (1855) records major hurricanes at Belize in 1787, 1813, 1827, and 1831; the most important since then have been in 1931, 1942, 1945 (Toledo District), and 1955. The most recent have been Hurricane "Abby" in 1960, and Hurricane "Anna" in July 1961, which we witnessed at sea near Placencia, examining the damage along the mainland coast shortly afterwards. Many hurricanes have decreased in intensity by the time they have reached this coast, though during the 1955 hurricane the Chetumal anemometer broke at 150 mph. The effect of hurricanes is three-fold: the direct effect of wind in uprooting vegetation, especially coconuts; the local rise of sea-level, often of several feet, under the influence of winds and decreased atmospheric pressure; and the action of wind-generated waves in eroding and redepositing bottom material and often damaging the living reef (Moorhouse 1936; Blumenstock 1958a, 1958b, 1961; McKee 1959). The immediate physiographic effects on low land areas are considerable: deposition of rubble and fresh sand carpets, building of shingle ridges, and erosion of former land areas, and these effects will be detailed for the British Honduras atolls in the more detailed accounts which follow. Experience on Jaluit Atoll, Marshall Islands, however, shows that some of these changes are only temporary (Blumenstock, Fosberg and Johnson 1961).

The same observation may be made for the effects of "northers." Erosion often occurs along the northern margins of cays during "northers", with the building of sand spits proceeding at the same time to leeward (often at the southwest corner); but these are shortlived features and disappear when the easterlies reassert themselves. Small sandbores even appear and disappear seasonally in response to wind direction, and a similar observation has been made by Folk on Alacran (personal communication). Not all the changes are temporary, however, at least when measured in terms of decades. Marginal attrition of cays, and the slow disappearance of storm-built ramparts are a different matter from the disappearance of a cay altogether, especially if it is vegetated. Once a vegetated cay is swept away, it is a very long time before the re-emergent sandbore becomes sufficiently stable, through colonisation by vegetation and the formation of beachrock, to become a cay once more. No example is known on the British Honduras reefs where this has happened, except at Cay Glory (Barrier Reef), which now has a mat of Sesuvium and Euphorbia, and a single small coconut tree. Yet numerous examples of cays washed away in storms are known. In this respect it may be noted that the path of maximum destruction in hurricanes is narrow, and that rarely is more than one cay seriously damaged. Thus the 1935 hurricane, which destroyed Paunch Cay and flooded St. George's Cay on the barrier reef, did no damage whatever at English Cay four miles to the south.

Little is known of the effect of hurricanes on coral formation; though it is known that globular coral colonies may be rolled across reef-flats, and, in deeper water, large tree-like colonies of Acropora palmata may be completely inverted even in "northers".

There are few data on air temperatures, apart from the Belize records. Average records here for 1917-1949 (West Indies Pilot, I, 1956, 76) are as follows:

$^{\circ}$F.	Mean	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily max	85	81	82	83	86	87	87	87	88	87	85	83	81
Daily min	72	68	69	71	74	75	75	75	75	74	71	67	68

Air temperatures recorded at mid-day at Rendezvous Cay, barrier reef, September 1959 to May 1960, were:

Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
89	88	80	80	80	79	80	82	82.7

Mean mid-day shade temperatures fluctuate between 80 and 89°F throughout the year at Belize, falling at night to means of 67-75°. According to the West Indies Pilot, the means of the highest temperatures in each month, 1917-1949, range at Belize from 85° in December and January to 90° in May and August-October. The mean of the lowest temperatures in each month ranges from 57° in January to 69° in July and August. The most sudden variations in temperatures are associated with "northers": according to the Rendezvous Cay records these generally involve a sharp fall of 5-7°C lasting several days. It is worth noting that the sensible effect of such a fluctuation is much more intense for white persons accustomed to the heat than the figures might suggest, and cold can cause some discomfort on the cays in winter even though the temperature does not fall below 65°F.

Marine environment

Even less data are available on sea temperatures. The Rendezvous Cay records for September 1959 to May 1960 are as follows:

°C	Mean	Maximum	Minimum
September	29.8	30.5	28.5
October	29.9	31.1	28.5
November	28.6	29.5	27.5
December	27.1	28.0	26.0
January	27.0	28.0	26.0
February	26.4	27.0	25.5
March	26.5	28.0	25.0
April	28.0	30.5	26.0
May	28.8	29.0	28.5

The figures show a slight seasonal fluctuation in the means from 26.4°C in February to probably 30° or more in summer: the daily figures show that water temperatures remain unaffected by the sudden fall of air temperature during "northers". These temperatures are well within the optimum range for reef growth of 25-29° specified by Vaughan and Wells (1943, 55), and well above the lethal lower limit for most West Indian species of 16° (Mayer, 1915, 212).

This is of some significance in view of the great change in coral composition of the British Honduras barrier reef north of Cay Caulker, where the usual dominance of Montastrea annularis and Acropora palmata gives way to a community in which Siderastrea siderea is dominant, with some Montastrea cavernosa and numerous Gorgonians. Only one poor specimen of M. annularis was seen in a transect one mile south of San Pedro, Ambergris Cay. Vermeer noted that the reef here seemed less healthy and vigorous than the reef farther south, and suggested that this resulted from upwelling of cold water along this coast (1959, 123-4)(also H.O. Publ. No. 225). No figures are available, but certainly the water feels considerably cooler than anywhere else on the British Honduras reefs, irrespective of weather. Temperature-inhibition of reefs by upwelling was suggested by Crossland as long ago as 1902, and has subsequently been considered by Ranson (1952), Newell (1954, 1956), and Newell and others (1951). Mayer (1915, 212) showed that Siderastrea radians has a considerably lower death temperature than other West Indian corals: hence Vermeer's suggestion is certainly worth further study. It is probable that an area of upwelling does exist off Ambergris Cay, immediately north of Turneffe, but no effects of this have been noticed on any of the atolls. In particular, upwelling effects were not noticed on the eastern sides of the atolls, in spite of a similar situation to the Ambergris coast. The reef at the north end of Turneffe is particularly well developed, with a groove-and-buttress system even extending for a short distance down the leeward side.

Upwelling certainly takes place farther north along the east Yucatan coast, as shown in temperature profiles published by Agassiz (1888b, 219) and especially Parr (1937, 37, 42, 43, 46). According to Parr's sections, the 24°C isotherm at Cape Catoche reaches within approximately 10-15 fathoms of the surface, whereas at Bahia de la Ascension 140 miles to the south it lies at 100 fathoms depth. This latter point is still 130 miles north of Ambergris Cay.

The upwelling off Quintana Roo and presumed upwelling off Ambergris Cay are associated with oceanic circulation patterns (fig. 10) in the Caribbean Sea (West Indies Pilot, I, 1956, 20-25; Parr, 1935; Vermeer, 1959, 121-3). The main Caribbean Current flowing westwards from the Lesser Antilles sets west and north from Cabo Gracias a Dios towards the Yucatan Channels. In the angle formed by the Gulf of Honduras, a counter-current is created, flowing southwards. The main current flowing northwards attains a rate of 1½-2 knots in summer, and is less powerful during the winter "northers". At this period the counter-current becomes stronger, both on the coastal shelf and round the atolls; it is said to extend as far north in winter as Banco Chinchorro. On the coastal shelf, the counter-current sets south throughout the year, and continues eastward to Truxillo and beyond. The currents round the atolls are summarised in the West Indies Pilot (I, 1956, 462, 460) as follows:

> "In the vicinity of Glover reef, Lighthouse reef, and Turneffe islands, the currents during November, December and January depend on the winds; a north-going current is experienced during westerly winds, and a south-going current during northerly winds. During February and March the currents are mainly north-going, with a rate of about 1½ knots. In April and May they are nearly south-going, with a rate of about 1½ knots. In June, July and August the currents are mainly north-going, with a rate of about 1½ knots, which increases to 2 knots during September and October."; "...a strong west-going current has been experienced on several occasions between Glover Reef and Lighthouse Reef." (see also H.O. Misc. Pub. No. 10690).

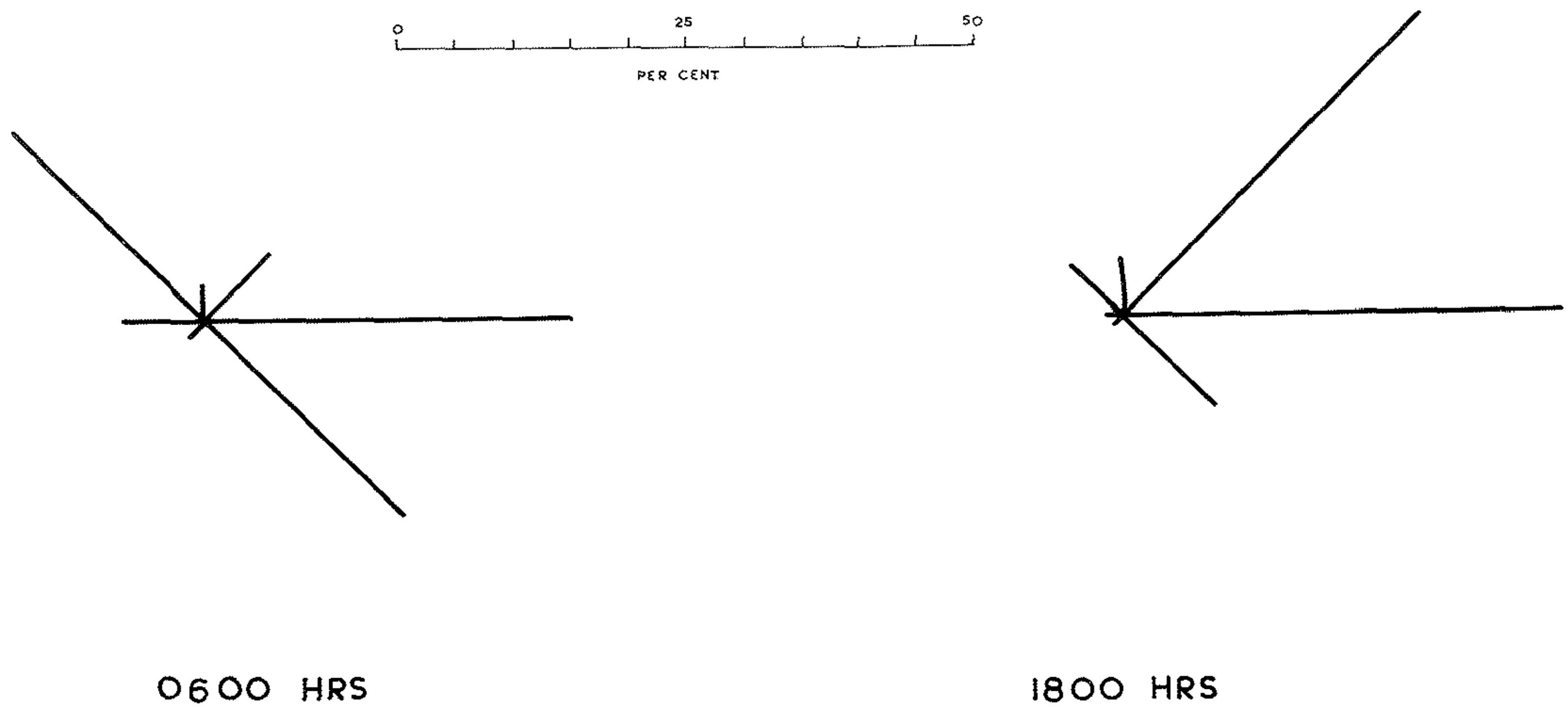
Tides are less than 2 feet throughout the area, and tides on the atolls probably average little more than a foot (Admiralty Tide Tables). More important in affecting the height of the sea surface on many occasions are the winds: north winds may depress the surface level 6 inches to 1 foot below its normal position, exposing large areas of sand, adjacent to islands, which are normally submerged, and exposing the upper parts of reef corals. Because of the small tidal range, tidal currents are not generally important, except in narrow passages between islands, especially the narrow entrances (bogues, creeks) connecting the Turneffe lagoons with the sea. These are locally sufficient to make small-boat navigation difficult against the set of tidal currents.

Even less is known of temperature and other conditions within the atoll lagoons, though there is some evidence that temperature and salinity are liable to extreme fluctuations within the enclosed Turneffe lagoons. Smith (1941) quotes surface temperatures in August 1939 within the Southern Lagoon of 29.5°-31°C. Salinity within the Southern Lagoon during June 10-20th 1939 reached 70°/oo, compared with 40°/oo at Calabash Cay on the eastern reef. By August the lagoon salinity was back to 36-38°/oo; the June high is explained by lack of rainfall and high temperatures. Measurements in 1938 at Man of War Cay (southern entrance of Southern Lagoon) averaged 37.6°/oo in June-August. These fluctuations in part at least may explain the absence of corals in the Turneffe lagoons. The lagoons of Lighthouse and Glover's Reefs, open to the sea, probably do not suffer from these extremes.

Surface temperatures measured in the Southern Lagoon, Turneffe, in June-July 1961 averaged 29°C, and in Lighthouse Reef lagoon 28.5°C.

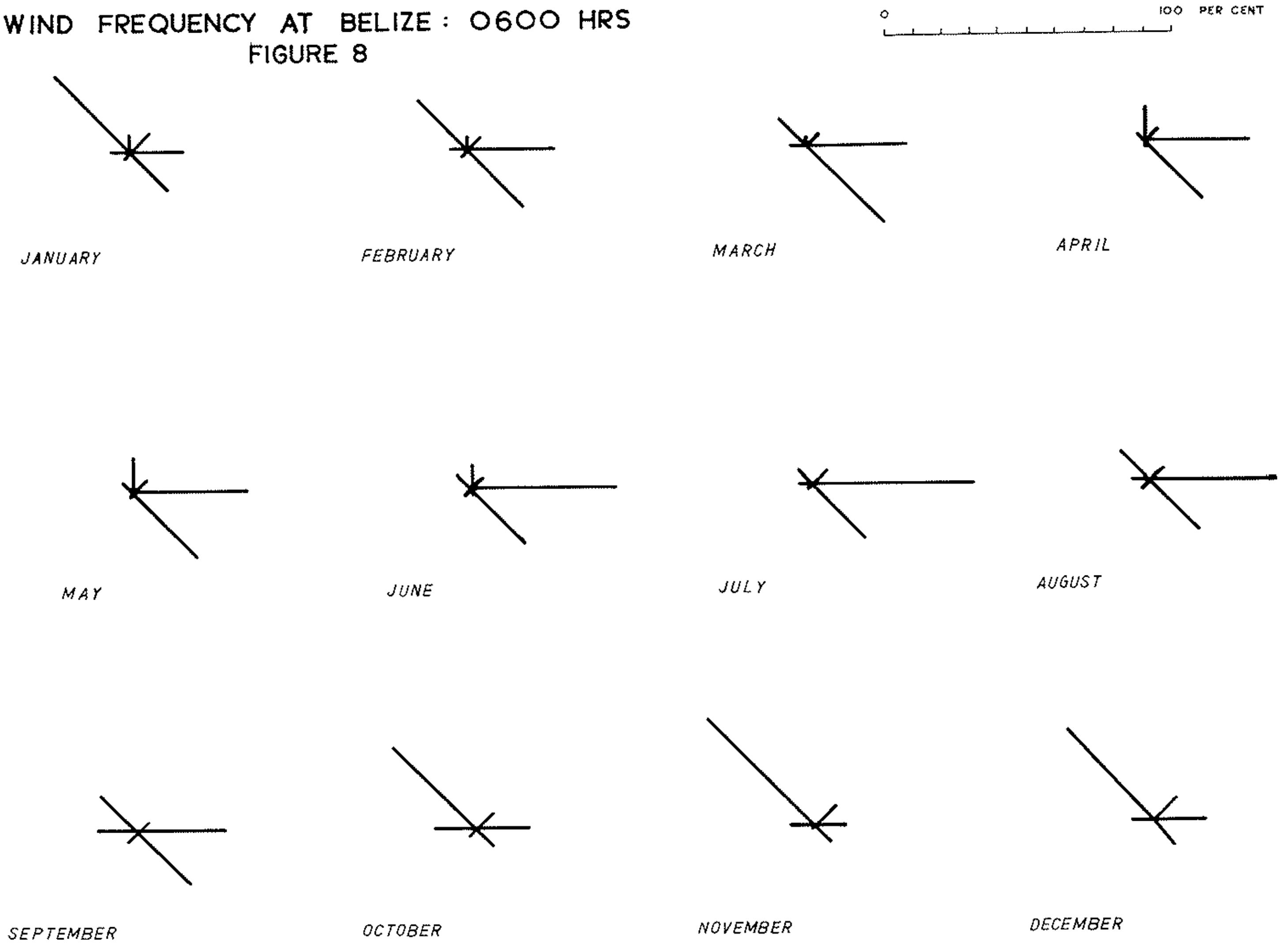
FIGURE 7

MEAN ANNUAL WIND FREQUENCY AT BELIZE

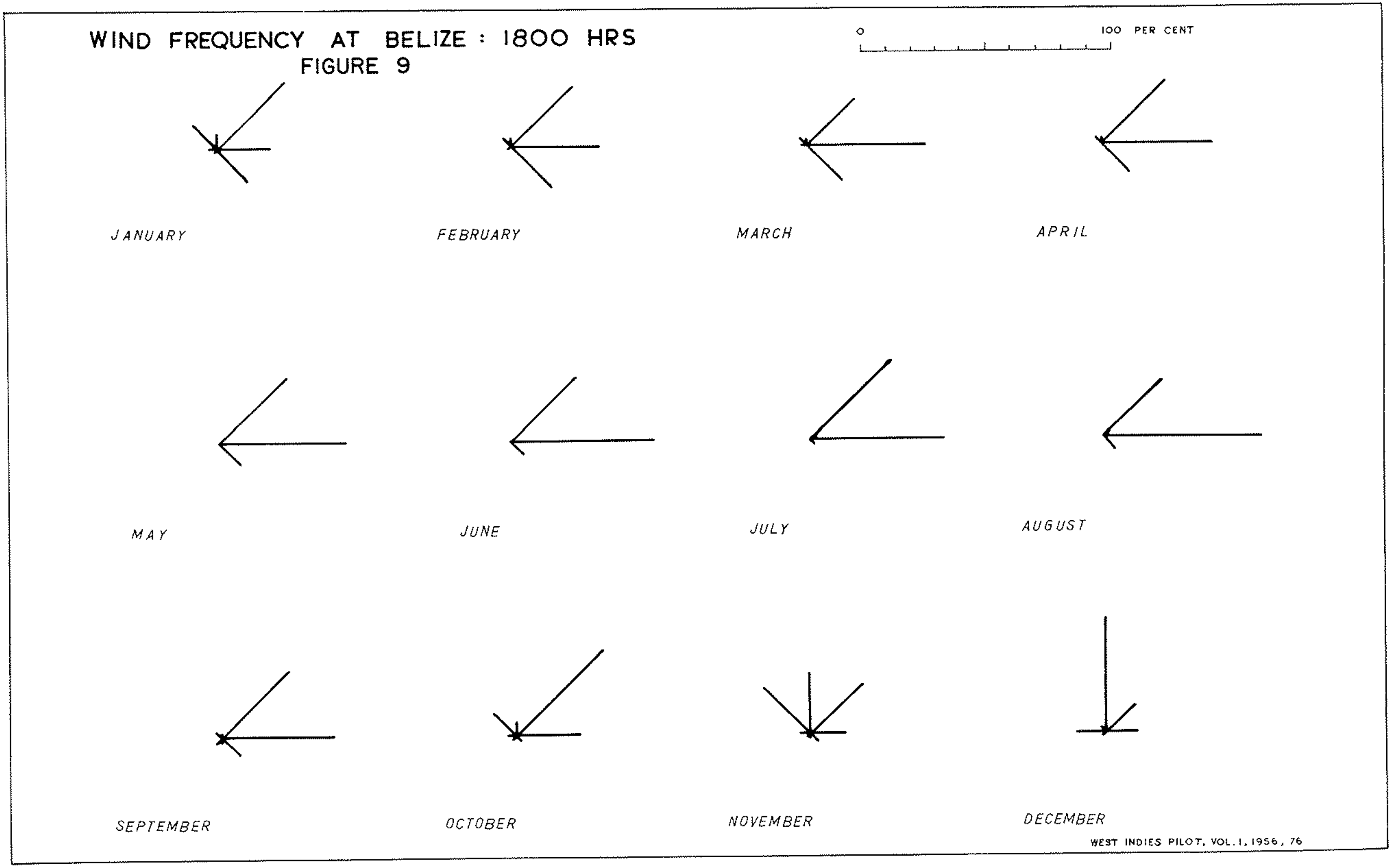


WEST INDIES PILOT, VOL. I, 1956, 76

WIND FREQUENCY AT BELIZE: 0600 HRS
FIGURE 8



WEST INDIES PILOT, VOL. I, 1956, 76


WIND FREQUENCY AT BELIZE : 1800 HRS
FIGURE 9
0
100 PER CENT
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
WEST INDIES PILOT, VOL. I, 1956, 76

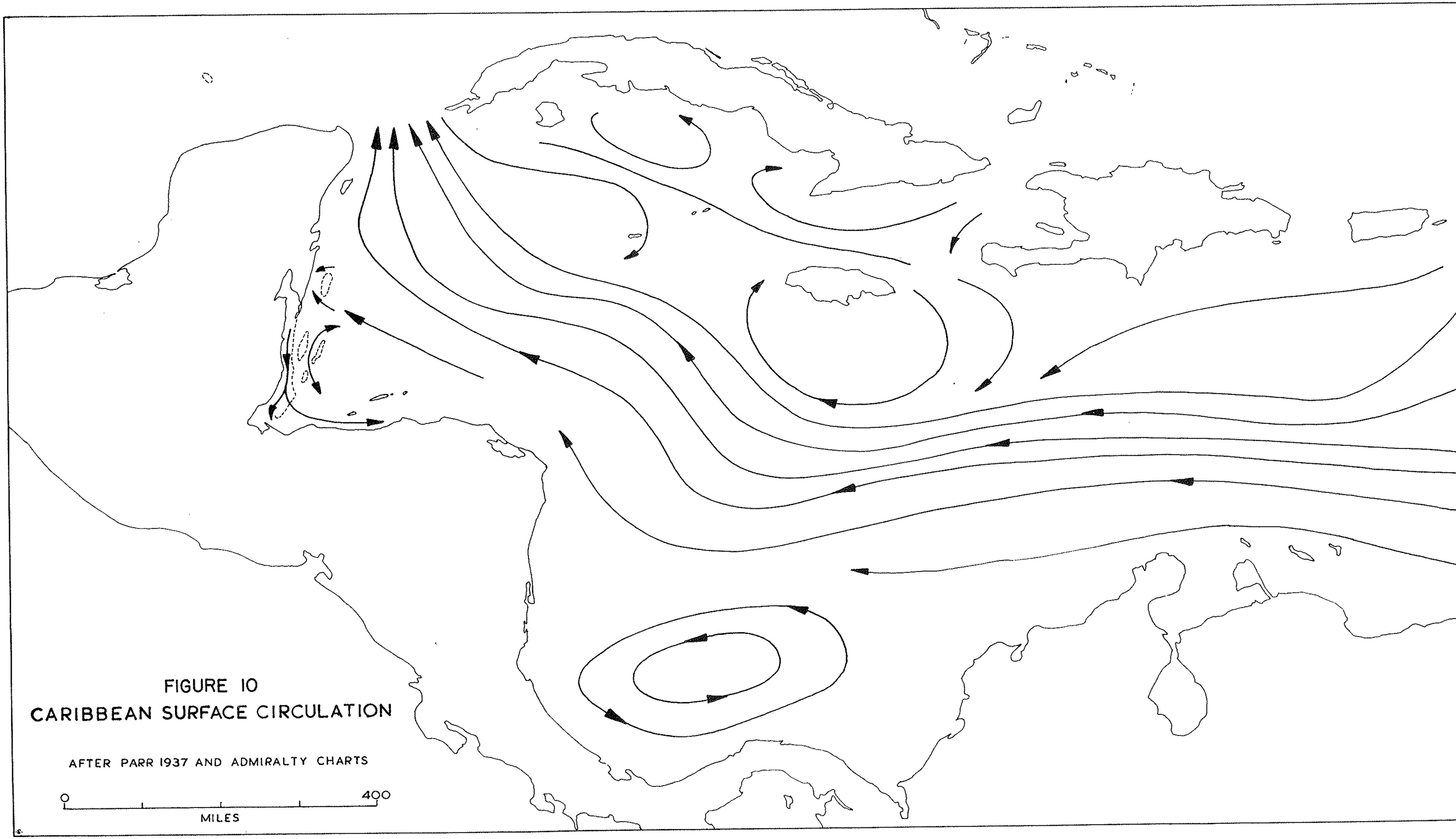


FIGURE 10
CARIBBEAN SURFACE CIRCULATION

AFTER PARR 1937 AND ADMIRALTY CHARTS

IV. THE REEFS OF THE ATOLLS

Species-composition of the reefs

It is proposed to treat the reefs of the atolls together, rather than deal with them under the more detailed accounts of individual atolls, to avoid repetition and aid comparison. So far as is known, there are no previous descriptions of the reef fauna or ecology of any of these atolls. A preliminary account of the distribution of corals on the Rendezvous Cay reef-patch, Barrier Reef, has been given by Thorpe and Bregazzi (1960), who list the following species of stony corals. From work elsewhere on the Barrier Reef it appears that this list is representative of the fauna of the Barrier Reef in general: only *Meandrina meandrites* was not found at Rendezvous Cay, but was collected nearby.

Table 1. Corals found at Rendezvous Cay
(Thorpe and Bregazzi 1960)

Seriatoporidae:
- *Madracis decactis* Lyman

Acroporidae:
- *Acropora cervicornis* Lamarck
- *Acropora palmata* Lamarck
- *Acropora prolifera* Lamarck

Agariciidae:
- *Agaricia agaricites* Linnaeus
- *Agaricia nobilis* Verrill

Siderastreidae:
- *Siderastrea radians* Pallas
- *Siderastrea siderea* Ellis and Solander

Poritidae:
- *Porites astreoides* Lamarck
- *Porites divaricata* Lesueur
- *Porites furcata* Lamarck
- *Porites porites* Pallas

Faviidae:
- *Favia fragum* Esper
- *Diploria clivosa* Ellis and Solander
- *Diploria labyrinthiformis* Linnaeus
- *Diploria strigosa* Dana
- *Colpophyllia natans* Muller
- *Manicina areolata* Linnaeus
- *Cladocora arbuscula* Lesueur
- *Solenastrea bournoni* Milne-Edwards and Haime
- *Montastrea annularis* Ellis and Solander
- *Montastrea cavernosa* Linnaeus

Trochosmiliidae:

Meandrina meandrites Linnaeus
Dichocoenia stokesii Milne-Edwards and Haime
Dendrogyra cylindrus Ehrenberg

Mussidae:

Mussa angulosa Pallas
Isophyllastrea rigida Dana
Mycetophyllia lamarckana Milne - Edwards and Haime
Isophyllia multiflora Verrill

Caryophyllidae:

Eusmilia fastigiata Pallas

Milleporidae:

Millepora alcicornis Linnaeus
Millepora complanata Lamarck

The reef fauna of the three atolls is closely comparable with this list from the Barrier Reef, but not all the species found at Rendezvous were seen on the atoll reefs. Conversely, *Meandria meandrites*, which is rarely seen living on the Barrier Reef and is rarely found in the debris of shingle ridges on the Barrier Reef cays, is a prominent constituent of shingle ridges on the atolls, especially on Glover's and Lighthouse Reefs. No living colonies have been seen on the atolls, however, which suggests that it is restricted to deeper, rougher water on the seaward slopes of reefs.

The Rendezvous Cay fauna corresponds closely with that of other reef areas in the Caribbean, though the number of genera, excluding *Millepora*, which is 20, and species (28), is less than in Jamaica (25 and 41 respectively: Goreau 1959). Table 2 summarises species records for a number of Caribbean localities, including Alacran Reef (north of the Yucatan Peninsula) (Kornicker and others 1959), Rendezvous Cay (Thorpe and Bregazzi 1960), Pedro Bank (Zans 1958), Jamaica (Zans 1959; Goreau 1959), and Bimini, Bahamas (Squires 1958). The records made in 1959-60 and 1961 at Turneffe, Glover's Reef and Lighthouse Reef are included, and though the record for these atolls is by no means complete, the most numerous and important species are probably included. Many of the gaps are undoubtedly due to omissions in collecting rather than to non-occurrence. 24 species (excluding *Millepora*) are common to the atolls, taken together, and Rendezvous Cay. 5 species have been recorded at Rendezvous and not on the atolls, while no species is recorded from the atolls which is not also seen at Rendezvous. The species not recorded from the atolls are all minor reef-builders: *Madracis decactis*, *Acropora prolifera*, *Agaricia nobilis*, *Isophyllia multiflora*, *Cladocora arbuscula* and *Solenastrea bournoni*. The comparison with the records from the two nearest reef areas--Alacran and Pedro Bank--is also interesting. Species recorded from the three atolls and not from Alacran include *Porites divaricata*, *Colpophyllia natans*, *Meandrina meandrites*, *Isophyllastrea rigida*, and *Mycetophyllia lamarckana*; *Colpophyllia amaranthus* is recorded from Alacran but not the atolls. Zans's records from the Pedro Bank are

Table 2

	1	2	3	4	5	6	7	8	9	10
Stephanocoenia michelini	–	–	–	–	–	–	–	x	x	x
Madracis decactis	–	–	–	x	–	–	–	–	x	–
Acropora cervicornis	–	x	x	x	x	x	x	x	x	–
Acropora palmata	x	x	x	x	x	x	x	x	x	x
Acropora prolifera	x	–	–	x	–	–	–	x	x	–
Agaricia agaricites	–	–	x	x	x	x	x	x	x	x
Agaricia fragilis	–	–	–	–	–	–	–	x	x	–
Agaricia nobilis	–	–	–	x	–	–	–	x	x	–
Siderastrea radians	?	–	x	x	x	–	–	x	x	x
Siderastrea siderea	–	x	x	x	–	x	x	x	x	x
Porites astreoides	x	–	x	x	x	x	x	x	x	x
Porites branneri	–	–	–	–	–	–	–	x	–	–
Porites divaricata	–	–	–	x	x	–	–	–	–	x
Porites furcata	x	x	x	x	–	–	x	–	–	x
Porites porites	–	–	x	x	x	x	x	–	x	x
Favia fragum	–	–	x	x	x	x	–	x	x	x
Diploria clivosa	–	x	x	x	–	–	x	x	x	x
Diploria labyrinthiformis	x	x	x	x	x	–	x	x	x	–
Diploria strigosa	x	x	x	x	x	x	x	x	x	x
Colpophyllia amaranthus	–	–	x	–	–	–	–	x	x	–
Colpophyllia natans	–	–	–	x	–	–	x	x	x	–
Manicina areolata	–	–	x	x	–	x	–	x	x	x
Cladocora arbuscula	–	–	–	x	–	–	–	–	x	–
Solenastrea bournoni	–	–	–	x	–	–	–	–	x	–
Montastrea annularis	x	x	x	x	x	x	x	x	x	x
Montastrea cavernosa	?	x	x	x	x	x	x	x	x	x
Oculina diffusa	?	–	–	–	–	–	–	x	x	x
Meandrina meandrites	–	–	–	x	x	x	x	x	x	–
Meandrina brasiliensis	–	–	–	–	–	–	–	–	x	–
Dichocoenia stokesii	–	–	–	x	–	x	–	x	x	x
Dendrogyra cylindrus	–	–	–	x	x	x	x	–	x	–
Mussa angulosa	–	–	x	x	–	–	x	x	x	–
Isophyllastrea rigida	–	–	–	x	x	x	x	x	x	x
Mycetophyllia lamarckana	–	x	–	x	x	x	x	–	x	–
Isophyllia sinuosa	–	–	–	–	–	–	–	x	x	x
Isophyllia multiflora	–	–	–	x	–	–	–	x	x	–
Eusmilia fastigiata	–	–	x	x	–	–	x	–	x	x
Millepora sp.	–	–	x	x	x	x	x	x	–	x

1. Vera Cruz (Heilprin 1890)
2. Blanquilla (Moore 1960)
3. Alacran (Kornicker and others 1959)
4. Rendezvous Cay (Thorpe and Bregazzi 1960)
5. Turneffe
6. Lighthouse Reef
7. Glover's Reef
8. Pedro Bank (Zans 1958)
9. Jamaica (Goreau 1959)
10. Bimini, Bahamas (Squires 1958)

based on boulder material from the cays only. Species recorded here and not on the atolls include Stephanocoenia michelini, Acropora prolifera, Agaricia fragilis, Agaricia nobilis, Porites branneri, Colpophyllia amaranthus, Oculina diffusa, Isophyllia sinuosa and I. multiflora. Recorded from the atolls and not from Pedro Bank are Porites porites, Porites furcata, Dendrogyra cylindrus and Mycetophyllia lamarckana.

The atoll fauna is thus typically Caribbean, and agrees in composition with Goreau's hypothesis of a species-maximum for Caribbean corals in the Jamaica-Puerto Rico-Florida-Bahamas area. Thirteen species are common to all three atolls, and they are all conspicuous constituents of living reefs. The list will probably be extended to include most, if not all, of the Rendezvous Cay fauna, when the atoll reefs are better known. These thirteen common species are:

Acropora cervicornis
Acropora palmata
Agaricia agaricites
Porites astreoides
Porites porites
Diploria strigosa
Montastrea annularis
Montastrea cavernosa
Meandrina meandrites (dead only)
Dendrogyra cylindrus
Isophyllastrea rigida
Mycetophyllia lamarckana
Millepora alcicornis

Zonation of the reefs

Much attention has been devoted in recent years to studies on the zonation of corals on reefs, both of atolls (on Bikini, Tracey, Ladd and Hoffmeister 1948, and Ladd, Tracey, Wells and Emery 1950; and on Arno, Wells 1951 and Hiatt 1957) and other reef-types (for example, Caribbean fringing reefs in the Barbados, Lewis 1960, and Jamaica, Goreau 1959). During the 1961 Expedition an effort was made to obtain data on reef zonation on the windward and leeward sides of each atoll, and a series of transects (figs. 11, 12) were made by swimming across the reefs accompanied by a boatman in a dorey or dugout canoe. Doubtful specimens were collected for later identification, and full notes were made immediately on leaving the water. In cases of doubt a second traverse was made near the line of the first. Unfortunately time only allowed one traverse on each side (windward and leeward) of each atoll, and there is the possibility that the line of transect chosen is not typical. Aqualungs were not used, and the transects could not therefore be carried into depths greater than c. 30 feet. Finally, on the windward sides of atolls, it generally proved impossible to penetrate seaward of the breaker zone: the transect was continued until turbulence made visibility nil. The transect areas were subsequently flown over at heights of 1-200 feet for observation of the zone beyond the breakers, and photographed. Depths and distances are estimated. The limitations of these transects are therefore clear: nevertheless, since in most cases zonation is clearly apparent, and since there is absolutely no published information on these reefs available, the transects are included here.

I. The windward reefs (fig. 11)

A. East reef, Turneffe Islands

The Turneffe Islands are surrounded by a reef which on the east side is narrow, well-defined, breaks surface, and is lined by surf, and on the west side is wider, more diffuse, and generally submerged. Small boats can cross the west reefs at almost any point, but can only cross the east reefs by a number of narrow reef gaps. The east reef was investigated at Calabash Cays: the weather was calm, and the transect was swum from Little Calabash Cay across the reef crest into deep water beyond. The following zones were recognised:

A 1. Seaward shore of cay.

A 2. Sand and rubble platform adjacent to the cay. This is covered with 6-12 inches of water and is some 200 feet wide. It is carpeted with Thalassia and small green algae, including Halimeda. The sand content of the flat diminished seaward, and near its outer edge the platform consists of brittle Porites rubble.

A 3. Reef flat. A sandy area sloping gradually seaward, under 12-18 inches of water, 20-30 yards wide. Small corals (Favia fragum, Porites divaricata) and sea-urchins (Diadema) are scattered in the turtle grass.

A 4. Inner reef zone. A sandy bottom under two feet of water, with scattered colonies up to a foot in diameter of Montastrea annularis, Porites astreoides and Dendrogyra cylindrus, with small colonies of Siderastrea radians. Sea fans and sea-whips are also found.

A 5. Cervicornis zone. Same as zone 4, but with a ground cover of Acropora cervicornis, much of it dead. The Montastrea and Porites colonies are larger (up to 2 feet diameter), but sea fans and sea-whips are not important.

A 6. Annularis zone. This is located immediately to landward of the breaker zone; the dominant colonies are large massive blocks of Montastrea annularis, Porites astreoides, Dendrogyra cylindrus and Siderastrea siderea. Minor constituents include both encrusting and foliaceous Agaricia, scattered Acropora cervicornis, and massively-built but scattered Acropora palmata with branches current-swept lagoonward. The larger colonies are intersected by deep winding channels 6-8 feet deep, floored with coarse, often rippled sand. The zone is 10-15 yards wide.

A 7. Reef-crest (Agaricia) zone. This consists of massive blocks of largely dead coral, covered on the upper surface almost exclusively with Agaricia agaricites. Channels between the blocks are up to 10 feet deep. The zone has a width of only a few yards.

A 8. Outer slope. A platform 10-15 feet deep, and deepening seaward. Colonies are rather small, perhaps averaging 2 feet in diameter, and very varied (Montastrea, Porites, Siderastrea). Between the boulder-like forms are scattered low colonies of Acropora palmata and Acropora cervicornis.

B. East reef, Lighthouse Reef

Lighthouse Reef is surrounded on all sides by a well-defined reef flat edged with living coral, rising on the one side from the lagoon floor and on the other plunging steeply down into great depths. The reefs are thus more clearly defined than those of Turneffe. Several transects were swum in the Half Moon Cay area: immediately southeast of the cay, half a mile to the north, and two miles to the north. That southeast of the cay was in deep water beyond the reef crest, and follows on naturally from that half a mile to the north, which ends at the breaker zone. The two traverses may be combined as follows; Zones B1-5 are from the transect half a mile north of the cay, B6 from that southeast of the cay, while B5 is common to both.

B 1. Reef flat. 3-6 feet deep, and deepening lagoonward; covered with large patches of Thalassia over a sandy bottom, with very large specimens of Manicina areolata and occasional Favia fragum and Siderastrea radians.

B 2. Lithothamnion pavement: a rocky bottom $2\frac{1}{2}$-$3\frac{1}{2}$ feet deep, covered with pink encrusting Lithothamnion and numerous unattached nodules 2-4 inches long of Lithothamnion. Occasional boulders of Porites astreoides, Diploria strigosa and Montastrea annularis. Width 20-30 yards and over.

B 3. Palmata zone. Bottom carrying 2-3 feet of water, with massive colonies of Acropora palmata current-swept lagoonward, and smaller colonies of Porites astreoides.

B 4. Mixed reef zone: similar in depth to zone 3, but more diverse: in addition to A. palmata and P. astreoides there are elongate colonies of Porites porites and smaller colonies of Agaricia agaricites. Nodular Lithothamnion is strewn on the floor between the colonies.

B 5. Elevated reef-rock zone: dead, eroded reef-rock, well cemented but highly fretted and bored, rising in small outcrops 12-20 inches above sea level. The sides are fringed with Millepora and algae, and are undercut below sea-level. The largest of the emerged patches is only about 4 feet long; and in the intermediate sections there is often a zone of dead reef-rock, similar in appearance but submerged, with clumps of Millepora.

B 6. Outer slope. Beyond the elevated reef-rock zone the floor falls steeply from 3-4 feet to over 20 feet, where it levels out to form a deep platform, covered with large and very massively built Acropora palmata, which is completely dominant. These are by far the largest specimens seen anywhere on the reefs, forming trees 10-20 feet tall. Between the A. palmata there is a carpet of open-branched Acropora cervicornis, interrupted here and there by large blocks of dead reef-rock topped with Agaricia agaricites and Millepora complanata. Between the coral colonies the floor is formed of white rippled sand.

C. East reef, Glover's Reef

Like Lighthouse Reef, Glover's Reef is surrounded on all sides by a sharply defined reef, edging a wide reef-flat, which in the case of Glover's Reef is much more sharply defined lagoonward than on Lighthouse Reef. The reefs are steep-to round the whole atoll perimeter. The windward reef transect was made several hundred yards north of Northeast Cay, about one-third of the distance along the east reef from its southern end. The following zones were recognised:

C 1. Reef flat. A sand flat 3-5 feet deep, covered with a low mat of yellow algae, Halimeda, and Penicillus, with very scattered colonies of Porites porites of brilliant blue colouration.

C 2. Porites zone. The floor, which carries 3 feet of water, is covered with broken branches of Acropora cervicornis, with scattered live colonies of Porites divaricata. Algae are unimportant.

C 3. Annularis zone. The reef-flat deepens slightly to 3-4 feet, and the dominant coral is Montastrea annularis in large colonies. Also present are boulders of Porites astreoides, Diploria strigosa, Diploria clivosa and Siderastrea siderea.

C 4. Porites-Lithothamnion zone. Seaward of zone 3, the Montastrea annularis ceases abruptly, the sea floor shoals slightly, and is covered with Acropora cervicornis rubble and very abundant nodules of pink Lithothamnion. The only living coral present is Porites astreoides, in small colonies spaced approximately six feet apart (cf. B2, B4).

C 5. Reef crest. Beyond the Porites-Lithothamnion zone the floor begins to fall away seaward, as seen in the narrow and intricate passages between the great blocks of dead reef-rock forming the reef-crest. These blocks appear to be formed mainly of Acropora palmata, and rise to within a few inches of the surface. They are encrusted with Lithothamnion, and near their upper surface with Agaricia agaricites (cf. A7). Porites porites and Millepora are present in small amounts. No living Acropora palmata was seen, and only very occasional A. cervicornis. There is a fairly dense growth of Halimeda on the walls of the reef-rock masses, and a considerable population of zoanthids. The bottoms of the channels consist of coarse Lithothamnion rubble.

(C 6. From air reconnaissance it seems that seaward of the breakers there is a well-developed groove-and-buttress zone, consisting mainly of Acropora palmata, and probably closely comparable with zone B6 at Lighthouse Reef. Unfortunately it could not be directly observed here.)

II. The Leeward reefs (fig. 12)

D. West reef, Turneffe Islands

By contrast to the east reef (transect A), the west reef of Turneffe does not break surface or rise to a well-marked crest. Reef growth rather begins a considerable distance from the mangrove fringe, from which it is separated by a 'lagoon' $1\frac{1}{2}$-2 fathoms deep, several hundred yards wide, and floored with Thalassia. The bottom of this lagoon slopes gradually from the mangrove fringe to deeper water, and coral colonies are simply distributed on this slope, beginning ¼-½ mile from the mangrove, and continuing seaward for 3-400 yards and more. The transect is taken in the latitude of English Cay, that is about half way along the length of the eastern reef. The following zones are recognised:

D 1. Lagoon, 9-12 feet deep, with a sandy floor thickly covered with Thalassia and gorgonians.

D 2. Thalassia-Gorgonian zone, 5-10 feet deep, similar to zone D1 but shallower, with scattered, mainly small colonies of Montastrea annularis and Porites. The most conspicuous element is the population of large and varied gorgonians. No large algae were seen.

D 3. Gorgonian zone. This is in all respects similar to zone D2, except that the Thalassia carpet is absent, and the bottom is formed of white sand.

D 4. Main reef zone. This has depths of 10-15 feet and a fairly flat bottom. The dominant corals are Montastrea annularis, Diploria labyrinthiformis and Diploria strigosa, with Porites porites and Agaricia agaricites, and small colonies of Dendrogyra cylindrus, Montastrea cavernosa, and occasionally Mycetophyllia lamarckana and Isophyllastrea rigida. Three subzones, from lagoon to sea, may be recognised:

a) the coral colonies are large and scattered, and interspersed with gorgonians and some sponges from zones D2 and D3.

b) the coral colonies are large and closely spaced, with a continuous undercarpet, not more than 2 feet high, of open-branched Acropora cervicornis. Gorgonians and sponges are of small importance.

c) coral colonies are sparser, and the cervicornis carpet gives way to a sandy bottom, populated with very large gorgonians, 4-5 feet high, and sponges.

Subzone (b) is clearly the main reef zone. Only a single small colony of Acropora palmata was seen in this transect.

D 5. Here the bottom slopes steeply into the blue, and is covered with much rubble. It is scattered with various small coral colonies not identified.

E. West reef, Lighthouse Reef

The leeward reef of Lighthouse Reef differs greatly from that of Turneffe. Along the greater part of the west side of the atoll there is a continuous rim of living reef at the surface, edging a wide sandy reef-flat, and falling fairly rapidly from the reef-crest into deep water on the outer side. Because of its leeward location the reef is rarely lined by breakers or surf, except during winter "northers", and then never to the same extent as the eastern reefs. The reef rim is so continuous that small fishing boats can only cross at one or two points: the most important of these gaps lies on the west side of Long Cay and continues northwards almost to the latitude of Saddle Cay. It is clearly shown on air photographs and carries 1-2 fathoms water. At occasional points on the rest of the reef it is possible for fishing boats to find a passage between the coral heads in 4-5 feet of water; one such point lies almost half way along the reef between the main gap and Northern Cay. These points are known to local fishermen.

The transect was made half way along the east reef, near the passage referred to. The following zones are clearly recognised at this point:

E.1. Reef flat. A wide expanse of barren white sand, 4-5 feet deep and more than 200 yards wide, lacking corals, gorgonians, sponges and algae. The sand is fairly coarse, and dead Halimeda is important.

E 2. Gorgonian zone. This is a narrow zone, about 10 yards wide, where the reef-flat is covered with sea fans and sea whips, and sparsely scattered with small colonies of Montastrea annularis. Algae are not of conspicuous importance.

E 3. Cervicornis zone. Seaward of the gorgonian zone, the reef-flat is covered exclusively with a carpet of living loose-branched Acropora cervicornis, in which no other colonial organisms are of importance. The zone is fairly continuously developed laterally, though only a few yards wide, and differs markedly from the zones on either side.

E 4. Reef-crest. At the outer edge of zone E3, the sea floor begins to fall from 4-5 feet in depth to 8-10 feet over a distance of 20-40 yards. The dominant coral is Montastrea annularis in large compound colonies many feet in diameter. Towards the outer edge are large wave-swept colonies of Acropora palmata; in and around them there are abundant encrusting and upright colonies of Millepora complanata and M. alcicornis. Between the Montastrea are globular clumps of Porites porites, and on the sides of the larger Montastrea blocks small subsidiary colonies of Mycetophyllia lamarckana and Isophyllastrea rigida. Encrusting Agaricia agaricites is abundant, but no foliaceous Agaricia was seen. Small boulders of Montastrea cavernosa and Dendrogyra cylindrus were also noted, but no Diploria or Siderastrea. There are numerous sea fans and sea whips in this zone, but quite subsidiary in number to the stony corals.

E 5. Zone E4 ends quite abruptly on the seaward side, commonly as an interrupted vertical wall of Montastrea, with its base at about 10 feet depth. From this point the bottom falls fairly uniformly to depths of 40-50 feet in 100 yards, and is lost in the blue. The bottom is composed of loose white sand with much Halimeda, and occasional small colonies of Montastrea annularis, M. cavernosa, Siderastrea siderea, and Dichocoenia stokesii. There are no gorgonians. Air reconnaissance shows the absence along the leeward reefs of any groove-and-buttress system.

F. West reef, Glover's Reef

The general form of the leeward reefs of Glover's Reef resembles that of Lighthouse west reef; it is continuous, with very few openings, none of them suitable for sailing vessels drawing more than 5 feet. It is steep-to on the seaward side, and edges a wide shallow reef-flat, which falls away steeply lagoonward to a deep lagoon floor. The only important gap is near the old site of Bushy Cay, bearing Northeast Cay 130°, Southwest Cay II 180° (uncorrected compass bearing): it is not a gap in the usual sense, but simply a narrow zone of reef-flat where the edging corals grow less profusely, and cannot be found without local knowledge. The transect is made immediately north of this point:

F 1. Reef flat, at least 100 yards wide, coarse white sand, with much dead Halimeda and Foraminifera, but devoid of larger organisms. It is 4-5 feet deep, and closely comparable to zone E1 at Lighthouse Reef.

F 2. Mixed cervicornis zone. A slightly shallower floor supporting a carpet of Acropora cervicornis, liberally interspersed with small boulders of Porites astreoides and Montastrea annularis, with much upstanding Millepora alcicornis. The zone is some 10 yards wide, and grades seawards into

F 3. Mixed palmata zone. This is much the same as zone F2, but deepens seaward from 5 to 8 feet. Large but scattered Acropora palmata colonies rise from a carpet of A. cervicornis, Millepora, Agaricia agaricites, and many sea whips. This zone forms the reef crest.

F 4. Annularis zone. A zone 30-40 yards wide, falling seawards to 15-16 feet, with a fairly continuous cover of low, small boulder-like colonies, mainly Montastrea annularis, but also M. cavernosa, Porites porites, Diploria clivosa, Isophyllia, Millepora, and Siderastrea siderea.

F 5. This is a continuation downslope of zone F4 into depths of over 30 feet. The limit of the zone was not seen but it is at least 30-40 yards wide. As the water deepens the colonies become more massive and taller. Long buttresses of Montastrea annularis are aligned downslope, and pillars of Dendrogyra cylindrus rise conspicuously between them. Diploria strigosa, Mycetophyllia lamarckana, Isophyllastrea rigida, and conspicuous clumps of Eusmilia fastigiata are also to be seen.

General features of the reef transects

These transects reveal a considerable variety in the atoll reefs --if, indeed, they are representative of more than local conditions-- though a number of common characteristics may be seen. The windward reefs of Lighthouse and Glover's Reefs both show extensive pavements of nodular and encrusting Lithothamnion, which are conspicuously lacking on the windward reefs of Turneffe, the leeward reefs of all three atolls, and over much of the barrier reef. The presence of massive Acropora palmata on the outer slopes beyond the breakers is common on the windward reefs. Montastrea annularis, with Porites and Agaricia, are the chief colonisers of the windward reef flats on Lighthouse and Glover's Reefs. The windward reef of Turneffe, protected from the easterlies by Lighthouse Reef, is quite different: M. annularis is again important, but A. palmata much less so, and the reef-crest consists only of Agaricia agaricites. This is strongly reminiscent of the reef-crest on the barrier reef north of Gladden Spit, where a subsequent transect showed a crest again composed of Agaricia agaricites over dead coral.

The leeward reefs also show important differences and similarities. Turneffe is unique in having no well-defined reef-crest or even a true reef-flat, which may be explained by its doubly-protected location--within a few miles of the barrier reef to leeward, and protected by long mangrove banks to windward. Lighthouse and Glover's leeward reefs are more closely comparable. In both cases there is a wide, shallow barren reef flat, fringed with a reef complex consisting mainly of Montastrea annularis, Acropora cervicornis, other boulder-like corals, and a little A. palmata in the wave zone. The main apparent difference is in the deep extension seaward of Montastrea and Dendrogyra on Glover's Reef, compared with the dwindling seawards of reef corals from the reef crest on Lighthouse Reef.

The reef complexes illustrated in these six traverses can be interpreted largely as responses to differing degrees of exposure to waves, winds, and wave- and wind-generated currents, affecting both the physiography of the reef and its composition. This latter can best be illustrated by the distribution of certain indicator organisms, such as Acropora palmata, Lithothamnion, and gorgonians. The windward reefs of Lighthouse and Glover's Reefs are most exposed; the leeward reefs and the windward reefs of Turneffe next so; while the most protected of all the atoll reefs is the leeward reef of Turneffe. Sections of the leeward reef of Turneffe in fact bear a striking resemblance to the northern reef-complex of the Rendezvous Cay patch-reef, described by Thorpe and Bregazzi (1960). Taken as a whole, the reefs of Lighthouse Reef and Glover's Reef are closely comparable in their form; while the reefs of Turneffe show sufficient differences from these to stand in a class by themselves.

Lagoon Reefs

Remarks have so far been confined to the peripheral reefs of the atolls, and nothing has been said of reefs situated within the lagoons. In the case of Turneffe no growing coral was seen at any point within the interior lagoons, though it is at least possible that the Thalassia beds of the lagoon floors include unattached colonies of Manicina areolata and Cladocora arbuscula. The shallow lagoon of Lighthouse Reef includes a number of patch-reefs reaching surface, of small area and without pronounced zonation; the dominant coral is Acropora palmata on the upper parts of the patch. In the Glover's Reef lagoon, however, the patches are larger in area, rise from much deeper water, and are very numerous. Many were seen at close quarters from the air, and one was investigated in detail under water.

The patch is located bearing Long Cay 70°, Middle Cay 135°, and Southwest Cays 215° (uncorrected compass bearings); it rises steeply from the lagoon floor, here lying at a depth of 48 feet (8 fathoms). It is roughly circular in shape, with a maximum diameter of about 100 yards, and the mean depth over the greater part of the top of the patch of 4-5 feet. There is a very pronounced zonation of corals on this patch, repeated (as seen from the air) on many others of the Glover's lagoon patch-reefs. Approximately half the rim of the patch on the east and northeast sides consists of a zone of dominantly compact, close-branched Acropora cervicornis, 2-3 feet in thickness and 5-10 yards wide. Scattered colonies of massive A. palmata rise from the cervicornis at intervals, especially near the wave-break zone. Towards the lateral extremities of the cervicornis zone, cervicornis becomes less dominant, and there are large patches of Porites porites and Montastrea annularis. On the upper surface of the patch, sheltered by the cervicornis zone and close to it, and extending in diffuse lobes round the patch margins, are large boulder-corals, mainly Montastrea annularis, with also Siderastrea siderea, Colpophyllia natans, Isophyllastrea rigida, Porites astreoides, Diploria strigosa, and encrusting Agaricia. Mussa angulosa is present in small but conspicuous clumps, nestling in hollows of larger colonies. The centre of the patch, 4-5 feet deep and with a sandy bottom, has little coral, apart from some straggling, loose-branched Acropora cervicornis and small colonies of Montastrea annularis and Porites astreoides. No Montastrea cavernosa was seen on the reef, and little Millepora.

This zonation suggests that the reefs within the lagoon on Glover's Reef are still sufficiently exposed to respond to the influence of the easterlies, probably in part because of the depth of the water (10-20 fathoms over much of the bottom); whereas on Lighthouse Reef, the effect of wind and waves is damped down by the shallowness of the lagoon.

Relative importance of species in reef-building

The zonation and relative importance of the corals in building the atoll reefs agrees well with what is known from Rendezvous Cay and other West Indian reefs. Taking the profiles as a whole, the dominant coral on the reef flat, and in less turbulent areas of the seaward slope, is Montastrea annularis, followed by other corals of similar habit of the genera Siderastrea and Diploria. In turbulent water and on the seaward slope of windward reefs Acropora palmata is overwhelmingly dominant. It should be noted that in no case was this outer palmata zone pursued to depths of more than 30 feet, and that Newell, drawing on Bahaman experience, described an even lower zone of Montastrea annularis at depths of 30-60 feet (Newell, 1951, 251). At the same time, though he spoke of "West Indian reefs", he clearly had in mind Bahaman examples where the living reefs are set back from the edge of the seaward slope, a condition which does not occur in British Honduras, to which his generalisations do not necessarily refer (Newell and others, 1951).

The primary importance of M. annularis as a reef-builder in the Caribbean area has been stressed in Jamaica by Goreau (1959, 84-85), in Barbados by Lewis (1960), and in the Bahamas by Newell (Newell and others 1951, 23; Newell and others 1959, 213; Newell and Imbrie 1955; Newell and Rigby 1957). Along the upper seaward slopes of windward reefs, however, the Montastrea dominance is replaced by massive branching colonies of Acropora palmata up to 15 feet high (except on the "protected" windward reef of Turneffe), with some A. cervicornis and scarcely any globular colonies. Newell and co-workers noticed similar conditions at Andros, Bahamas (Newell and others, 1959, 213), and Zans (1959) was inclined to rank A. palmata before Montastrea as the most important reef-building coral of Jamaica. Ginsburg suggested that on the Florida reefs A. palmata is "the primary structural element of the reef mass....(it) provides both a framework, around and on which detrital material can accumulate, as well as considerable cobble- and boulder-like debris" (1956). His description of the Florida reefs accords well with windward reefs in British Honduras, but taking the reefs as a whole, the palmata community is a restricted one, and the globular corals more important. Goreau suggests that the palmata community "probably indicates a reef community in the later stages of development. To provide the shallow conditions necessary for the growth of this coral however, a suitable platform must first be formed; in many cases this is accomplished by the activities of other coral species....predominantly by Montastrea annularis" (Goreau 1959, 85). This reason, and the ecological restriction of palmata to certain areas, indicate that Montastrea is the generally most important reef-builder in British Honduras.

Role of encrusting algae in reef-building

Many recent papers (Ladd, Tracey, Wells and Emery, 1950; Tracey, Cloud and Emery, 1955; Wells, 1957, 614-5) have stressed the importance of encrusting algae in atoll-reef formation, particularly following detailed work in the Marshall Islands. One of the most conspicuous features of reefs in this group is a ridge of pink encrusting algae ("Lithothamnion Ridge" or "Algal Ridge") at the outer edge of the reef flat, exposed at low tide, and best developed on the windward side of atolls (Tracey, Ladd and Hoffmeister, 1948; Emery, Tracey and Ladd, 1954, 25-27). Darwin had long ago recognised this feature, which he termed a "breakwater", at Tahiti and Cocos-Keeling, and it has subsequently been described from Funafuti (Finckh, 1904), Raroia (Newell, 1956, 344-6) (where it is developed on both windward and leeward sides), and elsewhere. Some writers, notably Howe and Setchell, have been so impressed by the importance of encrusting calcareous algae that they consider that modern coral reefs could not exist without them in their present form. Conversely, Gardiner (1903) does not specifically mention an algal ridge in his account of Minikoi, Maldive Islands, and it is known to be absent over much of the East Indies (Kuenen, 1950, 430-433). A similar conclusion has generally been reached in the Caribbean area, though Zaneveld (1958) describes a Lithothamnion reef from the Dutch West Indies. Thus Chapman (Steers and others, 1940, 312-3) found Lithothamnion to be "more or less insignificant" in Jamaican reefs, while Professor Stephenson (1950, 383) found "a very definite dearth of encrusting species between tide marks" in Florida, though he carefully qualified his remarks so as not necessarily to include the whole Florida reef tract.

In British Honduras the transects show that calcareous pink algae form a low pavement on the windward reefs of Glover's and Lighthouse Reefs, which may be a pale, anaemic analogue of the Marshall Island ridges. The pavement is covered with encrusting and nodular forms, with little coral, and is always submerged. The nearest approach in the literature to these pavements is the "Lithothamnion-Millepora ridge" at Andros, Bahamas (Newell and others, 1951, 22), "not exposed at normal low tide, though it may reach within a few inches of the surface." One cannot at this stage assess the significance of the encrusting algae in British Honduras reefs, except to note their dominance over restricted shoal areas of the windward reef. They never seem to occur on leeward reefs, and are probably only poorly developed on protected windward reefs, such as that of Turneffe and much of the barrier reef.

Groove-and-spur systems

Groove-and-spur systems (fig. 13) occur round all three atolls on their windward sides, irrespective of whether land backs the reef edge or not. The only criterion seems to be exposure to wave action. The systems are developed on the upper sections of seaward slopes of reefs on the north- and east-facing sides of atolls. Their distribution is shown in the map, compiled mainly from low altitude oblique photographs taken in 1961, and from the vertical air photo cover. This distribution agrees with data from the Pacific, where groove-spur systems accord well with intensity of wave action (Munk and Sargent, 1948). There is some controversy as to whether they are growth or erosion features. Workers at Bikini (Emery, Tracey and Ladd, 1954, 26-7) believe them to result from slow growth of algae-covered spurs, forming "a most effective baffle that dissipates the destructive energy of the waves and at the same time brings a constant supply of fresh water....to a maximum surface area." On the other hand, similar features have been described where growth of the spurs is not taking place, in basalt or oolite country rock, and here erosion of the grooves must be the chief factor (Newell and others, 1951, 25). Cloud relates them (1954, 201-4) to erosion, following a fall in sea level from a 6 ft. stillstand, itself leading to reef emergence and island formation. "The surf-driven water piles up against the barrier and escapes by flowing seaward beneath the incoming current....Wherever grooves....are well developed without an immediately inboard island the former presence of an island, or other barrier to cross-reef water movement, is suggested, and evidence of the missing island is to be looked for" (203-4). It is unlikely that land or elevated reef have ever completely surrounded the British Honduran atolls on their windward sides: if so, no trace remains (see Sections VIII and IX). The correlation with wave-direction is, however, clear, and it is interesting to note that the spurs are not invariably at right-angles to the reef edge, as usually described, but parallel to the wave orthogonals. Hence, at the north end of Turneffe and Lighthouse Reef, spurs trend at an angle of 60° to the reef in places.

The blanketing of the spurs by slow-growing calcareous algae is much emphasised in Pacific studies (Wiens, 1959; Cloud, 1954, 199), sometimes as evidence of the erosional origin of the systems. However, wherever seen from the air at an altitude of 100-200 feet, the spurs seem to consist of vigorous branching corals, chiefly _Acropora palmata_, with no indication of algal blanketing. Thus these arguments will not apply in British Honduras. Goreau has reported very similar spurs ("buttresses and canyons") from the north coast of Jamaica (1958; 1959, 76-79), which seem to be undoubtedly growth features. The upper surface of these Jamaican spurs is covered with _Agaricia agaricites_, _Acropora palmata_ and _Montastrea annularis_, while the sides consist of gigantic colonies of _Montastrea annularis_ and _Porites astreoides_.

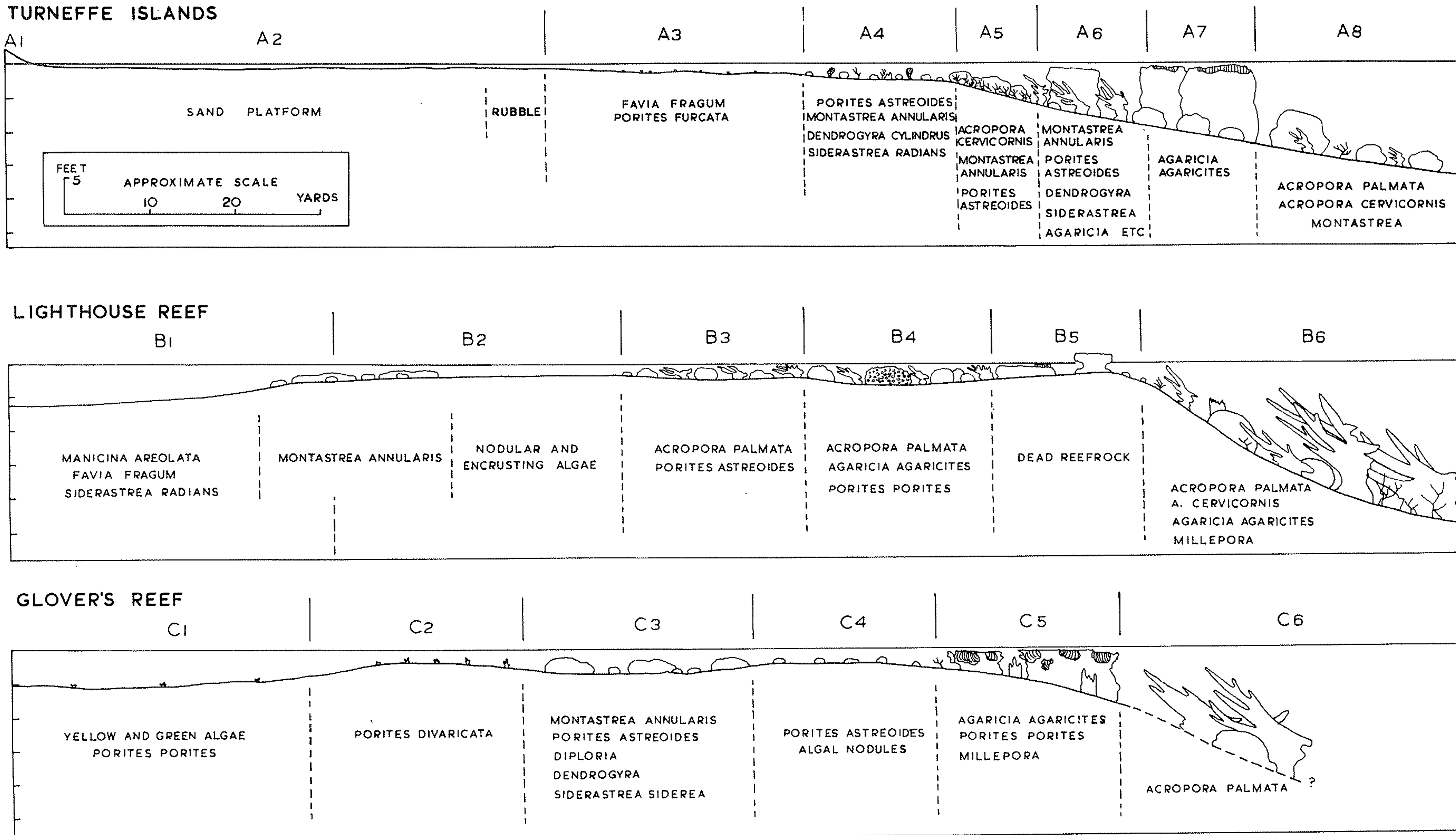


FIGURE II
WINDWARD REEF TRANSECTS

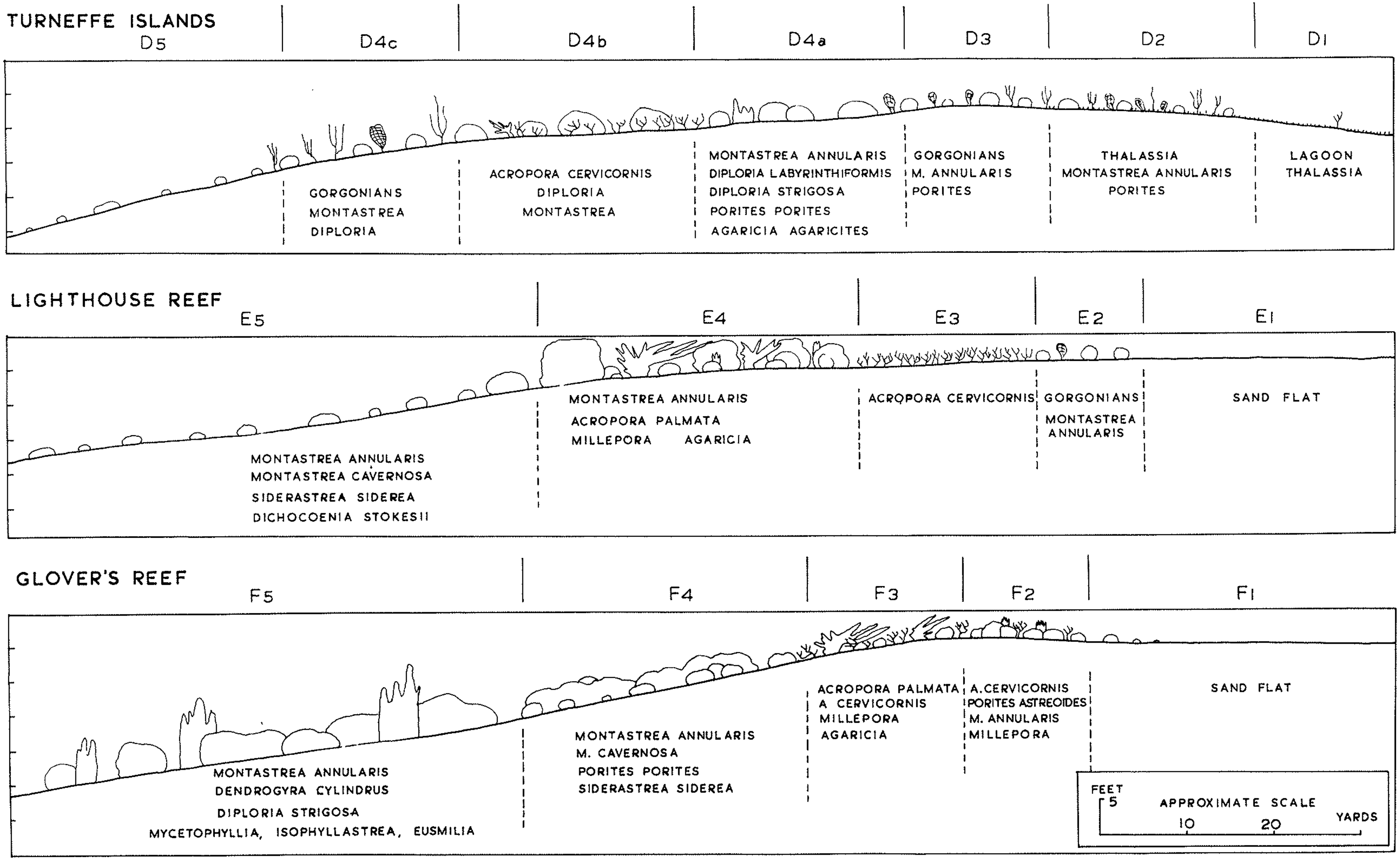
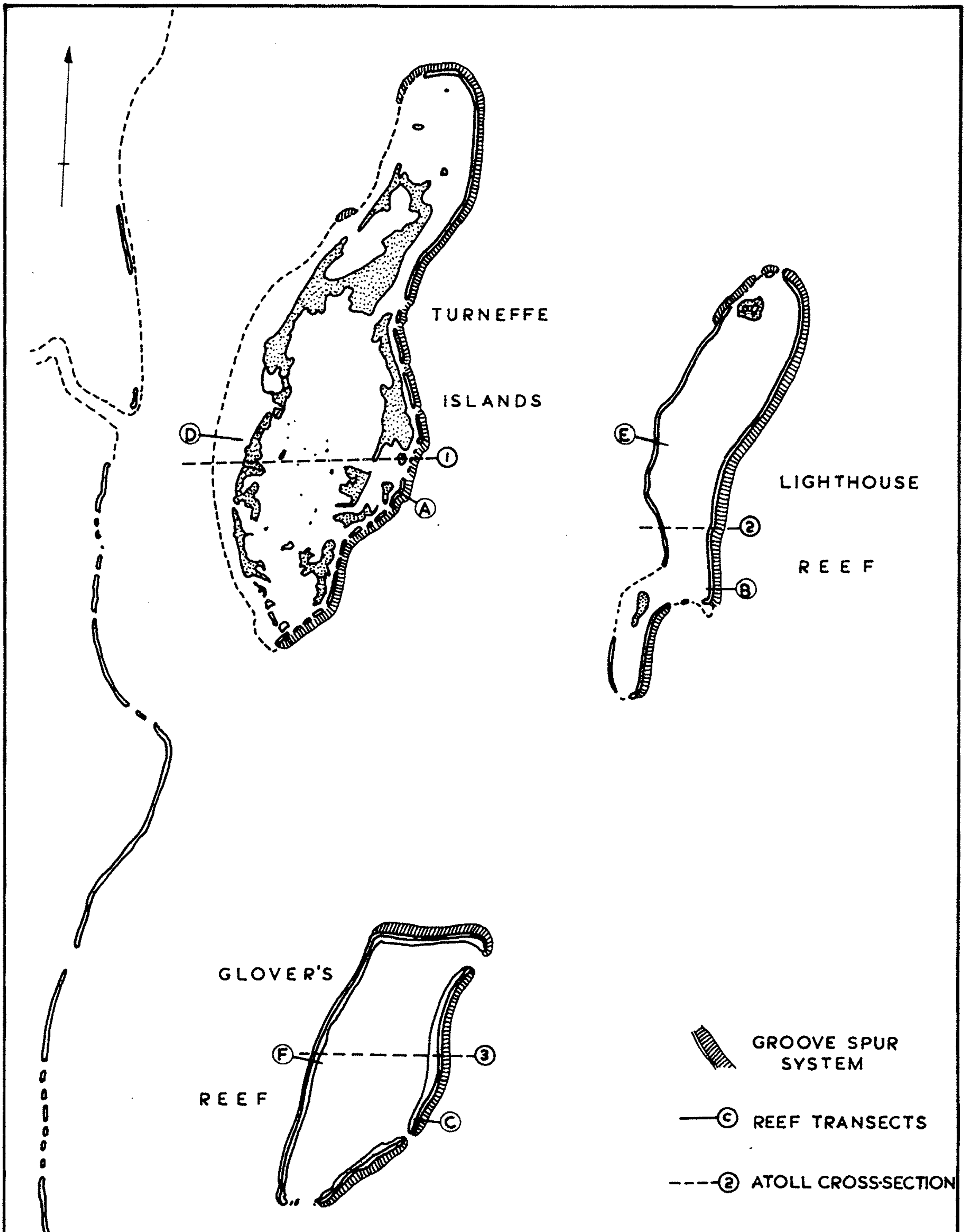


FIGURE 12
LEEWARD REEF TRANSECTS



GROOVE - SPUR
SYSTEMS ON ATOLL REEFS
FIGURE 13

V. TURNEFFE ISLANDS

The dimensions of the Turneffe block (fig. 14) have already been given; it has a maximum length of 30 miles, and varies in width up to a maximum of 10 miles. It is roughly lens-shaped, with its maximum width situated some two-thirds of the distance along the bank from the north-east end. Seen from the sea or barrier reef on the west side, and from the sea on the east side, Turneffe appears as a long, low continuous line of mangroves extending from its southern extremity north of Cay Bokel for all but 5-6 miles of its total length. The sketch-section (fig. 49) shows the main features of the physiography of Turneffe.

On the east, windward side, there is a well-defined narrow reef, described in transect A. The reef-crest zone is narrow, and fringes the outer edge of a reef-flat generally less than $\frac{1}{4}$ mile in width. The reef itself is highly segmented, and has some 23 reef-gaps, mostly less than 50 yards wide, carrying 1-2 fathoms water. On the inner edge of the reef-flat, which is usually submerged by 1-2 feet of water, and intermittently covered with Thalassia, algae and small corals, there are small sand cays, some with shingle ridges, located particularly but not invariably at the reef-gaps. From south to north, these sand cays include Cay Bokel, Deadman's Cays (I-V), Little and Big Calabash Cays, with two small cays east of Big Calabash, Soldier Cay and Blackbird Cay, and a large number of small cays near the northeast corner, which have not been visited. They include Dog-flea Cay and Cockroach Cay, but only the latter has been mapped. Aerial oblique photographs of all these cays were taken in 1961, but unfortunately the USAF vertical airphoto cover of Turneffe does not extend to this segment of the reef. Each of the cays visited will be described in detail below.

In places the reef-flat gives way to a deeper moat between the flat and the mangrove, with depths of 4-6 feet, which may in part be current-eroded. The floor of the moat is sandy and rippled. The greater part of the eastern side of Turneffe is fringed not directly with mangrove, but rather with a dry sand ridge, rising up to 5 feet above sea-level, and with a maximum width of some 200 yards. The ridge has a steep sandy shore, colonised by Ipomoea and Sesuvium, and its flat crest, decreasing in height away from the sea, is normally covered with coconut plantations (cocals) and an undercarpet of the lily, Hymenocallis littoralis. The thin line of coconuts is clearly visible on air photographs. As the ridge sinks westwards the coconuts give way to very tall, old, stilt-rooted Rhizophora and some Avicennia, now standing on dry land. The mangrove growth is very dense and impenetrable; at some small but unknown distance the dry Rhizophora-Avicennia assemblage is replaced by a broad belt of Rhizophora mangle standing in water. This zone of "wet" red mangrove, often hollow and containing areas of unvegetated mud, forms the eastern margin of the interior lagoons, and divides them from the eastern reef-flat. It reaches its maximum width near Soldier Cay (2 miles) and north of Northern Bogue ($2\frac{1}{2}$ miles). The gaps in the eastern mangrove wall are few but wide: they are, (from south to north) Southeast Entrance (nearly 3,000 yards wide), Grand Bogue (1100 yards), Calabash Entrance (1700 yards) and Northern Bogue (1100 yards, narrowing to 400 yards). Northern Bogue and Grand Bogue are free of living reef at their entrances, and are much used by fishermen; Calabash Entrance has more reef, but is also used. In places Rhizophora has extended eastwards of the eastern sand ridge (showing that it is, at least in part, a fossil feature), and is beginning to encroach on the reef-flat, as in the long section between Northern Bogue and Soldier Cay. Pelican Cay, detached from the main body of mangrove southeast of Northern Bogue, is in fact a mangrove, not a sand cay, with a dry cleared interior.

The mangrove rim described bounds the interior lagoons of Turneffe on their east side; a second rim bounds them on their west side, but of rather different nature. Generally speaking the western mangrove fringe is narrower and more interrupted than the eastern, and is generally only 500-700 yards wide, and often much less. It is widest at the northwest part of Southern Lagoon, reaching a width of over 2,000 yards. The gaps, too, are very different in character: whereas the "bogues" (Spanish, boca, a mouth) on the east side are wide, the "creeks" or "rivers" on the west are, as their names imply, narrow, often sinuous, sometimes bifurcating channels generally less than 50 yards wide, and varying in depth up to 10 feet. There are 13 of these creeks entering Southern Lagoon north of Cay Bokel; the most important are Blue Creek, Joe's Hole (according to Winzerling (1945) a corruption of the pirate's name 'Jol'), Little Joe's Hole, Grand Bogue Creek, Crooked Creek, Ambergris Creek, and Crickozeen or Grigyson Creek (spelling uncertain). Grand Bogue Creek is most often used: it gives ready access to Grand Bogue, and also to Calabash Cays by way of Northern Bogue. It is very noticeable that each of these creeks is prolonged both seaward and lagoonward by narrow strips of mangrove, so that in the case of Grand Bogue Creek, for example, the channel is approximately twice as long as the intervening mangrove is wide. The creeks are probably kept open by the strong tidal currents which set through them, which are so strong that fishermen often beat around Cay Bokel rather than attempt them. They are in fact drainage channels for Southern Lagoon, to dispose of the great quantities of water poured into it through the eastern bogues. The west rim of Northern Lagoon is much narrower (1-300 yards), than that of Southern Lagoon, and has three small gaps.

The eastern mangrove fringe consists entirely of the red mangrove, Rhizophora mangle. From the sea this presents a seemingly unbroken low wall of vegetation, and requires a practised eye to pick out the promontories which mark the creeks from distances of more than a mile. The eastern fringe is, however, hollow, for air reconnaissance shows that within a peripheral zone of mangrove there are often areas of unvegetated red mud and stagnant pools, with dead mangroves littered on the surface: a desolate landscape. The sand ridge prominent on the east side of Turneffe is here absent, except for a small segment in the extreme northwest, with coconuts. There are no beaches on the east side, except at the foot of this ridge, and one or two minute sandy areas in the south between Blue Creek and Cay Bokel. This is fully in accordance with the sheltered position of the west side.

North of the main mass of mangroves in Turneffe, which encloses the interior lagoons, there are one or two detached mangrove islands, notably Three Corner Cay, Crawl Cay and Mauger Cay. With the exception of Mauger Cay, none have any dry land, they consist of Rhizophora standing in water.

Interior lagoons

The mangrove rims, which seem so continuous from the sea, and which are shown on many maps as rimming a solid land area extending across the whole bank, enclose two lagoons: Southern Lagoon, some 17 miles long, and Northern or Vincent's Lagoon, one-sixth the area of Southern Lagoon, and separated from it by a "hollow" mangrove wall, 1-2,000 yards and more in width. Northern Lagoon was not visited, and was seen only from the air. It has but one small entrance on the windward side, which must greatly restrict the circulation of water and have considerable effects on plant and animal life therein. The depth of Northern Lagoon is not known, but is probably 1-2 fathoms at most.

Southern Lagoon was crossed in many directions in 1960 and 1961. Vermeer found that the depth ranged from 4-8 feet, but elsewhere he says that it is "never more than one fathom deep" (Vermeer, 1959, 18, 93). Soundings in 1961 in the southern part averaged from 1-2½ fathoms, averaging just over 2 fathoms. The greatest sounded depth was in the channel between Pelican Cay and Southeast Bight, carrying 3 fathoms: this is probably a scour channel draining the main body of Southern Lagoon southwards. It seems likely, from observations in 1960, that over most of the northern part of Southern Lagoon, the bottom lies at 2-2½ fathoms depth, and that it is shoaler on the west side than the east. Smith (1941) quotes depths of 1-3 fathoms. According to local informants the maximum depth in the whole lagoon is 21 feet (3½ fathoms) in the northern part.

Wherever seen the bottom is composed of calcareous sand and silt, covered over huge areas with <u>Thalassia</u>. No stony corals were seen, but gorgonians and sponges are found in great numbers. Green algae, chiefly <u>Halimeda</u>, are scattered through the turtle grass, and the most conspicuous animals on the floor are the large star-fish <u>Oreaster</u>, and holothurians. "The floor of the lagoon consists of calcareous mud with admixed shell and coral sand predominant near the eastern entrances, and with organic matter formed from the detritus of eel-grass and mangrove roots present in varying degree throughout the lagoon" (Smith, 1941, 415). It is almost impossible to collect good sediment samples from the lagoon floor, since clouds of fine detritus rise and obscure visibility as soon as the bottom is disturbed, while the subsurface layers are tightly bound together by the roots of grasses and algae. Some of the <u>Thalassia</u> leaves are a foot long.

The lagoon contains a number of islands, all of red mangrove, with no dry land seen. They are strikingly concentrated in north-south lines in the centre and southern parts of the lagoon, where they form "ranges" or groups of cays, such as Crayfish Range. Cross Cay and Pelican Cay (not to be confused with the Pelican Cay on the east reef of Turneffe) are larger individual cays in the south. The cause of this lineation is not known. Most of the lagoon islands, as Vermeer noted (1959, 95), rise fairly abruptly from the lagoon floor, and do not seem to be spreading laterally by colonisation of shoal areas with seedlings; though there are exceptions to this general rule. The origin of the atolls is briefly discussed in section VIII, but it may be suggested here that the islands stand on solid-rock eminences, on the crests of karst ridges developed on an emergent bank during glacially low sea-levels; that, in fact, they have a solid-rock core, much as envisaged by Agassiz (1894) for some of the cays and reefs of the barrier reef lagoon. Some such basement is required to explain mangrove islands rising from a floor too deep for mangrove colonisation. An alternative suggestion is that they are based on old patch-reefs developed before the growth of the eastern mangrove rim, when seawater had unrestricted access to the centre of the bank, the reefs being asphyxiated as the mangrove rim developed. However the size of some of the islands compared with existing patch-reefs in other atoll lagoons argues against this. On the other hand, comparable lineations, of patch-reefs rather than of islands, will be noted in the accounts of Lighthouse and Glover's Reefs.

The Southern Lagoon sponge beds formerly supported a thriving industry, already well-developed in 1896. "These were fished intermittently and in 1919 were almost completely wiped out by a disease. An attempt to restock a part of the Turneffe lagoon in 1926 failed completely" (Romney and others, 1959, 256). No reports on this mortality seem to have been published, but the beds were again flourishing when badly damaged in 1936. Dr. C.L. Smith visited Turneffe at that time, and concluded that mortality was caused by very high rainfall leading to lowered salinity in the semi-enclosed lagoon basins. No report was published. The beds recovered, but were again decimated in 1939 by some kind of fungus infection, investigated by Dr. Walton Smith of the Marine Laboratory (now Institute of Marine Science), Miami (Smith 1941). According to Smith, there were in 1939 700,000 cuttings planted out in the Turneffe lagoon, including 225,000 sheepswool sponges (Hippiospongia lachne), 475,000 velvet sponges (H. gossypina), and smaller quantities of other commercial sponges, such as Spongia barbara, S. dura and S. graminea. The disease first appeared in the Bahamas in 1938 (Galtsoff, Brown, Smith and Smith, 1939), and then spread to Cuba and the Florida Keys, appearing in Soldier Bight (Calabash Entrance), Turneffe, in June 1939, killing H. lachne. Within seven weeks it had spread to the whole Southern Lagoon, and at the end of July H. lachne was everywhere dead and H. gossypina dying. In August came a second attack, in the southern part of Southern Lagoon, killing only H. gossypina, and in September a third outbreak, killing all the sponges at Long Ridge (between Joe's Hole and Grand Bogue Creek). Noncommercial sponges were not affected, but 95% of the commercial ones were killed. Smith concluded that the mortality was caused by a water-born fungus, carried by currents through the Calabash entrance and then distributed throughout the Southern Lagoon, being most virulent in more stagnant areas. He also noted that the outbreak occurred after a period of no rainfall and high temperatures, leading to high salinity in the lagoon (Smith, 1939, 1941).

The industry never recovered from this disaster, partly because of the war, partly because of competition from the synthetic sponge industry. Piles of the small concrete plates used to plant out the sponges are still found at Calabash Cays, where one of the residents was in 1960 still cultivating a few sponges. There is some talk of reviving the industry, but interest is slight.

Land fauna of Turneffe

The land fauna of the atoll, with the possible exception of the avifauna, is very imperfectly known. A few lizards and snakes have been recorded: Schmidt (1941, 492-7) lists only Anolis sagrei Dumeril and Bibron (found also on the other two atolls), and the common boa, Constrictor constrictor imperator Daudin, but gives no localities. A single specimen of C. c. imperator was taken on Cockroach Cay on the east side of the atoll in 1960 (Thorpe and Bregazzi, 1961, 29), and is thought to be very common throughout the mangrove cays. According to Bond (1954, 2) "An iguana-like lizard (probably Ctenosaura), drab in colour with black bars across the back was noted on several occasions near Rendezvous Point at the northern end of the atoll."

The birds are better known. Devas (1953) has prepared a brief handbook of British Honduras birds, but the well-known text by Bond (1960) is the best field guide. On the birds of the Gulf of Honduras generally, see Salvin (1888, 1889, 1890), Chapman (1896), Griscom (1926). These remarks apply to the sections on avifauna of Lighthouse and Glover's Reef also . Osbert Salvin visited Turneffe, Lighthouse Reef and Glover's Reef in April and May 1862 (Salvin, 1864); and James Bond spent two days at the north end of Turneffe and Cockroach Cay in January 1954 (Bond, 1954). Salvin recorded 15 species and Bond a further 23 species from Turneffe, of which many are undoubtedly passing migrants. Among the common birds are the brown pelican, Pelicanus occidentalis; the man-of-war bird, Fregata magnificens Mathews; and the osprey, Pandion haliaetus ridgwayi Maynard (nests seen by Bond). Other nesting species are Sula leucogaster leucogaster (the brown booby, said to breed on Mauger Cay by Salvin; not seen by Bond; not seen on Mauger Cay in early 1960); Egretta thula thula Molina (Man-of-War Cay, Salvin; not seen by Bond); Sterna albifrons antillarum Lesson (Grassy Cay, Salvin; not seen by Bond); and Chaledrius wilsonia wilsonia Ord (Grassy Cay, Salvin). The most abundant species seen by Bond were Dendroica patechia bryanti Ridgway, Seiurus noveboracensis subsp., Quiscalus mexicanus mexicanus Gmelin, and Icterus oryzivorus L.

Many of the eastern cays are inhabited and have domesticated animals, mainly chickens, dogs and pigs. The largest piggery is at Calabash Cays, where the animals have the engaging habit of wandering between the Big and Little Cays across the reef-flat, up to their bellies in water, grubbing for food on the submerged sandy floor. It is not known whether this is usual behaviour for pigs on reef islands. There are some pigs at Soldier Cay, Cockroach Cay and Cay Bokel, but not at Deadman's Cays, Pelican Cay or Mauger Cay, though obviously the location of the pigs changes with their owners. Rats (Rattus rattus?) are a major pest in the cocals, both on the eastern cays and along the eastern sand ridge, from Rope Walk to Northern Bogue.

Cay Bokel

Cay Bokel (fig. 15) is the southernmost sand cay on the Turneffe bank. Speer described it as a "small short Key....very near joined by a Reef to Turnueff" (1771, 19), and it has probably remained fairly constant in size, though shifting in position, for several centuries. It is located at the extreme southern end of the eastern surface reef of Turneffe, which here edges a shallow reef-flat 500 yards wide. The cay stands at the inner edge of the flat, near its narrowest point, about 150 yards from the reef itself. Westwards, the water deepens and the reefless bottom lies at depths of $1\frac{1}{2}$-3 fathoms, forming a broad sheltered bay giving good anchorage for ships. This shelf or bay is 500 yards wide, and the floor falls rapidly from its western edge to depths of up to 197 fathoms within 900 yards. It was first sounded by Owen in 1830, and subsequently surveyed in detail by Captain R.W. Glennie, HMS Mutine, in 1921 (cf. West Indies Pilot, I, 1956, 461, and charts). The cay itself has not been previously described in detail.

The island is roughly triangular in shape, with sides about 35 yards in length, and has a total area of only 1,000 square yards. Its surface is low and sandy--a coarse sand, with much Halimeda, shell fragments, and brittle pieces of coral, mostly of small size. Along the eastern side, a little small shingle, mainly Acropora cervicornis, has been thrown up on the shore, but has not formed a ridge. No part of the cay rises more than 2 feet above the sea: it is highest on its south and east sides, and slopes westwards. The leeward shores are flat and sandy, the windward shores rather steeper. The wave refraction patterns affecting the cay are clearly seen from the lighthouse: the main east reef is lined by breakers, and water flows transversely across the reef-flat to the eastern shores, while a much less powerful but well-marked set of waves refracts round the south end of the reef and approaches the cay from the south and southwest.

In recent years the cay has been retreating northwards and probably westwards away from the reef. This is shown by the steep seaward shores and the lower prograding lagoon shores (note the spit at the north point), and also by beachrock. No beachrock is seen on the cay itself, but there is a single line 55 yards southwest of the cay, extending for about 10 yards. The rock dips seawards and must mark a former shoreline. Between it and the cay the bottom is shallow, with small corals in thick Thalassia, and ranges in depth from 1 foot near shore to 18 inches near the beachrock. In order to control this retreat, residents have attempted to protect the seaward shores with conch-shell ramparts, but to little effect. Conchs are taken from Turneffe to Belize, and piles of their shells also lie near the pier on the north side of the island. How far this retreat is due to long-term changes and how much to catastrophic hurricane damage is not clear; but Cay Bokel bears the marks of the spectacular and intense power of hurricanes. The present lighthouse--a steel-frame tower--stands near the south shore of the cay: it immediately overlooks the foundations of a second lighthouse, now 7-12 yards from the shore, washed by waves and standing in water 1-2 feet deep. Fifteen yards to the north, on the cay itself, are the remains of a third lighthouse foundation, partly obscured by sand. The lighthouse base now awash is a substantial concrete structure; and between it and the cay are the remains of a concrete-block seawall, presumably built since the base, and now much broken and itself awash. This light was destroyed by the 1931 hurricane. The other base, also of concrete, has been strongly tilted, and is now only partly exposed; this was destroyed in the hurricane of 1945 (information from the lighthouse keepers). Whether the beachrock dates from the period when the first of these lighthouses was built on dry land is unknown; if it does, then the cay was formerly larger than now. All the evidence, however, indicates continuing retreat in the same general direction.

Of vegetation, little remains. Jefferys noted "Low Bushes" in 1775, and Glennie "bushes and coconut palms, about 50 feet high" in 1921, but the bushes have now disappeared. Coconuts are the only larger plants on the cay, and there are some two dozen of them. The ground surface is bare, save for a patchy cover of *Ambrosia hispida* toward the leeward side, and a few lilies, *Hymenocallis littoralis*, to seaward. There are a few small *Rhizophora* seedlings on the southeast shore, beneath the conch rampart, but no mature mangroves; they are probably short-lived strays from the main Turneffe mangrove areas to the north.

The 36 foot high lighthouse tower is tended by a keeper with a substantial hurricane-proof house; he keeps some pigs. Apart from this there are no permanent inhabitants. The cay is so small that its continued existence if struck by a major hurricane is not without question. It is said to have been named by the Dutch buccaneer Cornelis Jol in the seventeenth century (hence also the bogue known corruptly as "Joe's Hole"), from the Dutch word for elbow or corner, i.e. the cay at the southern elbow of the Turneffe bank (Winzerling, 1946, 29).

The Deadman Group

This is a group of five small cays standing on the eastern reef-flat, between the reef-edge and the eastern mangrove rim, some four miles from the southern end of Turneffe. They are located toward the southern end of a reef segment, bounded by gaps giving access at northern and southern ends to Rope Walk and to the cays. The eastern mangrove rim behind this section of the eastern reef lacks the sand ridge so well developed farther north, and consists of pure *Rhizophora* with little or no dry land. The reef-flat along this reef-segment varies in depth, but generally carries less than 2 feet of water, and between some of the cays (such as II and IV) much less than a foot. The reef itself is steep-to; the main water currents are transverse to the reef with little refraction, and are deflected north and south by the mangrove wall. The pouch-shaped depressions back of the reef-gaps are scour-channels associated with the outflow of water draining laterally along the reef-flat and through the gaps. Because of the steepness of the reef-front, waves break heavily on the reef, and a heavy swell comes through the gaps, making them dangerous for small boats without local knowledge. The cays were visited in May 1960, and are here described from south to north, numbered for convenience I to V.

Deadman I (fig. 16)

Measured along its main axis, Deadman I is 110 yards long, and varies in width from 20 to 32 yards. It is aligned transverse to the main reefs. Its physiography is relatively simple: the cay is everywhere low, but rises at its eastern end to not more than 3 feet above sea-level, where it is composed of small blackened shingle. In the middle section of the cay the shingle is less widespread and intermixed with coarse dark sand, while at the western end, the shingle disappears and the cay is wholly composed of sand. The western end is little more than a foot above the sea. Westward of the cay a submarine spit extends for 10-20 yards, composed of fresh white sand, parts of it drying at low tide, and colonised by several Rhizophora seedlings. The cay is clearly extending lagoonward at its western end, though there is no corresponding evidence of retreat at the seaward end. Along the south shore, beachrock is exposed for nearly 20 yards: it is a soft, poorly indurated rock, passing inland under the cay sands. It is 12-18 inches wide, shows no marked dip, and its surface is covered with a spongy mat of blackish algae. The water immediately offshore is sheltered and subject to considerable overheating; numerous Rhizophora seedlings grow here.

Most of the cay has been cleared for cocal, and apart from an intermittent ground-cover of Sesuvium, Euphorbia and grasses, vegetation is very sparse. At the low western end the new sand has been colonised by Sesuvium and a couple of Tournefortia bushes. Rhizophora seedlings are found round the whole cay margin in shallow water, but the only mature mangrove is a gnarled Avicennia on the seaward shore. The coconuts which cover the island rise to a height of about 30 feet.

The island is not inhabited, though at the time of our visit in early 1960 there was a palm-leaf shelter at the west end of the cay.

Deadman II (fig. 16)

Deadman II is located 150 yards north of Deadman I, and rather more distant from the seaward reef-edge. It approaches a circular shape, with N-S and E-W diameters of 80 yards. It, too, is low: the seaward shore is composed of medium to fine shingle rising to a crest 2-3 feet above the sea. From this maximum height the surface declines eastwards to the leeward shore, which is wide, low and sandy, and faces a broad shallow bay between the cay and the mangrove rim. The bay has depths of only 1-2 feet, and near the cay is much colonised by Rhizophora seedlings. There is no mangrove zone on the cay itself, and only a few tall Avicennia. Laguncularia racemosa (white mangrove) was identified on the leeward shore by its distinctive club-roots.

The cay is planted to coconuts, but unlike Deadman I the undergrowth has not been cleared. Round most of the cay margins the upper beach is covered with Sesuvium and Euphorbia (on the leeward beach by Sporobolus and other grasses), passing inland under a dense zone of Conocarpus and Suriana bushes, from which the coconuts rise. As far as seen, there are no remnants of broadleaf forest on these cays. Tournefortia gnaphalodes was seen at one point on the northwest shore. The cay is uninhabited, and we found the sandflies troublesome.

Deadman III (fig. 18)

This cay lies about 170 yards north of Deadman II, and is the smallest of the group, having maximum dimensions of but 50 yards (E-W) and 35 yards (N-S). Though 100 yards back from the reef-edge, there is still small shingle on the seaward shore, rising about $1\frac{1}{2}$ feet above the sea. The rest of the island is sandy, and one has the impression that it is growing westwards fairly rapidly. A fresh sand spit at the west end is colonised by small Rhizophora and Avicennia. The vegetation resembles that of Deadman II: the main ground cover is Sesuvium, with some Ipomoea and Sporobolus. Tournefortia is found on the shingle ridge, and Conocarpus forms a dense zone on the leeward side. Between the shingle ridge and the Conocarpus zone are a number of low coconuts. Avicennia is also found at the north point. There is no beachrock or habitation.

Deadman IV (fig. 17)

Deadman IV is the largest of the group, separated from Deadman III by a shallow channel 20-30 yards wide, carrying only a foot of water or less, with a soft sandy floor scattered with worm mounds. The island is oval-shaped with its longest axis aligned north-south; its maximum dimensions are 125 yards (N-S) and 95 yards (E-W), and its total area only two-fifths of an acre. It is located closer to the eastern reef than the other Deadman's Cays, and hence the seaward shore consists of coarser material--less shingle, but more coral rubble, some of it lying in shallow water offshore. Back of the rubble zone the cay surface is sandy, and the north, south and west shores consist of fine sand. There is a little shingle forming lobes to north and south of the main seaward rubble zone. The seaward shore overlooks a rubble-strewn reef-flat with depths of 1-2 feet; the leeward shore faces a very shallow, sheltered sand bay, with restricted circulation, and many young Rhizophora seedlings.

The vegetation cover is dense and not easy to penetrate. Along the southern part of the seaward shore there is a hedge of Tournefortia, and elsewhere on the windward side the upper shore is covered with Sesuvium and Euphorbia. On the leeward shores Sesuvium is again widespread, with a little Euphorbia and much Sporobolus and other grasses. The centre of the cay is covered with a dense thicket of coconuts and bushes, mainly Conocarpus; no tall broadleaf trees were seen. The Rhizophora colonists in the leeward bay have been mentioned, and in addition, the low leeward shore is lined by scattered, more mature Rhizophora, Avicennia and Laguncularia, with many dead trees and branches, particularly of Avicennia. The mangrove does not, however, form a distinct zone separate from the sand cay.

Deadman V (fig. 18)

Deadman V is the most northerly of the group: it stands about 400 yards north of Deadman IV, and like it is close to the reef. In spite of this, however, the island is almost wholly built of sand, with only a very little shingle at the extreme eastern end, and some small pitted coral blocks lying on the reef-flat offshore. No part of the island rises more than 2 feet above the sea.

The cay falls into two sections. The eastern one is low and formed of rather grey humic sand. It is triangular in shape, with the apex facing east: its maximum E-W length is a little more than 50 yards, while the base of the triangle, along the west side, is 70 yards long. The vegetation has been cleared for coconuts, and apart from these and a small area of Sesuvium consists mainly of Sporobolus virginicus and

Cyperus planifolius beneath the palm trees. The second section of the cay lies immediately adjacent to the sand area on its west side; it consists solely of Rhizophora mangle, with little or no dry land. This forms a zone elongated in a north-south direction, with approximate dimensions of 70 x 35 yards. Along the south shore of the sand area there are a number of small Rhizophora seedlings, with a single mature tree at the east point, and the shore itself is lined with the dead roots and branches of a more extensive mangrove zone. Most of this cay probably originated as a mangrove island, and owes its present height above sea-level to more intense sedimentation near the east reefs. The dry areas may have been cleared for cocal in recent times. It is of interest that Owen's 1830 MS chart shows two small cays at this point, suggesting the existence of a narrow channel between the two segments of the cay, which has been filled in by mangrove growth in the last 130 years.

The Deadman's Cays are rather different in aspect and origin from other sand cays on this coast. They do not occur in association with reef gaps and refraction patterns, as is generally the case, and they are located where the eastern mangrove rim approaches closest to the eastern reefs, that is, where the "reef-flat" is narrowest. As noted, the eastern sand ridge of Turneffe does not occur at this point. The east reef here is exposed to considerable wave action, and much debris is washed across it and finds no means of escape. Some is undoubtedly flushed through the gaps--hence the "pouches"--but most must accumulate in front of the mangrove rim. This accounts for the general shallowness of the inter-cay area on the reef-flat, and the cays themselves probably represent only incidental, local, greater accumulations of sediment. The cays near the reef have some shingle, those farther back none (there are exceptions). The purely sandy areas may have originated as mangrove-capped shoals (Cay V), which, producing a further obstruction, would help to trap more sediment on the windward side. This would lead to ecological changes and colonisation by dry-land vegetation. This transition from mangrove has undoubtedly been aided by man's intervention in clearing for coconuts. None of these cays show evidences of erosion so common elsewhere, presumably because of the great supply of debris. The cays are probably growing both toward the mangrove rim, and, more slowly, laterally towards each other. Currents across the reef-flat will probably long keep open the present channels between the cays, but once they coalesce sufficiently to form a continuous line, then the intervening leeward depression between cays and mangrove would soon fill in, and a continuous sand-rimmed mangrove area be formed. This may in part explain the formation of the main eastern sand ridge of Turneffe. Finally, the structure of the cays--their lack of height, abundance of sand, small development of shingle ridges--can only reasonably be ascribed to the protective influence of Lighthouse Reef against the prevailing easterlies. This and other questions concerning the Deadman's Cays are discussed in Section VIII.

Calabash Cays

Northward of the Deadman Group the east reef extends with many interruptions, including the Grand Bogue entrance, to Calabash Cays, a distance of about 7 miles. Calabash Cays are located toward the southern end of an arcuate segment of reef 1½ miles long, which extends across the greater part of the Calabash Entrance (to the interior lagoon). The Entrance itself is a wide gap in the eastern mangrove rim, which is here rimmed by a sand ridge on its windward side. The group includes four cays (Owen charted 3 in 1830), two of which (Big and Little Calabash Cays) are named. The mouth of the Entrance itself carries at least 1 fathom of water, and its floor is sandy, with large north-south orientated ripples. Near the reef, particularly where backed by the mangrove rim, the water is shallower, and though access to the two main cays can be obtained in about a fathom of water, by keeping close to the mangroves, the cays themselves stand on a reef-flat carrying less than a foot of water.

Little Calabash Cay (fig. 19)

Little Calabash is the most southerly of the group, and is located at the southern end of the reef segment (cf. Transect A, Section IV). It has been much altered by man and now has little of interest. The cay is regular in shape, with maximum dimensions of 95 x 60 yards. It is highest on its northeast side, where a sand beach with much Halimeda rises to a crest approximately 2½ feet above the sea. The surface slopes gently to the low leeward shore, with no marked irregularity. There is a little evidence of marginal erosion, in the undercutting of coconut trees on the northeast shore, but this is probably much retarded and even outweighed by human agencies. The cay is the centre of the Turneffe coconut export trade, and at the north end there is a marked peninsula, about 15 yards long, consisting of nothing but split coconuts. Conchs are exported, too, and their shells form the shore near the pier and also along the seaward side, where they have probably been dumped to give protection. Erosion along the south and southeast shores (facing the reef gap) has been sufficient in the past to necessitate the building of a pile-wall on this side, backed with conch shells. This appears to have completely halted any natural erosion on this side. No beachrock is exposed near the cay. The seaward shore overlooks a reef-flat, covered with Thalassia, and carrying only 6-8 inches of water. The pier on the leeward side gives anchorage in 7-8 feet of water.

The pier itself is 30 yards long, and has at its end a transverse landing stage 40 yards long, with a large warehouse. This can accomodate at least two coconut boats at a time, and these rather ungainly, deep-hulled vessels, including the Corozal Packet, make regular runs to Belize. Little Calabash represents a clearing house for the Turneffe coconuts, which are brought here in small boats from as far as Rope Walk for transhipment. There are several small sheds on the island, and one substantial hurricane-proof house. The buildings include a small commissary, where a limited amount of supplies can be obtained on about three days a week. Black pigs are numerous here. The vegetation consists entirely of some 1½ dozen coconut trees, with a scattered ground cover of grasses and a low blue-flowered plant.

Big Calabash Cay (fig. 20)

Big Calabash Cay lies about 300 yards northeast of Little Calabash, with which it is connected by a very shallow sandy reef-flat, partly covered with Thalassia, across which, as noted, the pigs wander freely. The cay is aligned NNE-SSW, parallel to the reef, and is about 170 yards long. Its width varies from 35 to 55 yards, and it is uniformly low and sandy. The maximum height is reached on the east side, and lies between 2 and 3 feet above the sea. There is no shingle on the island, but in several places there are banks of conch-shells, and at one point a considerable accumulation of the small concrete plates formerly used for cultivating commercial sponges. At the south end of the cay there is a spit of fresh sand.

The vegetation has been removed for coconuts, and nothing remains apart from these and a sparse growth of coarse grasses, except for some peripheral mangroves--chiefly Rhizophora seedlings close inshore, and a couple of taller Avicennia trees near the north end. The coconuts form a ragged canopy only 20-30 feet high. This island has been settled for many years, and has several houses, especially one substantial building at the southeast point; rainwater is obtained from vats. The Big Calabash settlement was formerly more important, especially between 1900 and 1939, when it was the centre of the sponge industry, but since then Little Calabash has handled the coconut industry on account of its deeper anchorage. There are several small wooden jetties round the island, and the leeward bay gives anchorage of 4-5 feet.

East Cays One and Two

East and north of Big Calabash are two smaller islands, here named in order of proximity to it, Big Calabash East One and East Two Cays. East One (fig. 20) is separated from the main cay by a shallow channel only 14 yards wide, carrying up to 12 inches of water, with numerous Rhizophora seedlings. The cay itself is small and rounded, with a diameter of 40-50 yards. Its eastern shore lies close to the reef, is straight, and formed of coarse blackened coral rubble; it has little worn shingle and no sand. The rest of the island is sandy with varying amounts of small shingle, and nowhere does it rise more than 3 feet above the sea. It is covered with bushes, mainly Suriana maritima and Conocarpus erectus, with several low Rhizophora and taller Avicennia trees round its margins. Two distinct clumps of coconuts, totalling less than a dozen trees, rise towards the centre of the cay.

Big Calabash East Two (fig. 19) is smaller, and is located about 90 yards north of East One. It consists of a narrow strip of land 50 yards long and generally less than 10 wide, with some shingle at its east end. The greater part is low and sandy, and does not rise more than 18 inches above the sea. It is prolonged westwards by a fresh sand spit. The vegetation is low and windswept, and consists only of peripheral mangroves (Avicennia and Rhizophora, with many shoreline Rhizophora seedlings), a central thicket of Suriana maritima and coarse tall grasses, and two or three low young coconuts.

On none of these cays was any beachrock seen.

Soldier and Blackbird Cays

Rather less than 3 miles north of Calabash Cays, the east reef of Turneffe swings eastwards in a prominent elbow to its most easterly point. North of the elbow the reef is wide and strongly developed, with a wide sandy reef-flat, and well-marked groove-spur system on its seaward slope; south of it, the reef and sandy flat are narrow, but the reef growth is no less vigorous than that to the north. Immediately south of the elbow itself, two cays are located: the southernmost and largest is known as Soldier Cay; the northernmost is unmarked on charts but is known locally (according to fishermen at Calabash Cays) as Blackbird Cay.

Soldier Cay (fig. 21)

Soldier Cay is 145 yards long and has a maximum width of 55 yards. It stands some 50 yards back from the reef-edge, and parallel to it. The cay is fairly regularly shaped, and of simple physiography. The seaward, southeast shore, 110 yards long, is formed by a steep ridge of grey shingle, well interlocked, rising to a fairly constant crestline 5.5 feet above sea-level. In the south and centre of the cay the surface slopes gradually from this ridge crest to the shore on the east side; the interior surface is of fine grey sand with scattered coral fragments, tight-packed, and with the upper layers discoloured with humus. The lee shore itself is formed of fine white sand. At the northeast end of the cay (which faces the sea north of the main reef elbow) the shingle ridge continues round the shore, decreasing in height and in size of constituent material, and appears along the northern part of the lee shore as a distinct ridge rising 3-4 feet above the sea. This leeward beach ridge is broad, with a rounded profile, and contains more sand than medium shingle; the cay surface between it and the seaward shingle ridge consists of grey sand with scattered fine shingle. The two cross-sections (fig. 22) of the cay show these features plainly. There is no evidence of erosion round the cay margins, except at the south end, where the old grey sand area is bounded by a distinct low cliff-line. However, a fresh sand peninsula 20 yards wide projects up to 15 yards in front of the undercut zone, and is now being colonised by vegetation.

The most distinctive feature of the physiography of the cay is the platform on which it stands, for here, uniquely in British Honduras, is a segment of drying reef. This begins near the north end of the cay, borders its seaward side, and extends southwards for over 200 yards. Its average width is about 20 yards. It consists of detached loose boulders, generally less than 2 feet in diameter, much blackened and pitted, piled on a rock pavement which lies slightly above low tide level. The platform itself is thus submerged at high tide but many of the blocks remain exposed--many of them are so weathered as to be no longer identifiable. None are in the position of growth, and all are probably thrown up from the reef-front by wave action in time of storms: the location at the eastern elbow, where refraction would be greatest, may help explain the feature. The surface of the rock platform is irregular (though curiously unlike such possible emerged reef-rock surface as at Half Moon Cay), and at low tide contains isolated pools of water subject to great overheating. Small fish and morays are seen in the deeper pools, mollusca are very abundant, but stony corals are absent. Large algal growths are not common. The surface seems to slope lagoonward and to be highest near its seaward edge; the number of blocks is also greatest near the wave-break line, and diminishes lagoonwards. Neither north nor south of this small area is any drying reef to be found.

The whole cay is planted thickly with coconuts, and the natural vegetation has been almost entirely removed. The cay is said (Romney and others, 1959, 245) to have been planted at one time with sapodilla (Achras sapota L.) and mahogany (Swietenia macrophylla King), but no trace of these or any other broadleaf trees remains. The steep seaward shingle ridge bears oval-shaped patches of Sesuvium portulacastrum, and low spray-swept bushes of Tournefortia gnaphalodes, with a little scattered Euphorbia. At the north end of the cay are bushes 4-5 feet high of Suriana maritima, and an undercover of Sesuvium and Euphorbia, but apart from this, a patch of Sesuvium on the new southern sand spit, and sparse Sporobolus underneath the coconuts, the cay surface is bare. Most of the coconuts are about 40 feet high; but one at the south end is about 15 feet higher than the rest. There are numerous Rhizophora seedlings in shallow water near the cay, along the west and south shores.

There are several houses and sheds on the island, none substantial, but no-one was living there at the time of our visit in 1960. There is a small wooden jetty at the south end of the cay, and in shallow water to westward two palm-leaf fish-traps.

Blackbird Cay (fig. 23)

Blackbird Cay is situated about 100 yards NNE of Soldier Cay: it is a small, crescent-shaped island, transverse to the reef-flat at this point, some 70 yards long. It is widest at its seaward side, where it fronts a dry zone of coral blocks, mainly massive palmata slabs. The cay is highest on this side, rising from a beach of Halimeda sand to a core of large shingle 3 feet high. This core has a diameter of 25 yards. To leeward the shingle is finer, and the island is prolonged southwestwards by a spit of fresh sand with fine shingle. The north side of the cay, which faces the open sea across the reef north of the main elbow, is also fronted with palmata slabs. The channel between Soldier and Blackbird Cays has a maximum depth of 15 inches.

The southeast seaward shore is fringed by a zone of mangroves, unusual in so exposed a location, including both Avicennia and Rhizophora about 15 feet high. Three solitary young coconuts rise to a height of 20 feet to leeward of the mangroves, from a ground cover of Sesuvium. Between coconuts and mangrove are a number of low but dense Conocarpus bushes. An unidentified black bird was nesting on the cay at the time of our visit.

Pelican Cay

From the Soldier Cay elbow, the eastern reef trends slightly northwestwards for nearly seven miles to Northern Bogue. The eastern mangrove rim lies 600-700 yards back from the reef-edge; and though the eastern sand ridge is here well-developed, it is divided from the reef flat by a narrow fringe of Rhizophora. Only a single cay is found along the whole of this section of the reef. Owen in 1830 (MS H57) marked two distinct cays, "Pelican Cays", one small island some distance south of a larger one, and the two cays are both marked, and so named, on later charts. The cay was visited in 1960 and photographed from the air in July, 1961, when only a single cay existed. We were unable to ascertain whether the former two cays have grown together, or whether one has been destroyed, perhaps in a hurricane; the latter view seems most likely.

The cay (fig. 23) is rectangular in shape, and aligned with its long axis parallel to the reef, i.e. north-south. The dry land area has maximum dimensions of 100 yards N-S, and varies from 40 to 60 yards in width E-W. When visited in 1960 the whole dry land area was surrounded by a belt of Rhizophora mangle, with a little Avicennia and Conocarpus on its dry-land margin. This mangrove rim was interrupted only in three places, two of them artificial boat harbours rimmed by conch shells. The cay surface probably does not rise more than 18 inches above the sea; it is flat and featureless, composed of grey sand with no shingle. The interior of the cay has been completely cleared and planted to coconuts, and has only a scanty undergrowth, mainly of grasses with a little Sesuvium. When photographed from the air in July, 1961, however, the Rhizophora rim of the northeast side had been completely cleared, revealing a narrow, white-sand shore. Southeast of the dry sand area there projects a rounded mass of tall bushy Rhizophora, forming a peninsula about 35 yards in diameter.

The cay is inhabited and has two huts, one occupied in 1961 by a Carib fisherman. It is quite possible that this island originated as a mangrove cay, and that its present appearance is almost wholly man-made.

The Cockroach Group

Between Northern Bogue and the northern end of the main mass of the Turneffe lagoon mangroves, between the east reef and the eastern mangrove rim, are a number of mangrove-sand cays and sand cays here termed "the Cockroach Group" (fig. 24). Cockroach Cay is one of the larger islands in the group, the only one inhabited, and the only one visited and mapped. The group extends from Dogflea Cay in the north for a distance of 3 miles, ending in the south at a large mangrove cay about 500 yards long, set at an angle to the reef. Cockroach Cay and the cays to the north were visited or seen at a very early stage in this investigation, but the extent of the group to the south of Cockroach Cay was not realised until they were flown over and photographed at the close of the second expedition. Each cay was photographed, looking west, from a height of 200 feet, and the following remarks are based on these photographs. The area has never been mapped in detail or shown on charts, and unfortunately only the southernmost part is included in the air photograph cover. A very general sketch map has been prepared showing these islands; it is hoped that they may soon be fully mapped, and our record of the British Honduras cays so completed.

The group includes 28 cays altogether, of which five are longer than 250 yards, 15 are between 20 and 100 yards long, and the remaining 8 are mere specks of land, mostly mangrove. The smaller cays, especially in the south, are mainly and sometimes entirely mangrove; the larger cays, with the exception of the southernmost, show a distinct zonation into seaward sandy beach, sand area with bushes, and leeward red mangrove zone. Coconuts are not generally found, except on Cockroach Cay, which has been cleared and given over to cocal. Altogether, four cays, including Cockroach and Dogflea, lack mangrove entirely, and of the rest, 8 have large sandy areas covered with bushes, with mangrove restricted to the leeward side, and the remaining 18 are wholly or mainly mangrove, many with only very small areas of dry sand. Perhaps half a dozen of these cays would repay detailed mapping. To some extent they resemble the Deadman's Cays farther south, but otherwise they form a distinctive cay-type on the British Honduras atolls, not being associated with reef-gaps. The chief dry land vegetation seems to consist of bushes such as Suriana and Conocarpus.

Cockroach Cay (fig. 25)

Cockroach Cay is situated near the northern end of the group, with six cays to the north. It is a long narrow island, aligned parallel to the reef edge, here interrupted by a gap immediately south of the cay. The island has a maximum length of 310 yards, and varies in width from 55-60 yards. Along its seaward shore for a distance of 180 yards the beach is formed by a shingle ridge rising to a crest 3 feet above sea level. Back of the ridge the cay surface declines to the leeward shore and is composed of sand with large amounts of blackened and broken coral, much of it still recognisable. The greater part of the northern section of the cay, however, is sandy; and a fresh sand peninsula is also building southwards from the southern end of the island. The leeward shore is everywhere low and sandy, facing a shallow bay with large numbers of Rhizophora seedlings close inshore.

The vegetation has been almost wholly cleared for coconuts, now planted in orderly rows, with little ground vegetation apart from grasses and Euphorbia. At the southeast end of the leeward shore, however, there is a thicket of old mangrove and low bushes, from which we obtained a specimen of the common boa, so widespread in the Turneffe mangroves.

Dogflea Cay, the northernmost in the group, is low and sandy, with a narrow sand beach. It is covered with a thicket of Suriana bush, from which rise four low coconuts.

The Northern Cays

Three prominent cays stand to the north of the main mass of the Turneffe lagoon mangroves: Three Corner Cay, Crawl Cay and Mauger Cay. The first two were seen from close range, and the last visited. Crawl Cay and Three Corner Cay are almost wholly mangrove, with little dry land. Three Corner Cay is shaped as its name implies; Crawl Cay is elongated east-west and is convex to the north. Mauger Cay is also orientated east-west and is convex northwards, and it is the only one with dry land. Unfortunately the dry land area is so small, the vegetation so tall and dense, and the deflecting influence of the cast-iron lighthouse so great, that no map could be made, in spite of some effort. The eastern and western lobes of the cay consist of Rhizophora with no dry land. The central part, which has been cleared, is low and sandy, with prominent clumps of Rhizophora along both its north and south shores. The cay has clearly suffered some erosion (though it is located nearly $1\frac{1}{2}$ miles south of the reef-edge and well within the lagoon), since the whole of the north shore of the cleared area is bounded by a thick masonry wall. The cay surface does not rise more than 2 feet above the sea. The cleared area is small and irregularly-shaped; it has less than a dozen coconuts, all less than 15 feet high. The sandy areas are covered with Sesuvium, Ageratum maritimum, and Cyperus planifolius. A very wide-spread shrub, 2-3 feet high, with fleshy leaves, cannot unfortunately be identified. Towards the west end of the cleared area is the 64 foot high open-frame light-tower, with three substantial houses for its keepers. According to Winzerling (1946, 59) the cay received its name from the women prisoners (mugeres) which pirates brought here after the sack of Bacalar in 1648. The West Indies Pilot refers to a prominent "portion of a stranded wreck on the northern edge of the reef, about 1 3/4 miles north-north-eastward of Mauger Cay" (1956, 462), and this was seen again in 1960.

The Eastern Sand Ridge

As already stated, the eastern side of the eastern mangrove rim of Turneffe is fringed for much of its length by a sand ridge. This forms the seaward shore on the south side of Northern Bogue, both sides of the Calabash Entrance, and on both sides of Grand Bogue. It was either visited or seen at close quarters at Northern Bogue, Harry Jones (north side of Calabash Entrance), Calabash Cays, and Rope Walk (its most southerly extent). Between Northern Bogue and Rope Walk it forms a fairly continuous feature, though often hidden from the sea by a narrow belt of mangrove. It generally rises, with some local shore undercutting, to a crest 3-4 feet in height, consists of sand with little coarser material, and declines westward to pass under the inner belt of lagoon-fringing mangroves, Rhizophora and Avicennia. The ridge is almost entirely planted to coconuts, with an intermittent undercover of Hymenocallis and grasses, and along the shore a little Tournefortia, Suriana, Ipomoea, Sesuvium, and in places Coccoloba uvifera. It has clearly been built up along the seaward edge of the mangrove by the great amounts of debris being washed across the eastern reefs, which cannot otherwise be disposed of. It is thus analagous with the formation of such mangrove-sand cays as Cay Caulker and Long Cay on the coastal shelf, though on a much larger scale. Whether it grew at a uniform rate along its whole length, or consists of several distinct patches subsequently united, is not known; and whether it is currently undergoing growth or not is questionable. The widespread growth of mangroves in front of the ridge, and its undercutting elsewhere, suggest that it is in fact a fossil feature.

Dixon (1956) in his memoir on the geology of southern British Honduras figured a section of elevated beachrock from this ridge, which he described as marking a former shoreline 7 feet above the sea. He did not give its location. Vermeer, however, though he did not find this or any other raised beach on Turneffe, quotes Dixon's brief caption and reproduces his photograph (1959, 87, 95, 96)(in both cases the photograph is reversed left to right). The existence of this beach, together with other "raised beaches" on Ambergris Cay and Long Cay, Lighthouse Reef, which Vermeer described, led him to correlate them all: "Each of these was on separate geomorphological units and each stood at a height of 5 to 7 feet above sea level. ...The uniformly raised beaches clearly point to a negative eustatic change in sea level" (1959, 87). One of the conclusions of the present study is that no such fluctuation can yet be demonstrated, and is in fact on present evidence extremely doubtful; this may be illustrated by reference to the Turneffe example.

Harry Jones Point (fig. 26), northern side of Calabash Entrance, was visited in April 1960, and the existence of the raised beachrock noted. The area was mapped, with special reference to the beachrock outcrop, which was subsequently recognised as that figured by Dr. Dixon. I am grateful to Dr. Dixon for sending me some further photographs and comments on it. Dr. Dixon visited the area with the British Honduras Land Use Survey Team, and Dr. Romney has also given me his comments. In May 1961 the area was again visited, levelled, and augered.

Beachrock outcrops only along the north-south trending shore of Harry Jones, for a total distance of 220 yards. To the north the shore sweeps westward in a broad bay; to the south the shore becomes low, trending westward into Calabash Entrance. The sand ridge is here 30-50 yards wide, and is covered with coconuts, ending abruptly at the margin with tall Rhizophora and Avicennia. The undergrowth beneath the coconuts consists of Sesuvium, Euphorbia, Hymenocallis, grasses, and Iresine celosia. At the easternmost bluff (i.e. the most northerly extent of the beachrock) are a number of Tournefortia and Suriana bushes, and the whole of the east-facing shore, where the beachrock outcrops, is clothed with dense, overhanging Coccoloba uvifera. The crest of the sand ridge varies in height, but is generally 3-4 feet above sea level. It rises highest at the eastern bluff, reaching 5.5 feet above approximate low tide level. The surface of the sand area slopes back towards the mangrove rim, and I doubt whether any part exceeds 6 feet in height in the Harry Jones area.

The beachrock also varies in height. It is highest at the eastern bluff, where the outer edge of its upper surface lies 1' 8" to 2 feet above approximate low water level; it slopes southwards along the shore, and for the greater part of its extent lies only slightly above mean sea level. The southernmost sector lies at about low water level, and is covered with beach sands and banks of dead Thalassia. The outcrop is being eroded, especially at the eastern bluff, and many blocks have been undercut, broken off, and now lie on the shore. It is difficult at the bluff itself to determine original dip: the surface of the beachrock, roughened and pitted by erosion, seems approximately horizontal, though Dr. Dixon thinks it slopes upwards from the sea. Away from this bluff, the beachrock dips seaward like any other beachrock, and indeed looks much the same. At the bluff itself the beachrock is overlain by the ridge sands, here rising to rather more than 5 feet above sea level, and the question arises, how far does the rock extend beneath the sand, and

and how high does it become? In this connection, Dr. Dixon writes (personal communication, 1960):

> "....the beachrock slopes upwards away from the sea and disappears under a thin covering of grass and sand. ....Starting about 10 yards or so back from the top of the bank we put down some hand auger holes to examine the soils, and just below the surface there was a layer much more compact than the soft material below it. This compact layer got softer as the water-logged mangrove area at the west side of the cay was approached. We assumed that it was the same beachrock, rotted perhaps by the fresh water in the soil, but the height was only a rough guess."

In 1961 we put down two auger holes, one 5 yards inland from the bluff, striking beachrock at 2 feet depth, one 10 yards inland, not striking beachrock at all. The beachrock thus rises at this point to 2-2½ feet above approximate low tide, and as the sand surface steadily declines westwards, cannot get much higher than this.

The true beachrock at Harry Jones thus has a vertical extent of about 3 feet, does not rise more than 3 feet above the sea, is 5-10 yards wide at most, and extends for over 200 yards. The lateral (as distinct from normal transverse) gradient I believe indicates tilting of the whole exposure, since pronounced lateral dip is not a feature of intertidal beachrocks. Lateral tilting has raised the north end to give abnormally high beachrock at the bluff; in this connection we can refer to the drying reef at Soldier Cay a few hundred yards to the north. This is the only exposed reef in British Honduras, and might reasonably have been involved in--indeed, caused by--the Harry Jones tilting.

The softer rock a few inches below the surface described by Dr. Dixon from augering is not, I believe, rotted beachrock, but "cay sandstone" (Kuenen 1933; see Sections VIII, IX), the induration resulting from fresh water percolation and evaporation. If the true beachrock and this sandstone are continuous, then they must form a plate 200 yards long and up to 50 yards wide: altogether improbable for beachrock formed by intertidal cementation on medium-gradient beaches with small tidal range. Unfortunately time did not allow a full programme of augering in 1961 to trace the extent of this "cay sandstone" induration.

In my view, this beachrock owes its appearance to tectonic, not eustatic causes; but even if it can be shown to be eustatic, then it cannot be referred to a sea-level higher than 3 feet above the present, and certainly not to any 6 foot stillstand.

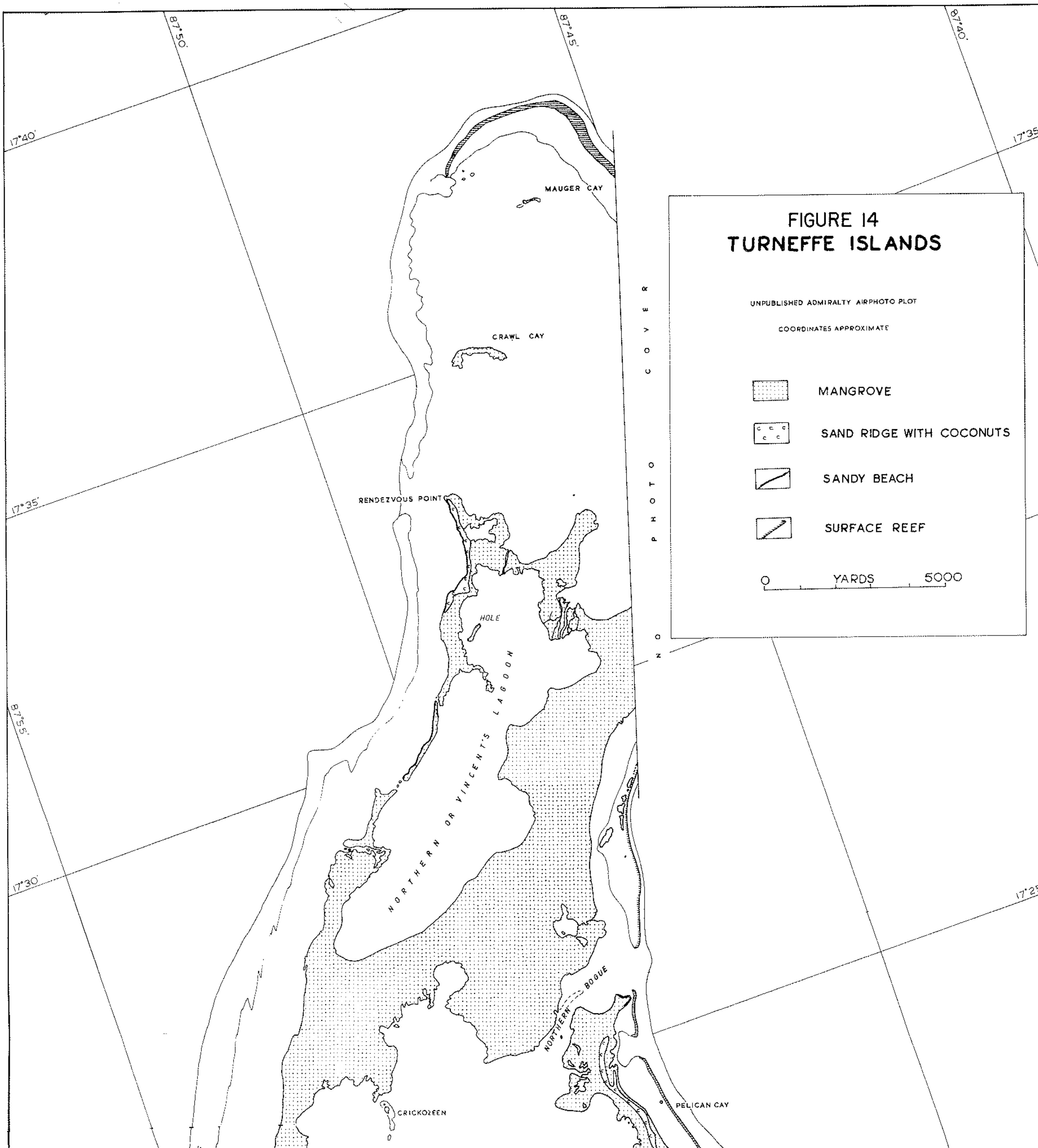


FIGURE 14
TURNEFFE ISLANDS
UNPUBLISHED ADMIRALTY AIRPHOTO PLOT
COORDINATES APPROXIMATE
MANGROVE
SAND RIDGE WITH COCONUTS
SANDY BEACH
SURFACE REEF
0 YARDS 5000
87°50'
87°45'
87°40'
87°55'
17°40'
17°35'
17°30'
17°25'
MAUGER CAY
CRAWL CAY
RENDEZVOUS POINT
HOLE
NORTHERN OR VINCENT'S LAGOON
NO PHOTO COVER
NORTHERN BOGUE
CRICKOZEEN
PELICAN CAY

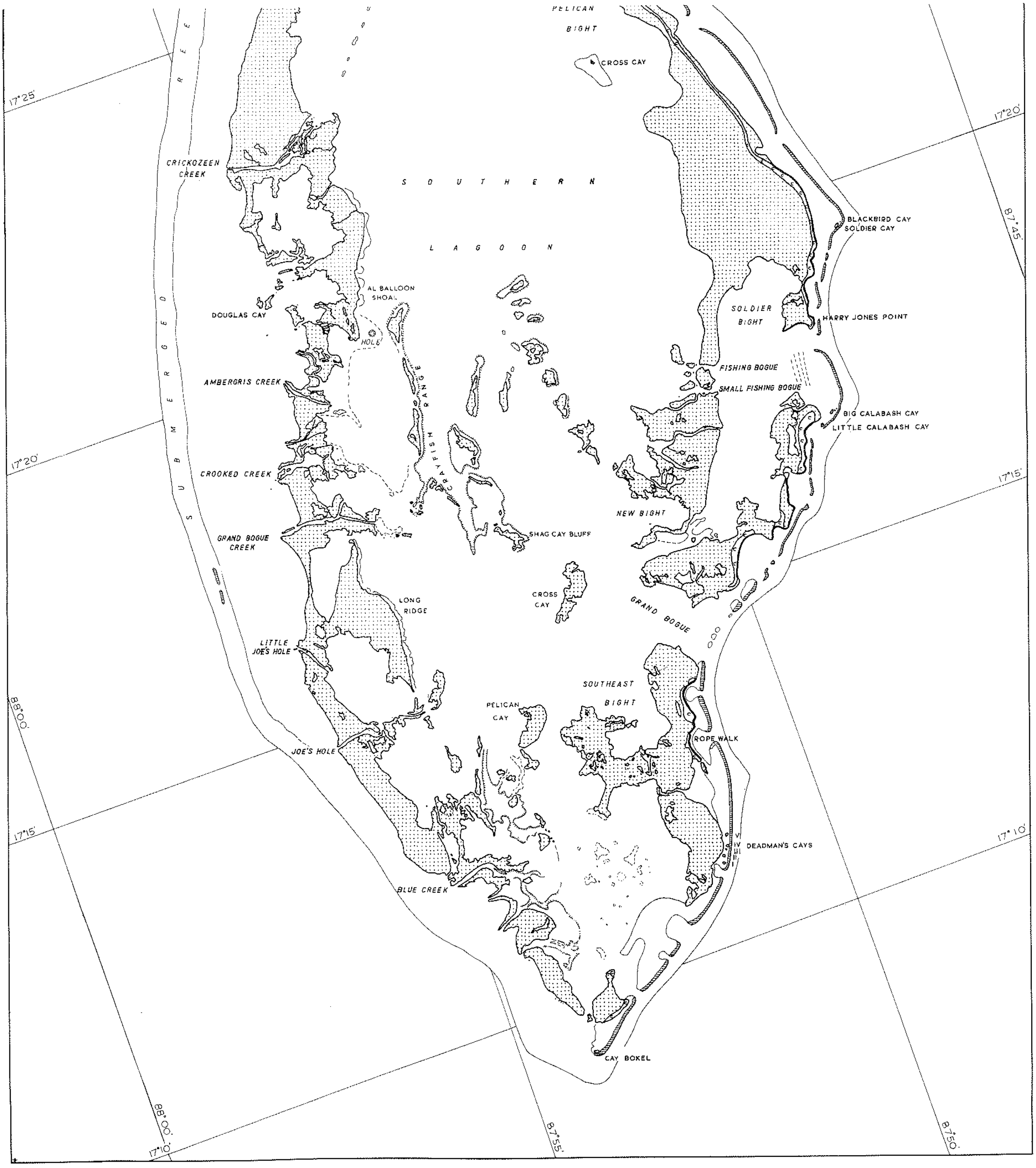
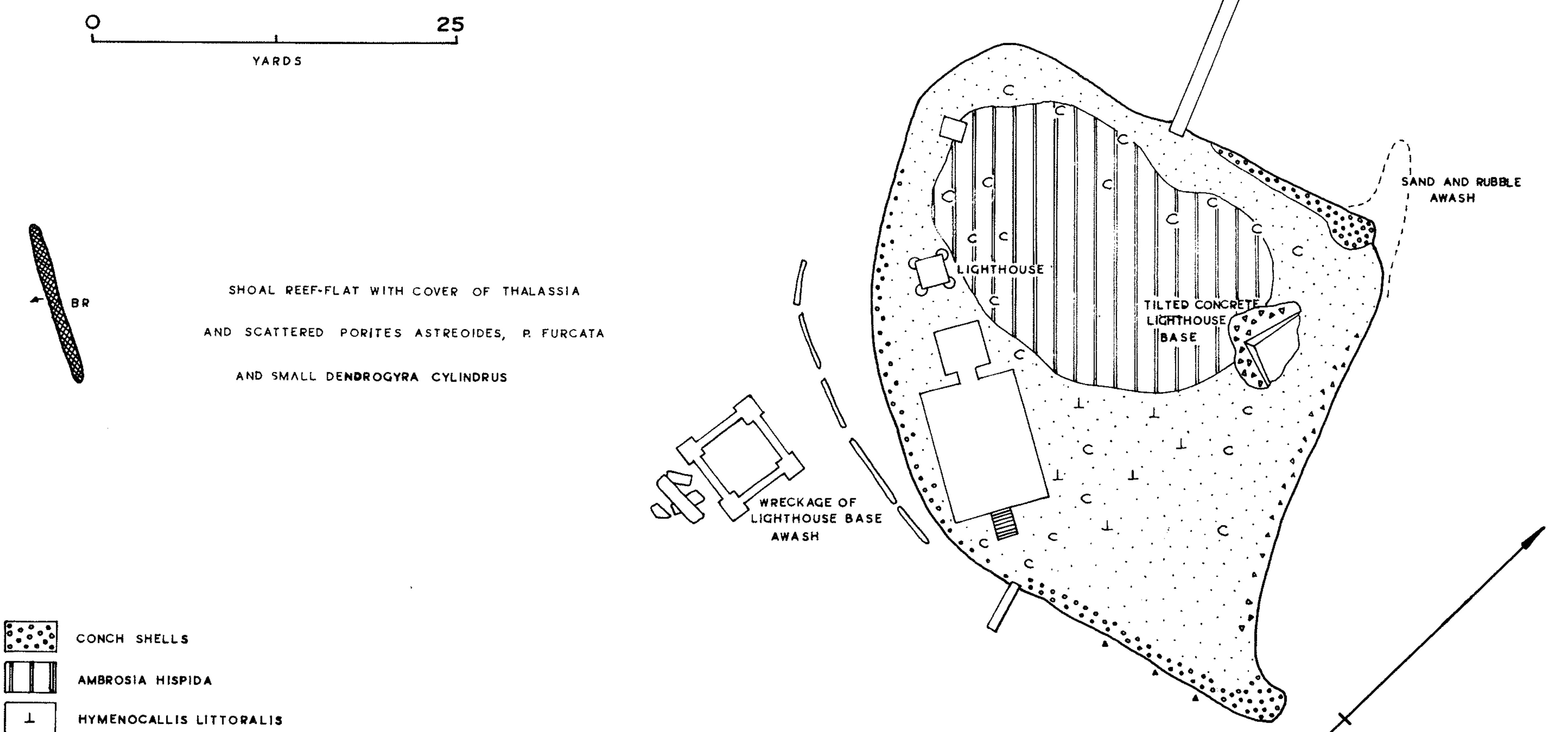

PELICAN
BIGHT
CROSS CAY
17°25'
17°20'
R E E
SOUTHERN
LAGOON
CRICKOZEEN
CREEK
BLACKBIRD CAY
SOLDIER CAY
87°45'
AL BALLOON
SHOAL
DOUGLAS CAY
HOLE
SOLDIER
BIGHT
HARRY JONES POINT
FISHING BOGUE
SMALL FISHING BOGUE
AMBERGRIS CREEK
BIG CALABASH CAY
LITTLE CALABASH CAY
CRAYFISH RANGE
SUBMERGED
17°20'
CROOKED CREEK
17°15'
NEW BIGHT
GRAND BOGUE
CREEK
SHAG CAY BLUFF
LONG
RIDGE
CROSS
CAY
GRAND BOGUE
LITTLE
JOE'S HOLE
88°00'
SOUTHEAST
BIGHT
PELICAN
CAY
ROPE WALK
JOE'S HOLE
17°15'
17°10'
DEADMAN'S CAYS
BLUE CREEK
CAY BOKEL
88°00'
87°55'
87°50'
17°10'

FIGURE 15
CAY BOKEL



ACCURACY OF MAP LIMITED THROUGH COMPASS DEFLECTION BY CAST IRON LIGHTHOUSE

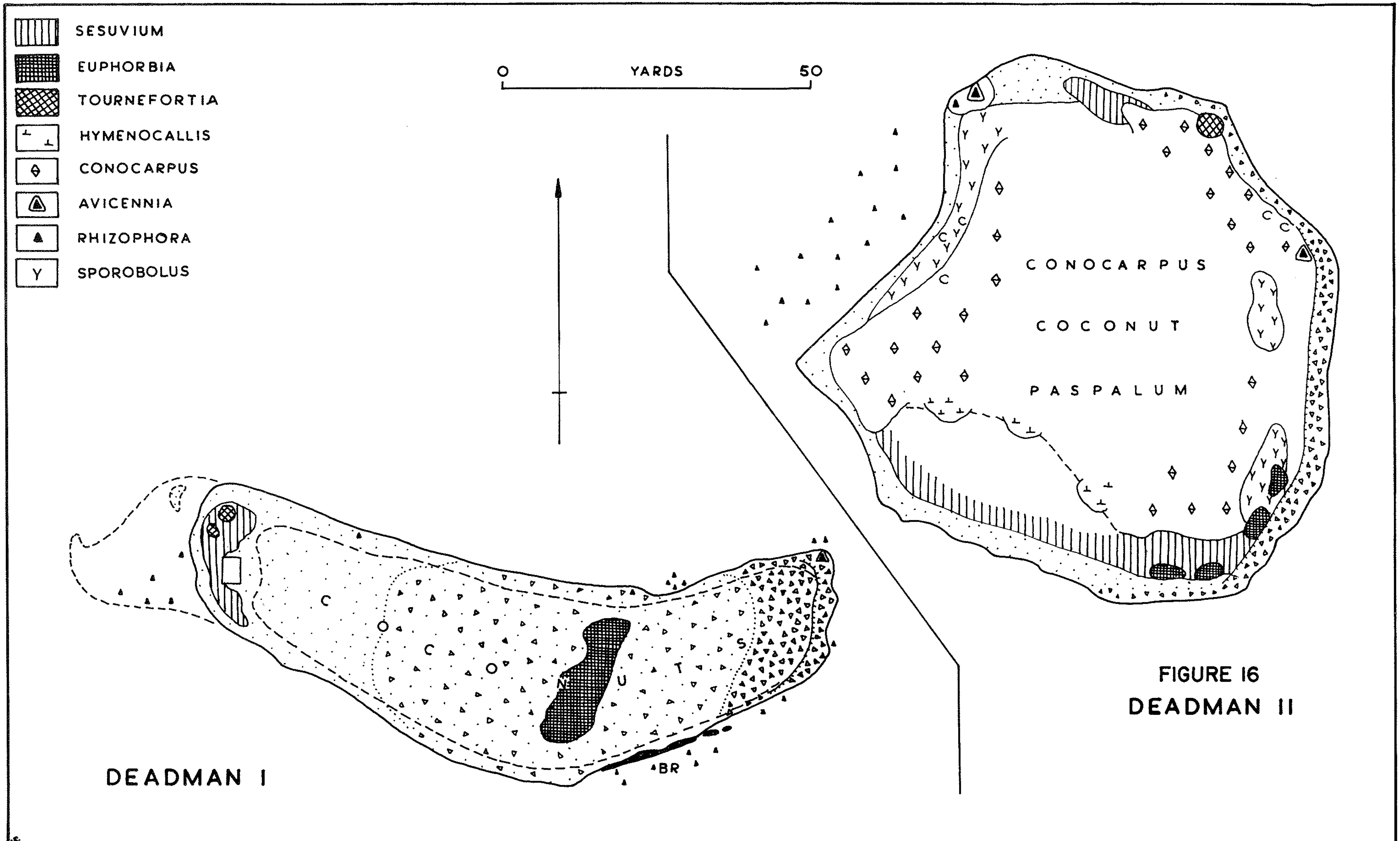
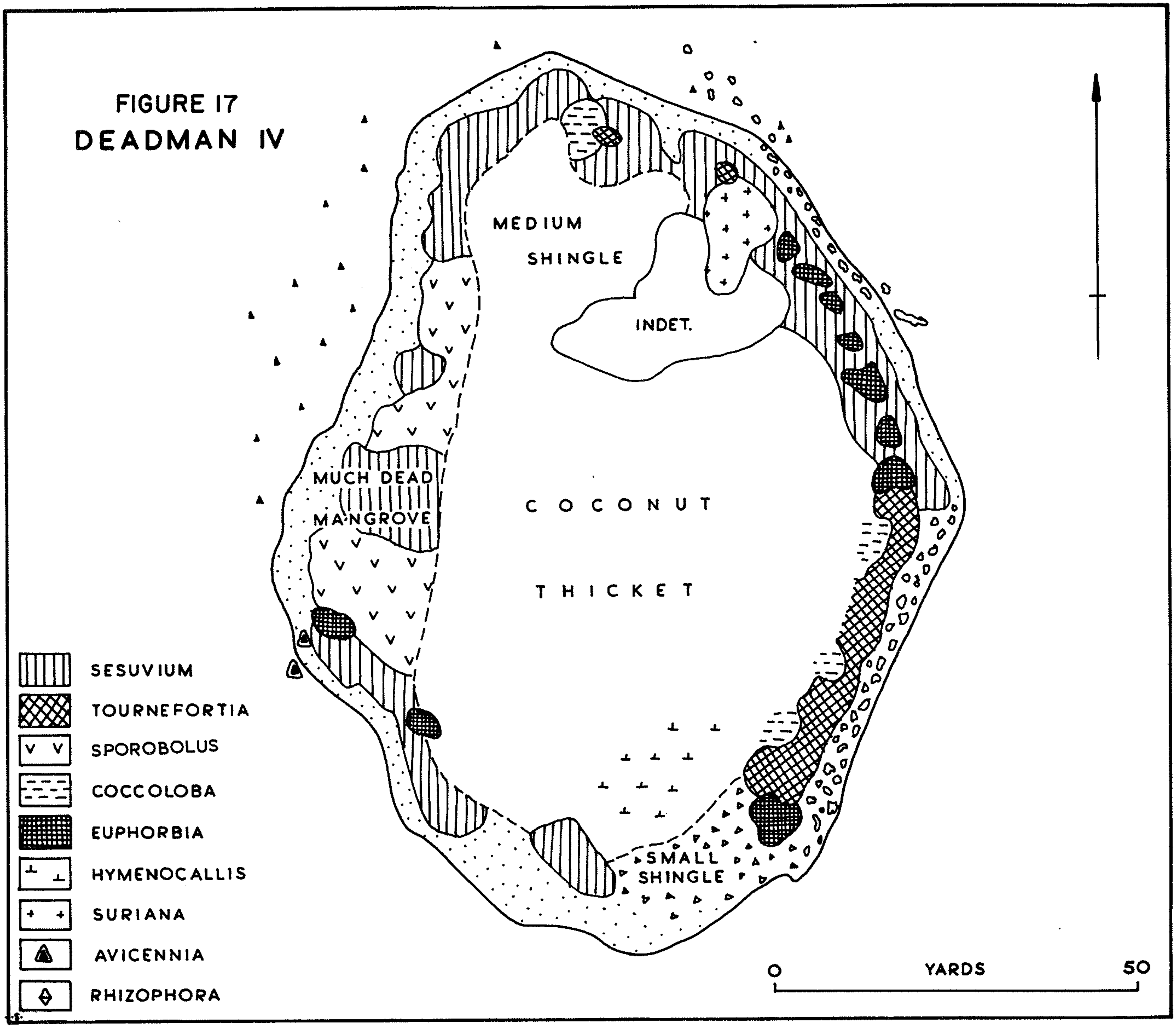


FIGURE 16
DEADMAN II

FIGURE 17
DEADMAN IV



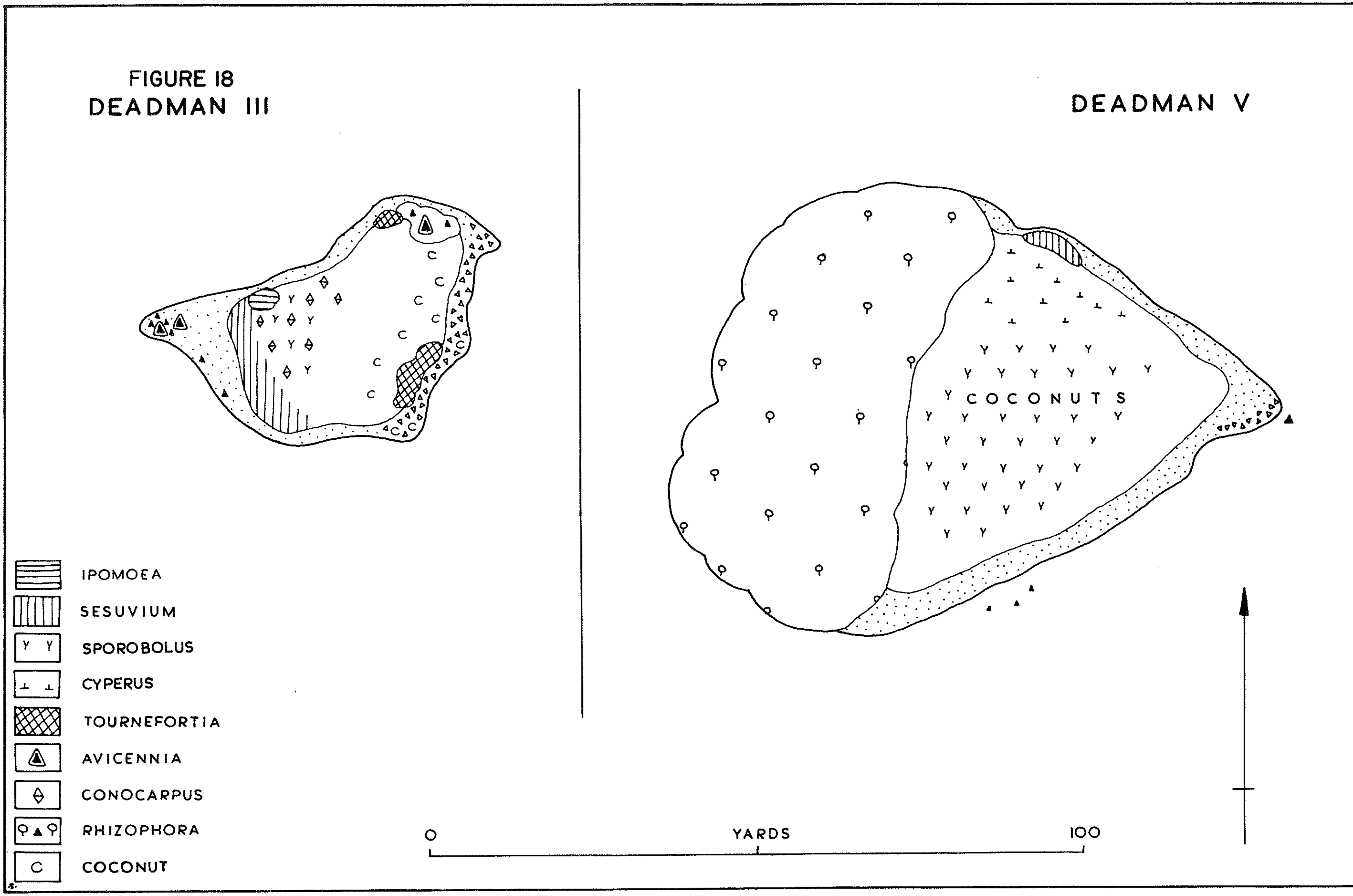


FIGURE 18
DEADMAN III
DEADMAN V
COCONUTS
IPOMOEA
SESUVIUM
SPOROBOLUS
CYPERUS
TOURNEFORTIA
AVICENNIA
CONOCARPUS
RHIZOPHORA
COCONUT
0
YARDS
100

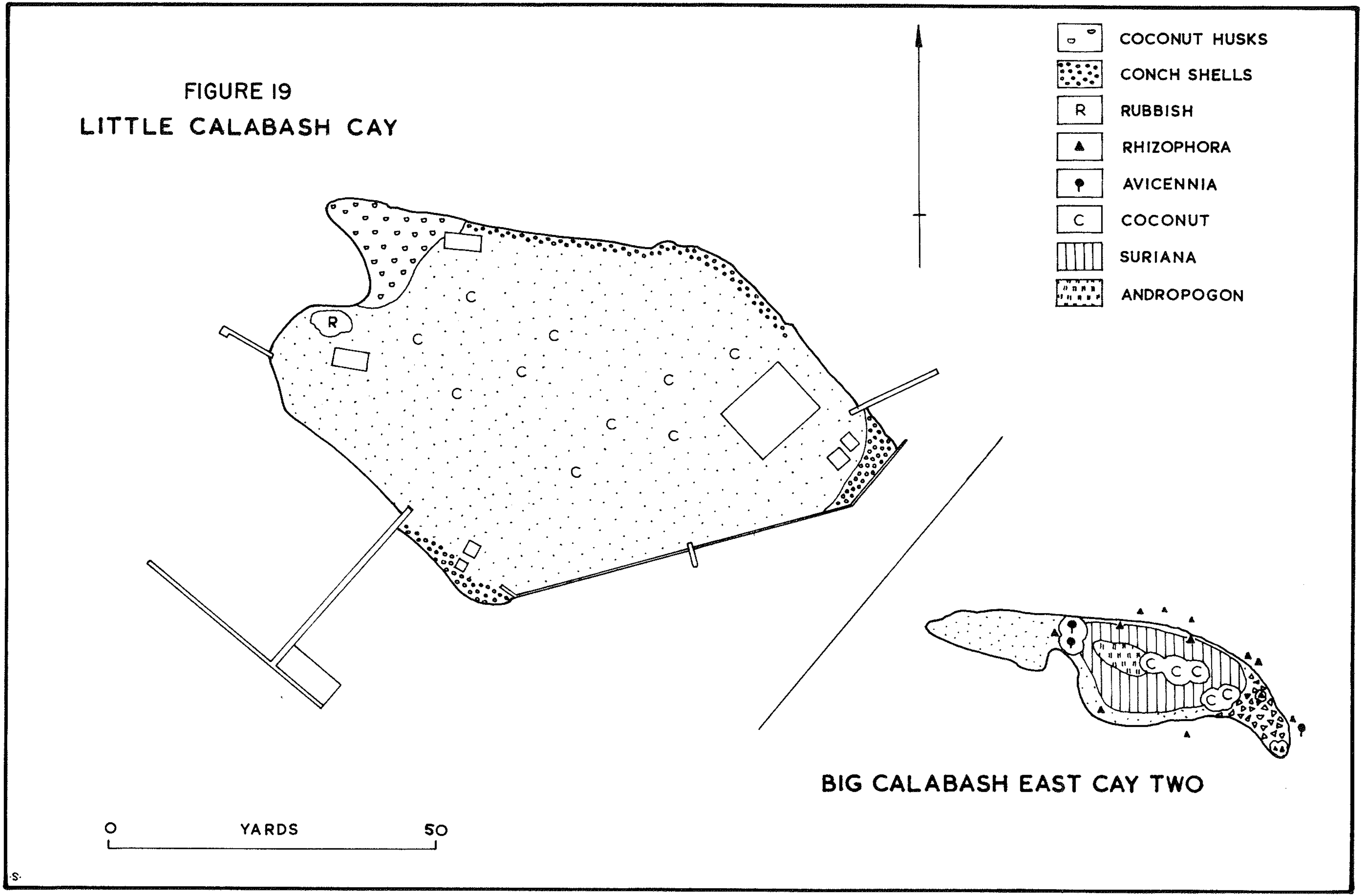


FIGURE 19
LITTLE CALABASH CAY

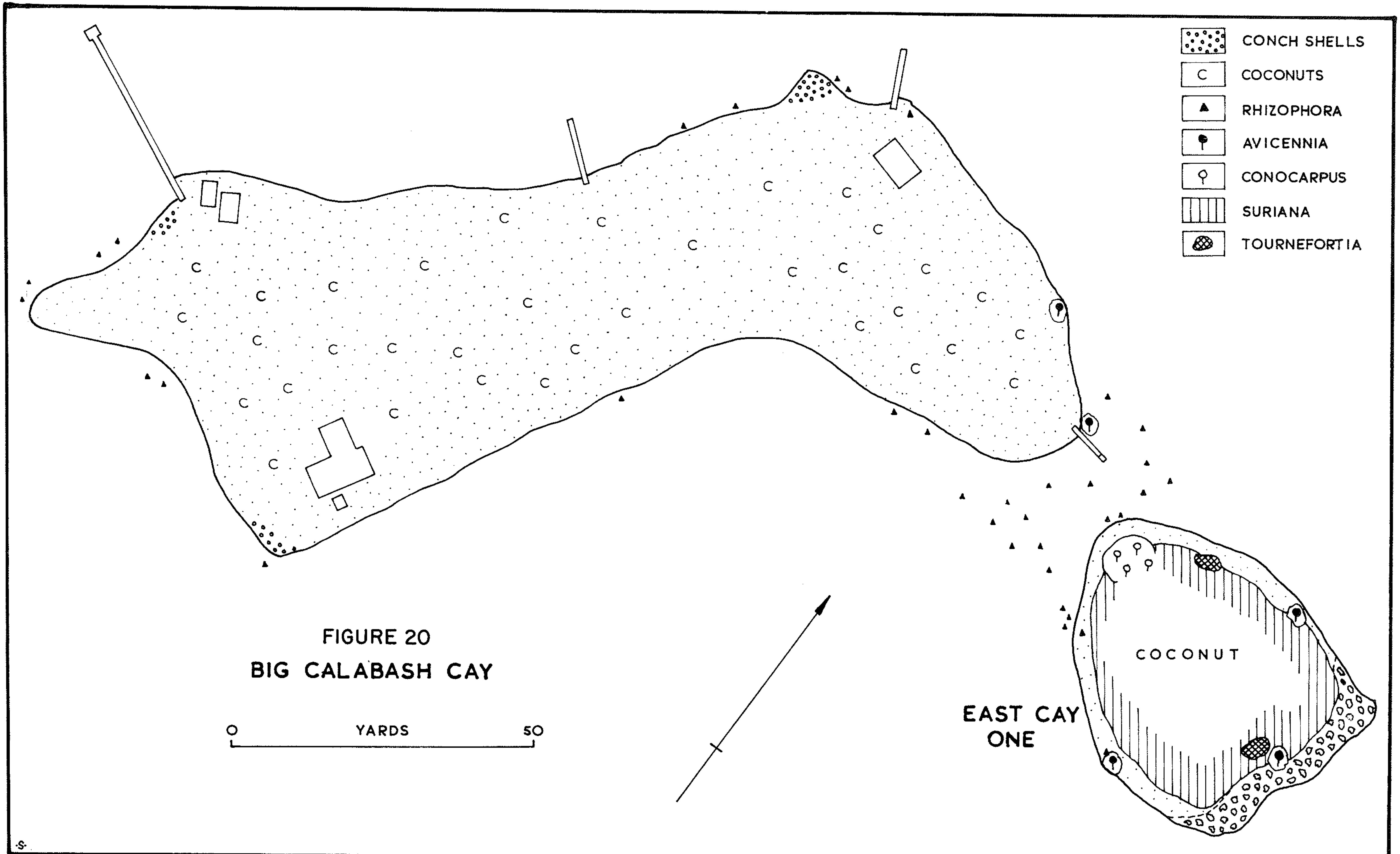


FIGURE 20
BIG CALABASH CAY

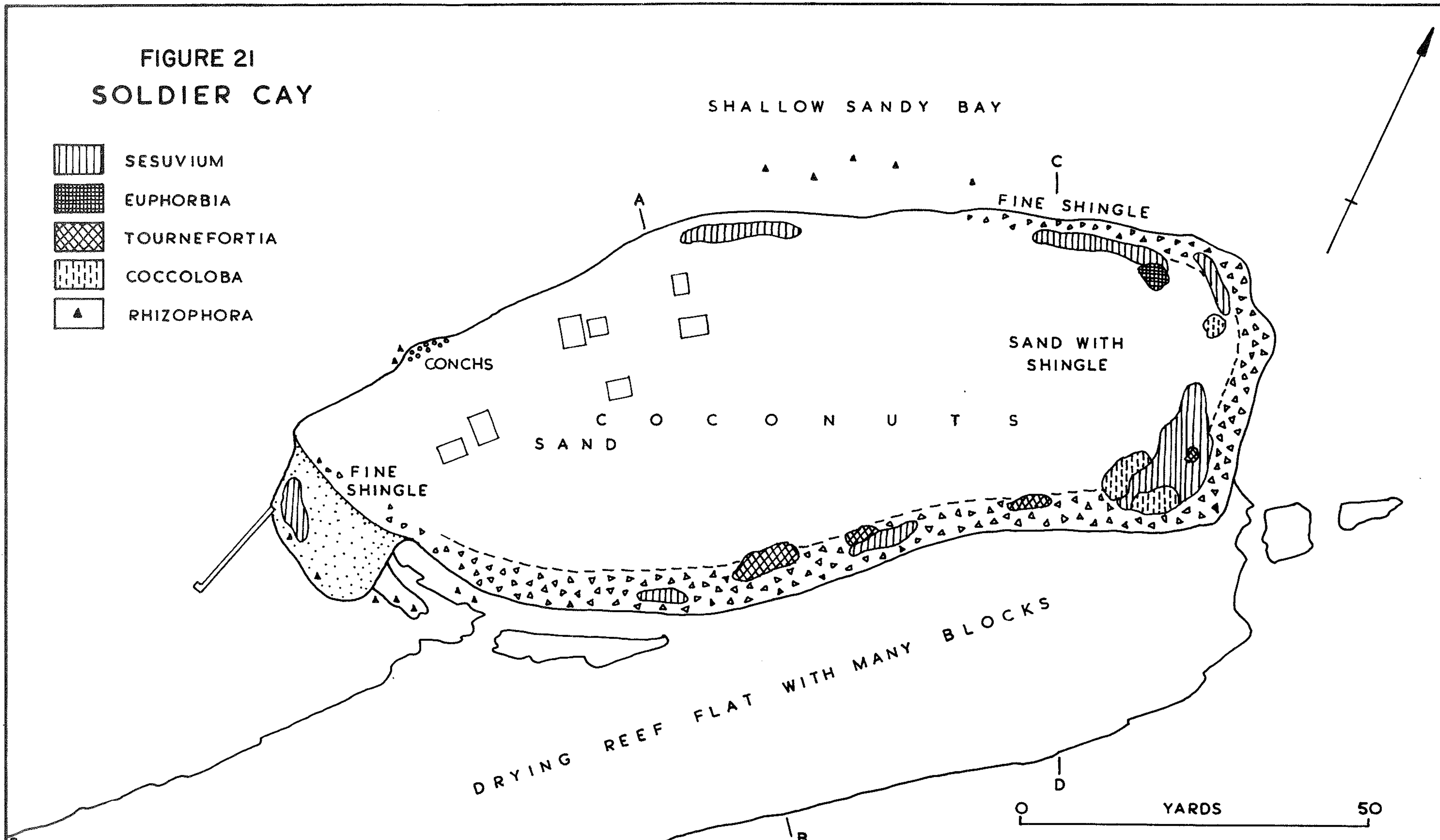
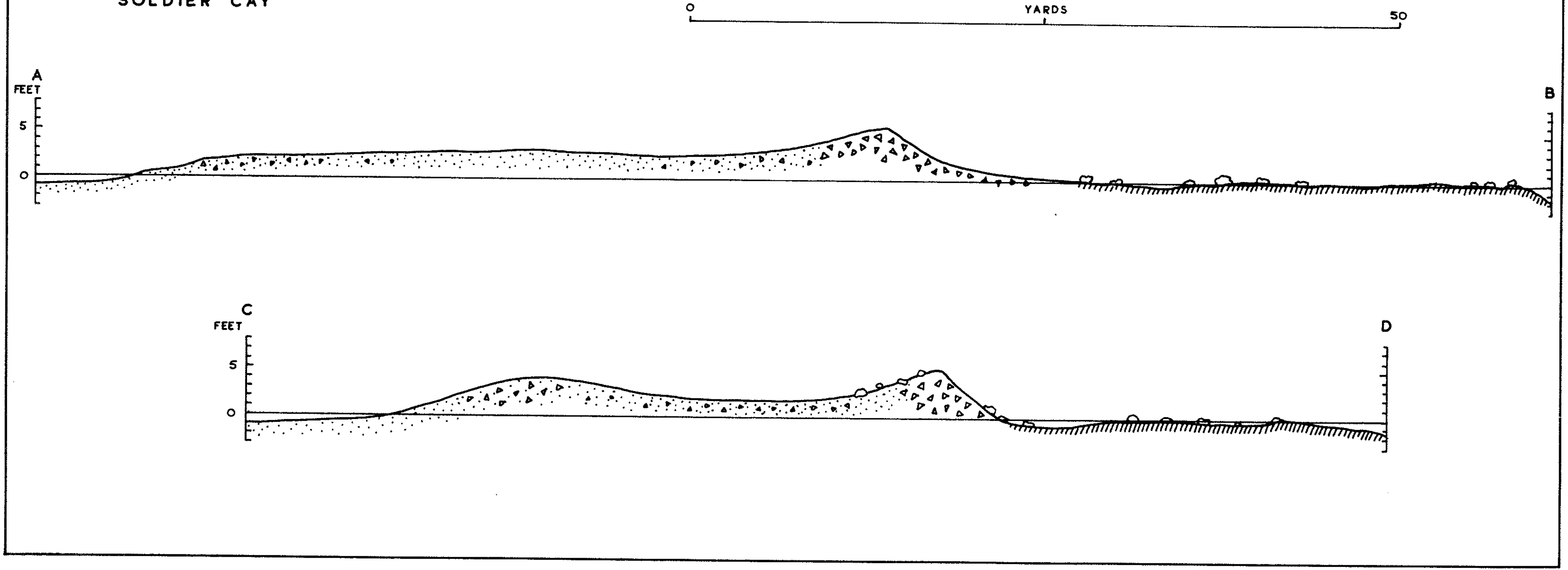


FIGURE 21
SOLDIER CAY
SESUVIUM
EUPHORBIA
TOURNEFORTIA
COCCOLOBA
RHIZOPHORA
SHALLOW SANDY BAY
A
C
FINE SHINGLE
CONCHS
SAND WITH SHINGLE
COCONUTS
SAND
FINE SHINGLE
DRYING REEF FLAT WITH MANY BLOCKS
D
B
0
YARDS
50

FIGURE 22
SOLDIER CAY



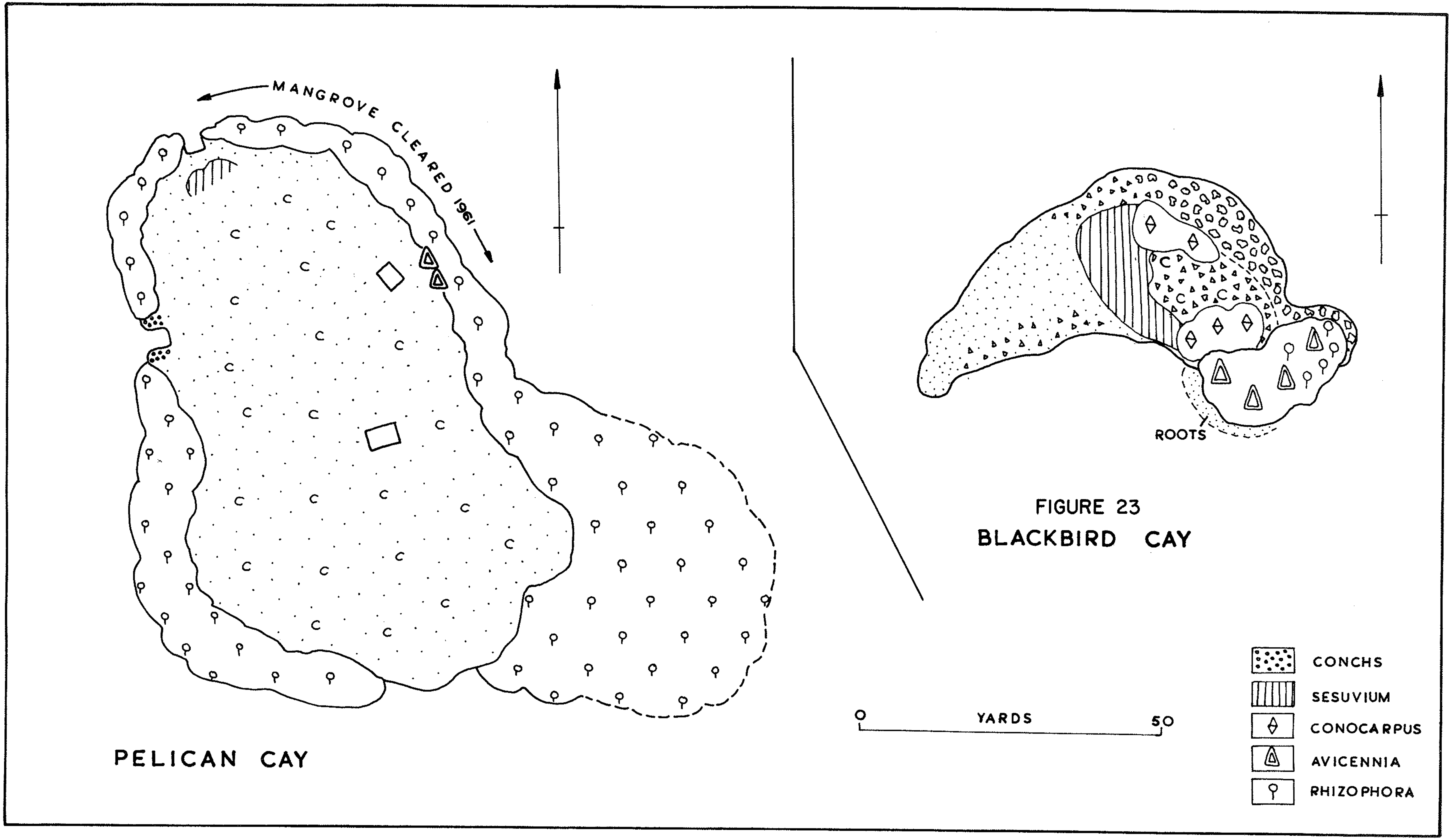


FIGURE 23
BLACKBIRD CAY

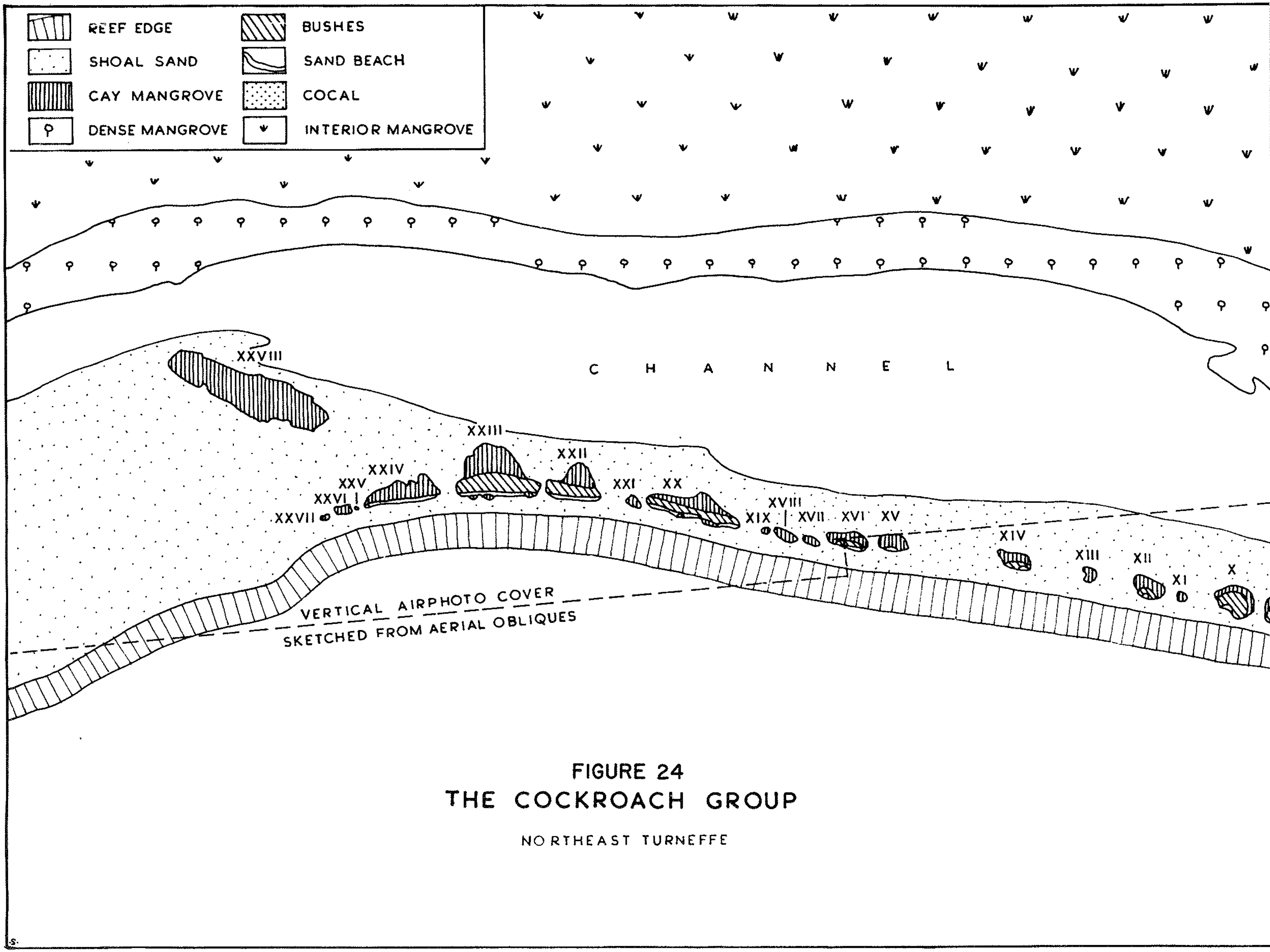
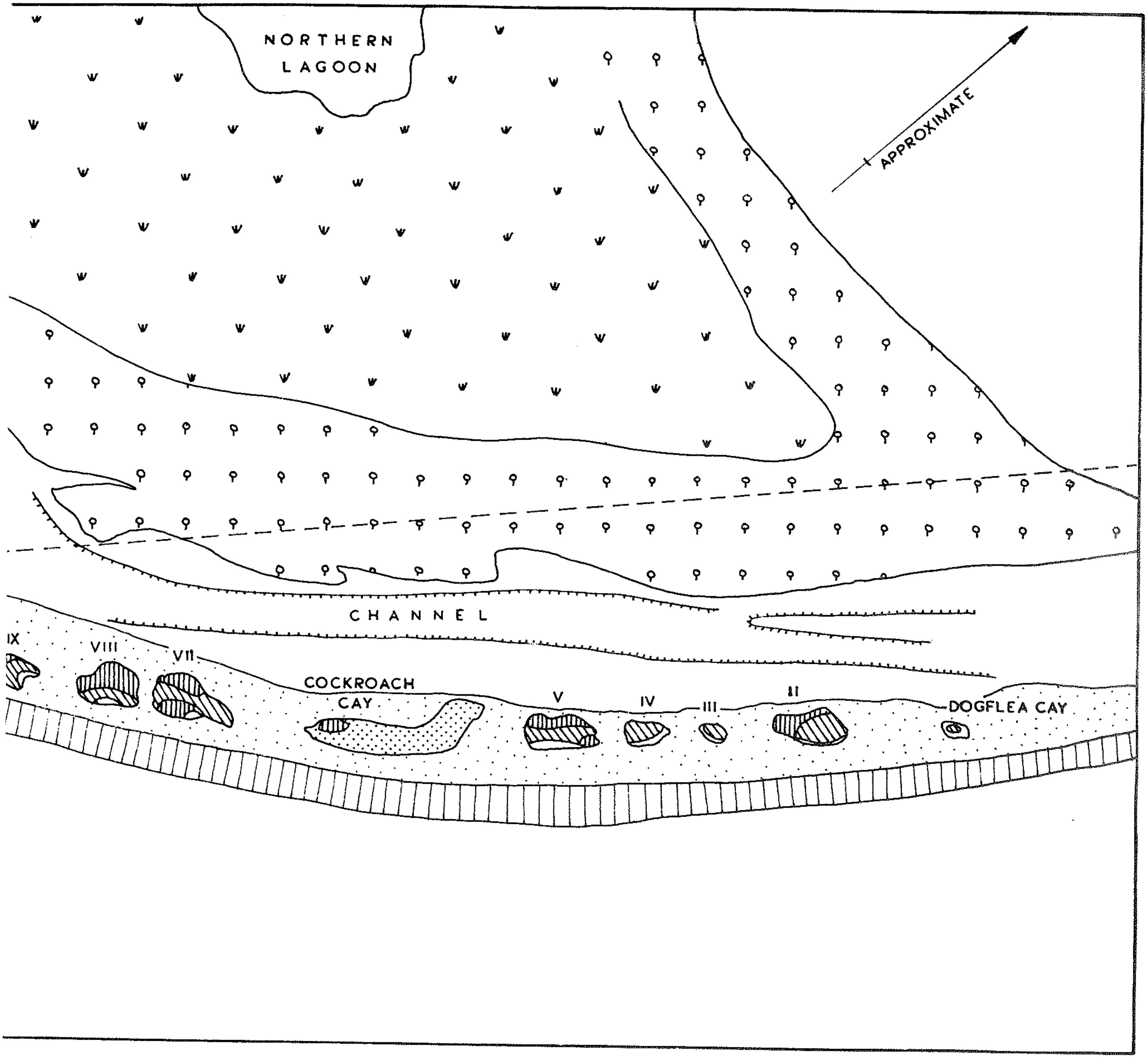


FIGURE 24
THE COCKROACH GROUP

NORTHEAST TURNEFFE


NORTHERN LAGOON
APPROXIMATE
CHANNEL
IX
VIII
VII
COCKROACH CAY
V
IV
III
II
DOGFLEA CAY

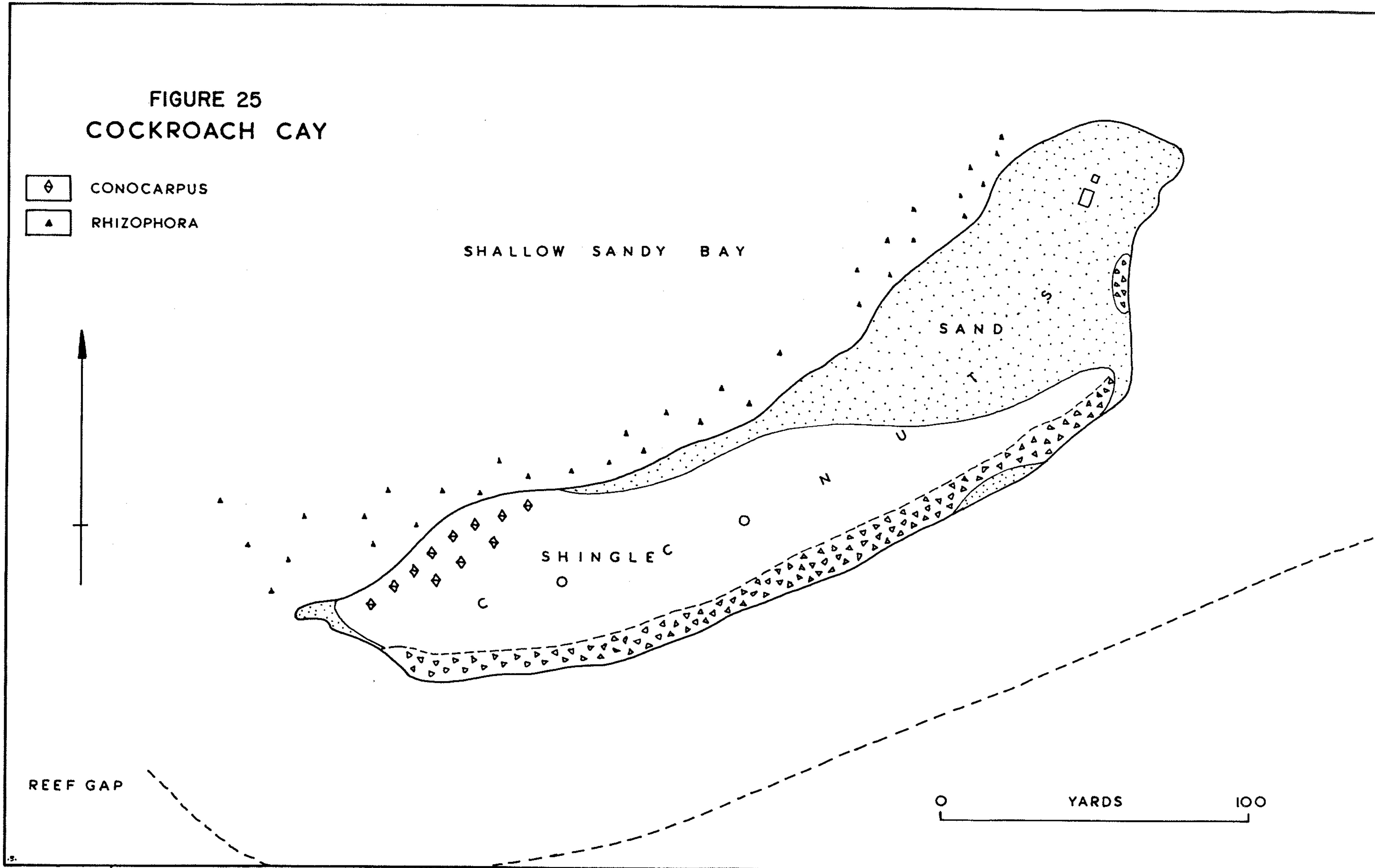


FIGURE 25
COCKROACH CAY

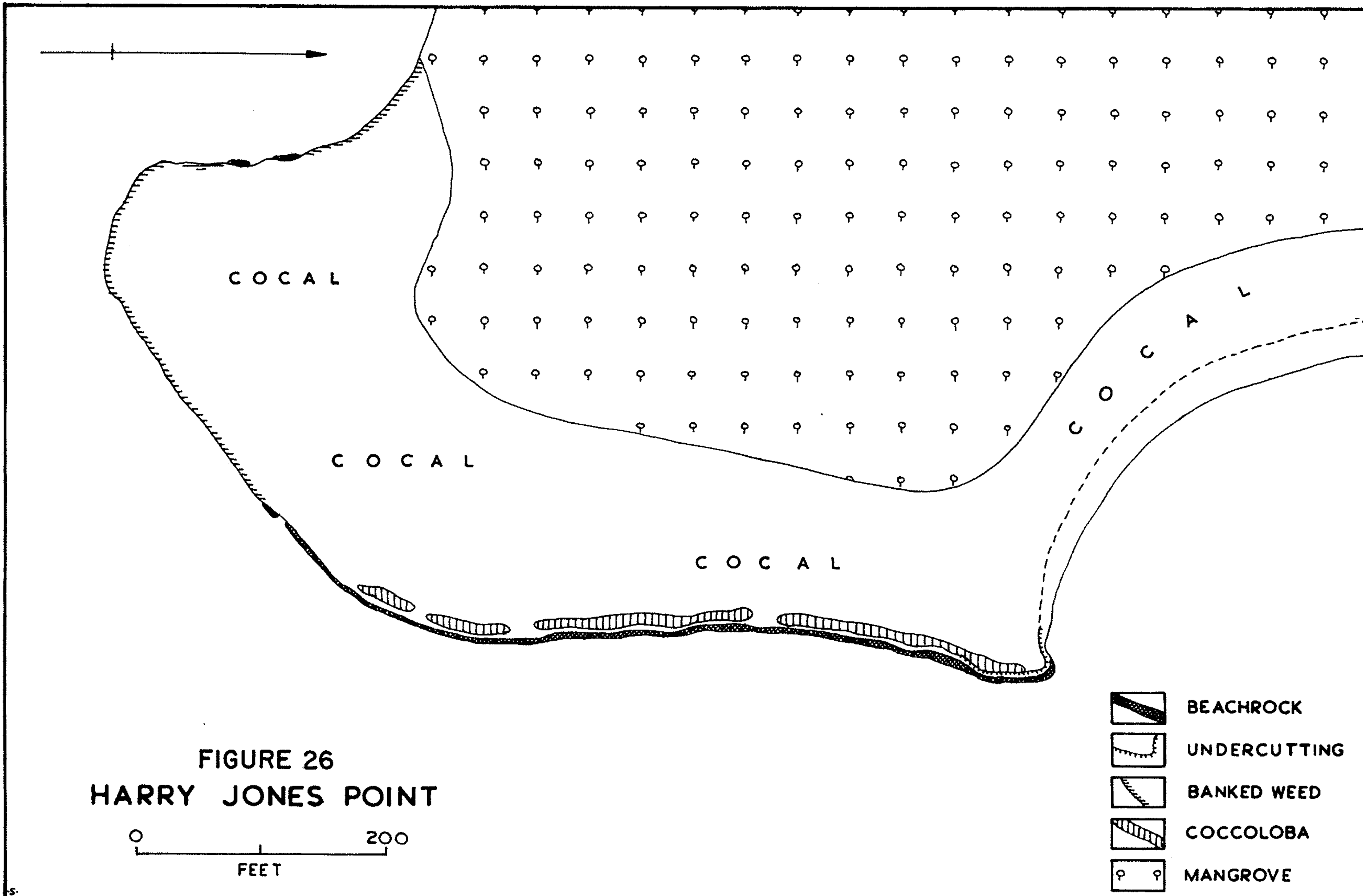


FIGURE 26
HARRY JONES POINT

VI. LIGHTHOUSE REEF

Lighthouse Reef (cf. Vermeer, 1959, 18-19, 95-103), with an overall length of 25 miles, width of 4½ miles, and approximate area of 78.5 square miles, is the smallest of the three atolls in area (though longer than Glover's Reef), and the most irregular in outline (fig. 27). The main part of the atoll measures some 17 miles in length, and to the southwest corner of this is appended an arc-shaped reef segment some 8 miles long and only 2 miles wide. The cause of this great southeastern bight between Half Moon Cay and the south end of the atoll is not known, but the suggestion made by Fairbridge (1950) that similar irregularities on Pacific atoll rims may result from submarine slumping could apply here, especially in view of the great depths off the east reefs near Half Moon Cay. Published charts of the atoll are extremely rudimentary, and the airphoto cover only extends to some two-thirds of the atoll area, so that our knowledge of the gross features of the reef and lagoon is incomplete.

Lighthouse Reef is surrounded by a well-developed reef-rim, with only three major gaps: one at the north end, giving access to Sandbore and Northern Cays; another west of Half Moon Cay, along the north side of Southeast Bight; and the third and largest on the west side of the atoll, immediately north of Long Cay. These never carry more than 1-2 fathoms water and are interrupted by scattered coral heads. In addition it is possible for small boats (maximum draught 5 feet) to cross the western reef at several points by threading between the coral colonies; but local knowledge is required for this.

The eastern reefs are remarkable for the breadth of the zone of living reef and the breadth of the reef-flat. The outer edge of the reef is shallowly sinuous in plan, and steep-to; it is lined by a well-developed groove-and-buttress system similar to that reported in Jamaica by Goreau (1958) and on exposed reefs in many parts of the Pacific (e.g. Emery, Tracey and Ladd, 1954; Munk and Sargent, 1954; Newell, 1956). The average width of the windward reef-flat, from air photographs, varies from 1,000 to 2,000 yards, and averages 1200-1500 yards. The width of the zone of living reef on the outer edge of the reef flat averages 500 yards. As was seen in transect B, much of this area consists of a submerged pavement of encrusting and loose nodular Lithothamnion, with only sparse growth of stony corals. Seaward of the algal pavement the dominant coral is massive Acropora palmata on the seaward slope, and lagoonward, Montastrea annularis on the reef-flat. The east reefs are continually pounded by surf, and the reefs are further remarkable in the strength of the current continually flowing across the reef-flat under the influence of prevailing winds and waves. This is estimated at 2-3 knots, and locally possibly more, and is so powerful that it is impossible in many places to swim against it; it may indicate the existence of a higher sea-level outside the reefs than in the lagoon. No such current is experienced on the windward reefs of Turneffe, though the drift there is also westwards.

The reef-flat forms a broad shoal area carrying as much as 5-10 feet of water. From the air and from the sea it is seen as a broad swath of translucent green water, in sharp contrast with the ultramarine of the sea beyond. It consists for the most part of loose detrital sands, with much algal and foraminiferal material. The air photographs show submerged sand ripples on this flat, especially north of Saddle Cay, and on the west side of the southeast bight, aligned transversely to prevailing winds, generally about 1,000 yards long and 2-300 yards apart. These were seen from the air in 1961, but no opportunity arose to inspect them under water. They are quite invisible from the sea, and may, even in shallow water, be crossed without being noticed. They appear very similar to the much more striking ripple formations of the Bahama Banks (Rich 1948; Newell and others, 1951; Newell and Rigby 1957). Ripples are also well-developed on the barrier reef flat between Cay Glory and Gladden Spit. So far as is known, reef-flat ripples have not received much attention in previous atoll or barrier reef studies, perhaps because most Pacific atolls are too exposed to permit their formation on reef-flats. Hence such ripples may be restricted to more sheltered atolls and reefs, and it would be interesting to see whether they are developed on the atoll reef-flats of the easternmost East Indies.

The somewhat anomalous location of Saddle Cay on the inner edge of the eastern reef-flat deserves notice.

The western, leeward flats and reefs are of a quite different character. Towards the north end of the atoll, the western reefs are backed by great lobe-shaped accumulations of barren white sand up to 1,000 yards in width, the living reef forming an extremely narrow fringe. Transect E was in such an area. Farther south the sand lobes disappear, and the narrow reef fringes a shallow reef flat 4-8 feet deep, which merges almost imperceptibly into the lagoon floor. Groove-and-buttress systems are not developed on these reefs, except in the extreme north, west of Northern Cay.

The lagoon enclosed by the two reefs is of unequal depth, and is generally shallower on the west side, where it grades into the reef flat, and deepens eastwards; the slope from the eastern reef-flat to the lagoon floor is steep and well-defined. No systematic sounding has been carried out since Owen recorded depths of 1-2 fathoms between the Long Cay reef-gap and Half Moon Cay, but it can be stated that the average depth of the lagoon on the east side of the atoll is 2-3 fathoms. On the west side it is shallower, and averages 1-1½ fathoms. These differences in depth can be clearly seen on the air photographs (e.g. CAE-6-186), where the shallow western sector appears to end fairly abruptly along a north-south line in the middle of the lagoon, the junction being fringed with patch-reefs. This feature is known locally as "Middle Reef", and certainly extends some distance north of the area covered by air photographs. Numerous small patch-reefs rise to the surface from the shallow western sector of the lagoon floor; those that rise from the deeper floor to the east are larger, more widely spaced, and better defined. They do not, however, approach the density of patches in the Glover's Reef lagoon. According to reliable local informants the maximum depth of the whole lagoon is found on the east side some 8-9 miles north of Half Moon Cay, where the bottom carries 4½-5 fathoms water.

Perhaps the most remarkable feature of the Lighthouse Reef lagoon is the deep depression in the lagoon floor 4 miles north of Saddle Cay and some 2200 yards from the eastern reef edge. This is shown on air-photograph CAE-6-186: it is a perfectly round, reputedly bottomless pit, rimmed by living coral, known locally as the "Blue Hole". The reef-rim is most extensive on the southeast side, and on the south and southwest; there are two small gaps on the north side, giving access to the hole itself, which has a diameter of 500-600 yards. The surrounding reef consists mainly of Montastrea annularis, with one or two colonies of Acropora palmata on its inner edge. Other corals present include Agaricia agaricites, Porites astreoides, Mycetophyllia lamarckana and Isophyllastrea rigida. No Acropora cervicornis or finger Porites was seen. The reef-rim rises to sea-level, and the two reef-gaps carry 2½ fathoms water. Two leadline soundings were made in the Blue Hole, one of 464 feet, the other of 472 feet. The first brought up a little very fine calcareous mud, impalpable, creamy-grey in colour, and smelling strongly of hydrogen sulphide, thus suggesting conditions of restricted circulation in the depths. Attempts to obtain large samples with improvised equipment failed.

The most reasonable explanation of this feature is that it is a subaerially eroded sinkhole cut in limestones during a period of karst erosion in the time of glacial low sea-levels (cf. Pearse, Creaser and Hall, 1936). The fact that only a single instance is known from all three outer banks is disturbing for this hypothesis, especially in view of the size and depth of the single instance known. Similar depressions, known as "ocean holes", have long been known, and thus interpreted, in the Bahamas (Agassiz, 1894, 42; Newell and Rigby, 1957, 28), and others have been recently described by Jordan (1954) from the Florida Straits. Doran (1955, 10-12, Map 3) has detailed their occurrence in clusters in the Bight of Acklins, Southeast Bahamas. Here 17 holes have depths ranging from 11 to 198 feet, and areal dimensions of from 20 to 285 feet: all of them much smaller than that on Lighthouse Reef. Doran has described another hole, however, (ibid. 12, Map 11), located south of Grand Caicos, which is "round and about half a mile in diameter, its depth is unknown but greater than 100 feet. This hole is many times greater than others described in the literature and is strangely symmetrical in plan. Although probably also due to subaerial erosion it does not fall into the same pattern as all other ocean holes." The Grand Caicos hole seems very similar to the Blue Hole. I have not been able to discover references to similar holes in Pacific atoll lagoons, though deep depressions of less regular outline do in fact occur, for example on Clipperton almost-atoll (M.-H. Sachet 1962). The term "ocean hole" is well-established in the literature dealing with the Bahamas, but "blue hole" seems to me preferable: the holes need have nothing to do with the ocean, while the term "blue hole" confers an immediate impression of their most striking characteristic.

Land fauna of Lighthouse Reef

The land fauna of Lighthouse Reef is rather better known than that of the other two atolls, and this is particularly true of the avifauna. Salvin (1864) visited Half Moon Cay, Saddle Cay, and Northern Two Cays in April and May 1862; Bond (1954) spent a day on Northern Cay in January 1954; while Verner has visited Half Moon Cay twice, and more briefly Northern Two Cays, during his study of the pink-footed booby colony (Verner, unpublished thesis, 1959). In addition to Mr. Verner, now of the University of Washington, Half Moon Cay has been briefly visited by other members of the Museum of Natural Science, Louisiana State University, under Dr. G.W. Lowery, Jr. Verner makes use of unpublished notes on the birds in the Carnegie Museum of Pittsburgh.

Less is known of the other land fauna. Half Moon Cay was visited by the Field Museum Mandel Caribbean Expedition in 1940, which collected the lizards Anolis sagrei Dumeril and Bibron, Anolis allisoni Barbour, Iguana iguana rhinolopha Wiegmann, and Ctenosaura similis Gray (Schmidt, 1941, 492-494). Verner (1959) records A. sagrei, A. allisoni, Iguana, and Ctenosaura, and adds Phyllodactylus sp. Bregazzi again collected the anolids and the two larger lizards in 1960 (Thorpe and Bregazzi, 1960, 29). Schmidt comments on the restricted distribution of A. allisoni, which is not apparently found on the mainland, but is confined to island locations, its next nearest record being in the Bay Islands. Schmidt also draws attention to the local name of "wish-willy" for Ctenosaura similis, which does not seem to be used elsewhere. It may be suggested here that this name derives from the Mosquito (?) word Illishle, for Young (1842, 47), speaking of the cays around Bonacca, Bay Islands, says that "a species of guana, called illishle, is to be found in abundance on every key." I have not been able to trace any other reference to this word. Ctenosaura grows to lengths of 3-4 feet on Half Moon Cay; it is a drab yellow colour, with black bars on its back. Iguana iguana, locally known as "iguana" or "bamboo chicken", is esteemed for its flesh; it grows rather larger than Ctenosaura, and is a drab red colour, with black bars. Local fishermen capture both Ctenosaura and Iguana with the aid of a string noose on the end of a stick, creeping up behind the animal and slipping the noose over its neck. The swimming ability of Iguana, which excited Oviedo's attention (1526, translation 1959, 18), is remarkable.

No snakes are known from Half Moon Cay, and apart from hermit crabs (Verner, 1959, 8), the only other large land animal is the rat, Rattus rattus, common in the wooded eastern part, where it is a serious coconut pest. According to fishermen, this is the main reason why no attempt is made to cultivate fruit trees on the cay, though it is questionable whether they would thrive in the poor soil anyway. It was probably accidentally introduced by shipwreck in the nineteenth century. Rats are also common on Northern Cay. Here Bond (1954, 2) noted "some iguana-like lizards, sooty black, but otherwise like those mentioned above (i.e. Ctenosaura), and a small black lizard, probably of the genus Anolis." Land crabs reach enormous sizes on Northern Cay, and are said to invade the houses when rain threatens. No mention seems to be made in the literature of the crocodiles of the interior lagoon of Northern Cay; they are unique on the atolls, and have not been identified. They are sufficiently numerous to be hunted. The common crocodile of the Belize area is Crocodilus moreletii (Romney and others, 1959, 319).

The birds of Half Moon Cay are famous, and more is said in the description of this cay of the colony of pink-footed boobies, Sula sula sula, first recorded by Salvin, and studied by Verner. Besides the booby, Verner recorded Fregata magnificens as nesting on Half Moon Cay, and "probably" also Columba leucocephala (bald-pate pigeon) and Crotophaga sulcirostris later in the year; he doubts that other species breed there. A nest with three ospreys (Pandion haliaetus) was seen on Saddle Cay in 1960, and by Bond on Northern Cay in 1954. According to fishermen, the brown pelican, Pelicanus occidentalis, breeds on Hat Cay, but no nests were seen there when that cay was visited in 1961. Salvin saw 40-50 pelicans on Saddle Cay in 1862, and thought they were breeding there.

Verner "recorded 98 species of birds on Half Moon Cay, ... and at least 77 of these were migratory forms. Seventeen of the migratory species were recorded regularly enough to indicate that they winter on or near the cay" (1959, 7). Salvin recorded 10 species from Half Moon, 6 from Saddle Cay, and 3 from Northern Two Cays. Bond in a day's collecting observed 24 species at Northern Cay, of which the most abundant were Fregata magnificens Mathews, Florida caerulea L., Thalasseus maximus maximus Boddaert, Dendroica petechia bryanti Ridgway, Seiurus noveboracensis subsp., and Quiscalus mexicanus mexicanus Gmelin. The hummingbird Anthracothorax prevostii prevostii is recorded from Half Moon Cay by Todd (1942, 294), and according to Bond there is a specimen of the flycatcher Elaenia martinica chinchorrensis Griscom from Half Moon in the British Museum. This species is known elsewhere only from Middle Cay, Glover's Reef, and from Chinchorro Bank.

There are a number of pigs, chickens and dogs on Half Moon Cay, dogs on Long Cay, and pigs, chickens and dogs on Sandbore Cay and Northern Cay. There are no domesticated animals on Hat Cay or Saddle Cay.

The cays of Lighthouse Reef

There are at present six cays on Lighthouse Reef, and no positive indication of the former existence of others. Speer (1771) marks four at the north and four at the south end of the reef, but no subsequent chart confirms this. In addition, in his sailing directions, he describes the existence of five cays at the southern end (1771, 18):

> "When you first make the Southern Four Kays, you will see two Kays bearing about N.W. half N. or N.N.W. The southernmost is a long Kay, called Half Moon Kay; the northernmost is a short Kay, called the N.E. Kay. As you near them you will see a small Kay between these two Kays, and a small Kay to the south end of Half Moon Kay; and some distance to the southward of that Kay, there is a very small round Kay called Hay Kay; and is joined by a Reef to Half Moon Kay."

The Half Moon Kay here referred to is not the cay now so called, but the modern Long Cay (this confusion was noted in Section I). The passage taken literally seems to indicate the existence of a "small Kay" between modern Long Cay and Hat Cay, and if this is so, then it seems most likely that the cay in question is the rounded mangrove appendage at the southern end of Long Cay, the intervening section having been filled with mangroves in the last two centuries. The "N.E. Kay" which Speer refers to is modern Half Moon Cay. Jefferys (1775), in the various editions of his chart, marks "North Two Keys", still so called, including "the

Bushy Spot" (Sandbore Cay) and Tall Trees Key (Northern Cay), and Southern Four Keys. These include "Half Moon Key" (Long Cay), "Easternmost Key" (Half Moon Cay), Hat Cay, and a large cay north of the present Long Cay, termed "North Key". This is presumably modern Saddle Cay. All these were charted by Owen in 1830, and still exist.

These cays vary greatly in size, from Saddle Cay, only a few yards in diameter, to Northern Cay, which covers over $2\frac{1}{4}$ square miles. Northern Cay and Long Cay are large, and have considerable swampy areas; Half Moon Cay is a large sand and shingle cay; and Saddle and Hat Cays are smaller sandy cays with varied vegetation. Vermeer states that "On Lighthouse Reef bank, the other deep sea bank which I visited, only sand cays occurred. In this case, insufficient protection of any part of the bank appears to account for the absence of mangrove cays" (1959, 40). This may apply to Half Moon Cay and Sandbore Cay, but not to the cays of the atoll taken as a whole. Rough calculations based on the detailed maps show that of a total land area on the atoll of rather more than 2,000 acres, less than one-fifth is dry land, and the rest high mangrove swamp, lagoon, and dead and dying mangrove. The percentage of dry land is greatest on the smaller cays, while the greater part of the two largest cays is mangrove swamp. All six cays were visited, some several times, in 1960 and 1961. They are here described, with detailed maps, which in the case of the two large cays have been partly plotted from aerial photographs.

Sandbore Cay

Sandbore Cay (fig. 28) is the most northerly island on Lighthouse Reef, and the smallest of the Northern Two Cays. It is located at the northern end of the long eastern reef, at the Northern Entrance of the lagoon, and is situated at the leeward edge of the reef-flat, about 1,000 yards back from the reef-edge. It is unfortunately obscured by clouds on available air photographs. Salvin visited it in 1862, Verner in 1958, and our party in April, 1960, and July, 1961.

The cay has a more complex shape than usual in the British Honduras sand cays, and this probably results from the speed of water currents sweeping across the reef-flat and refracting through the northern entrance, and the quantity of debris supplied from the exposed eastern reef. In outline, the island consists of two spits extending lagoonward from a "core" at the eastern end; the northernmost spit is short and wide, the southernmost long and narrow. They enclose a lagoon 4-5 feet deep near its mouth, shoaling shoreward, part of which has been enclosed to make a fish trap, thus further restricting circulation. The gross outline of the cay is triangular: the north side of the island, ignoring irregularities, is some 400 yards long, the south shore 500 yards, and the third side of the triangle, formed by the open mouth of the lagoon on the west side, about 300 yards long. The southern spit varies in width from 20 to 65 yards, while the northern spit forms a rectangular block of land some 150 yards square. A third, small peninsula extends into the lagoon from the north side.

The whole island is built of sand, and none of it rises more than three feet above the sea. The greatest elevations are found along the southeast margins of the south shore (3 feet) and the north shore of the north spit (2-3 feet); the rest of the island lies between 1 and $2\frac{1}{2}$ feet above sea-level. A little shingle is found in places on the crest of the south shore sand-ridge, but it is quantitatively of small importance in the build of the cay. The sand is a medium to coarse coral-algal sand, with fine sand and silt round the margins of the lagoon. Beachrock is exposed at two points: one, on the south shore, consists of a single line about 50 yards long and 18 inches wide, dipping slightly seaward, just exposed at low tide, on a very shallow sandy bottom, and difficult to see; the other consists of two, perhaps three, subdued lines of rock at the east end of the cay, both dipping north. Both rocks are moderately well cemented calcarenites forming a rather thin surface layer, and their significance is discussed later.

The vegetation of the cay is of interest, for while Jefferys (1775) called it "the Bushy Spot", and though much has been cleared for coconuts, large areas are still covered by little-disturbed growth, especially on the spits. At the eastern end of the south shore is a tall growth of Suriana maritima and some Avicennia, with an undercover of Euphorbia. Further west along the same shore Tournefortia gnaphalodes, Conocarpus erectus, tall grasses and Euphorbia occupy the ridge crest, and Suriana in particular occurs sporadically right to the end of the spit. Much of the north shore at its eastern end has been cleared, but along the rest Suriana is again dominant, with low Tournefortia bushes along the northwest shore. Suriana is scattered over the interior of the northern spit, but the only other area of high woody vegetation is near the head of the lagoon on its north side, where there is a thicket, mainly of Conocarpus erectus, with some Suriana and Coccoloba uvifera. The Conocarpus reaches a height of 20-25 feet. The rest of the vegetation is in broad view simply distributed. Along the southern spit we find patches of tall grasses, Ipomoea, Euphorbia, and towards the end a large area of Ambrosia hispida, passing seaward into a mixed zone of Ambrosia, Ipomoea and grasses. On the broad northern spit, there is an inner (eastern) zone of Ambrosia, tall grasses such as Andropogon glomeratus, and lower grasses such as Sporobolus virginicus; and in the outer (western) zone, an area in which Andropogon is the dominant member, with some Ambrosia, Ipomoea being locally dominant along the shore. The extent of Ambrosia found here is somewhat unusual on the sand cays.

There is some evidence of erosion and aggradation of the shores of the cay. Thus the eastern part of the north shore is marked by fallen and leaning coconut trees, and slight cliffing extends westwards beneath the Suriana hedge. On the south shore, slight retreat is shown by the beachrock described. The ends of both spits seem to be expanding lagoonward, particularly so in the case of the northern spit. Here the northwestern and western shore is formed by a broad sand beach, 10-20 yards wide, thrown up in concentric ridges, colonised at its inner edge by low, young Tournefortia, and with tendrils of Ipomoea beginning to extend across it. The two prominent "tongues" extending southwards from this spit represent earlier stages in its growth westwards.

The most striking evidence of erosion, however, is at the east end of the cay. Here a lighthouse was built on dry land in 1885. Since that time, the shore has been gradually pushed back until now the base of the lighthouse stands 75-80 yards out from the shore—an average retreat over 75 years of at least a yard a year. How far back from the sand shore of the cay stood the lighthouse when it was built is not known. However, as a result of this retreat a concrete walk was built to connect lighthouse and cay. This extension is 20 yards long, an average retreat, over the last 15 years, of 4 feet per year, or rather faster than the average for 1885-1945 (slightly under a yard a year). The beachrock previously mentioned at the east end of the island, just north of the concrete walk, clearly dates from the last half century. The outline of the now-eroded cay is clearly seen from the top of the lighthouse as an area of shoal sand, marked on the map. There is a hint of more beachrock immediately east of the light, but the waves break with some force on its foundation and further investigation was not possible.

This is the only instance on this coast where the almost universal lagoonward retreat of sand cays can be dated with accuracy. It is noteworthy that on Owen's 1830 MS chart, Sandbore Cay is shown as a long thin island, without any prominent recurved spits or enclosed lagoon, and thus the present outline has probably developed entirely since that time. The retreat of the east shore and progradation of the two western spits would be interesting to observe over a period of years. One may suggest that, while this retreat has been in progress for some considerable time, it may shortly come to an end, for the cay has very nearly reached the lagoonward limit of the reef-flat on which it stands, and will soon have to advance into deeper water. This will at least retard the western extension of the sandspits, and if erosion continues on the east side, then the eastern part of the cay will gradually be pushed further and further onto the remains of the sandspits, the lagoon will disappear, and ultimately the cay itself will be washed off the flat into the lagoon, leaving the solitary lighthouse as its lone memorial. This could well happen within the next 500 years, if present trends continue. This cay, therefore, though by no means a small one compared to other sand cays on the reefs, vividly illustrates the ephemeral nature of the simple accumulations of unconsolidated reef debris, which basically, is all that sand cays are.

Northern Cay

Northern Cay (fig. 29) is by far the largest island on Lighthouse Reef, and though of quite different shape and larger, it has several features of physiography in common with Long Cay, at the southern end of the Reef. With the exceptions of the ornithologists Salvin and Bond, Northern Cay has not been visited by naturalists and has never been described. It has a maximum east-west extent (along its south side) of over 3300 yards, and a maximum north-south extent (toward the east side of the island) of a little over 3,000 yards. The total area of the cay is a little over 7 million square yards (1460 acres or 2¼ square miles);

of this, approximately $1\frac{1}{4}$ million square yards, or a little more than a fifth, is interior lagoon and standing water; approximately 3.8 million square yards, or about three-fifths, is under mangrove and swamp; and the rest, only one fifth of the whole, is dry land, mainly under coconuts.

The north and west sides of the island approach close to the west reef of the atoll, which here trends NE-SW. The reef crest lies at an average distance of 600 yards from the cay, and the reef-flat at its narrowest is still over 400 yards wide. It is shallow and sandy, generally carrying less than half a fathom of water, and very shoal for some distance from the cay. The reef itself is marked by small breaking waves and a number of projecting blocks of dead coral, which serve to locate it accurately from the shore. The reef-facing shore itself consists of a number of broad embayments and promontories, the deepest embayment being the most northerly, where the shore begins to diverge eastwards from the reef. This shore is sandy throughout and overlooks (except in the northern embayment) a broad low intertidal ridge, covered with Thalassia and worm mounds, and exposed at low tide. A similar feature is also found to the south of the island, fringing the mangrove shore. The sand shore itself is so extensive that it will be described in three parts: the western sand shore, the sand shore of the northern embayment, and the eastern sand shore.

The western sand shore, overlooking the drying Thalassia ridge, extends for 2600 yards from the southwest corner of the cay. It is undercut by wave action for almost the whole of its length, thus forming a cliff whose height depends on the height of the cay surface inland from the beach. Near the southwest corner, the cliff is subdued, and the cay surface only 2-3 feet above the sea; the Thalassia ridge in front of the cliff is scattered with small Rhizophora seedlings. As the beach is followed northwards, however, the height of the cliff increases, reaching a maximum of 7-8 feet near the middle of its extent, and not falling below five feet north of this point. The "cliff" is not always an abrupt feature. Generally a beach of fresh soft sand rises gently from low water level to the base of a steeper slope 3-5 yards away; and while the cliff is in places a vertical wall of sand, it is more usually a rounded, subdued feature. It is doubtful whether much erosion is now going on along this sheltered shore, and the cliff at the present time may be a fairly stable feature. The most interesting feature of this shore is its relict beachrock (BR I), intermittently outcropping along it for about 1500 yards. All this beachrock maintains a constant altitude of about 1 foot above low tide level at the base of its outer edge. It varies in thickness from 6-9 inches, and is deeply pitted and eroded. Its surface is blue-black in colour, presumably through algal encrustation, and passes landwards under the cliff sands for an unknown distance. Because of the depth of the overlying sand it was impossible to trench and find out how far it extended. At many places along its outcrop the underlying sands have been sapped away, and broken slabs several feet long lie on the beach. The surface of the rock recalls, on a much smaller scale, the sharp irregular topography of exposed reefrock, such as that on the north Jamaican coast. The rock itself is, for the most part, a well-consolidated calcarenite, ringing to the hammer, but much of the induration is surficial, and the sandstone within rather friable. This is the most extensive outcrop of beachrock found on the British Honduras coast. Because of its extent, and on account of its slight raised elevation above the sea, the question arises as to whether it is a true intertidal beachrock or a cay sandstone. Most of the outcrops show some dip to seaward, and it is thus thought to be a beachrock, possibly developed during a very slightly higher sea-level than the present (i.e. predating a small uplift of Lighthouse Reef itself).

The sand shores of the northern bay are gentler than those on the west side; cliffing is generally absent on the west side of the bay, and the beach of fresh white sand rises gently to a crest about 7-8 yards from the sea. The nearshore Thalassia ridge is not developed in this bay, but submerged Thalassia and other plants are common on the bay floor. The height of the beach crest varies, but averages 5-6 feet above sea-level. The extensive raised beachrock of the west shore is not found in this bay; the only example of beachrock occurs in a small indentation on the east side of the bay, where it is clearly now in the process of formation. At the head of the indentation, and slightly above low tide level (drying at low tide), is a small area of fine indurated sand some 2 feet long and 1 foot wide, passing landward under beach sands. The induration is superficial, forming a crust of soft beachrock 1-2 inches thick. The layer can be traced under the beachsands for over a foot, where it appears to be rather harder than in the exposed area. The induration is sufficient to hold the layer as a whole together, but once a specimen is broken off, it is difficult to prevent it crumbling. The beachrock has a slight dip to seaward, but less than that of the beach itself.

The east side of this bay, like the west coast, is being undercut. The shore itself bounds on one side a triangular-shaped peninsula, jutting out to the North Point (here so called) of the cay. This peninsula, as will be described, is largely built of dune sands, and the shore cliffing exposes sections of fine, cross-bedded dune-sands, permeated by fine roots, and sufficiently cohesive to maintain a vertical wall as the cliff cuts back. The cliff can be traced as a continuous feature right round the peninsula, but is not everywhere exposed to erosion. In detailed form, the beach consists of a number of cusps of new white sand, alternating with shallow embayments, at the head of which the sea is attacking the cliff. Where the cusps occur the cliff is temporarily protected from wave attack. Its average height in this area is 3-4 feet.

At North Point itself, the cliff seems to have been protected for some time. Several concentric ridges of fresh sand have built out below the cliff (here only 1-1½ feet high), and air photographs show that a broad tongue of sediment extends reefward for some distance from the Point itself. The ridges of new sand are only 1½-2 feet high, though broad, but it is interesting to note that similar ridges form part of the peninsula itself, inland from the line of cliffing, which roughly delineates the vegetated area. At least three distinct concentric ridges can be traced inland from the cliff, and another two seaward from it. The ridges pass landward into the peninsula dune-sands.

The eastern sand shore extends along the eastern side of the northern peninsula, and then southwards for about 1100 yards altogether. In the north the peninsula is low (where built of the concentric ridges), clearly defined by an old cliff line, with a bank of clean white sand forming the present shore. The area immediately to seaward is thickly covered with Thalassia. Further south, beyond the limits of the peninsula, the cay surface lies at a higher level, the shore is cliffed (3-4 feet high) and the beach below it very narrow (2-3 feet wide). Offshore the bottom is very thickly covered with grasses and algae, with many small black snails (Batillaria?); as one moves south, the number of Rhizophora seedlings near the shore increases. There are two areas of beachrock along this section of the coast. BR III occurs just south of the small pier on this side of the island. It consists of three small outcrops of well-cemented sand, 1-2 feet wide, dipping seaward, and just submerged at low tide. The surrounding area is thickly covered with Thalassia, and the beachrock is not easy to see from the shore. The second outcrop, BR IV, is found near the southern limit of the eastern beach, and is remarkably similar to BR I, so extensively exposed on the opposite shore of the island. For a distance of 4-5 yards the rock outcrops in the face of the eroded sand-cliff, 12-15 inches above the sea; it is well-cemented, rings to the hammer, and is much eroded. The exposure is 6-9 inches in thickness. The resemblance between BR I and BR IV is probably significant: and the two are probably of the same age and mode of development. BR IV has no discernible dip, lending support to the cay sandstone explanation of its origin.

Little can be said of the rest of the eastern coast and the whole southern coast of the island, for though they were seen at close quarters on many occasions in 1960 and 1961, they consist wholly of Rhizophora mangle, standing in water 1-2 feet deep. They could not be mapped, and the outline shown on the map of the cay is taken from air photographs CAE-6-199 and 200. At no point on this mangrove coast is any sand beach to be seen, and no landing was made along it; at one point near the southeast corner, two lone coconut trees raise their heads above the mangrove some ten yards from the shore, so that a drying ridge some yards within the mangrove probably separates the sea from the cay interior over much of the mangrove shore. The mangrove is mature, and 20-25 feet high.

Northern Cay covers such a large area that it was impossible to see more than a fraction of its interior in the time available. In particular, no visit was made to the interior lagoons, though they were seen from the air. These are said to be 5-7 feet deep, and can be approached through the mangrove from the east coast with very shallow draught boats (dories), or from the northern sand area. They are inhabited by an unidentified crocodile. Far too little is known also of the interior of the northern sand rim, and its vegetation cover. It has an average width of about 200 yards, reaching a maximum width on the west side of the island of over 400 yards. The whole sand area has been planted at some time, deliberately or naturally, with coconuts, but in recent years little attempt has been made to keep the cocals clean, and ground vegetation proliferates, especially along the west side of the cay remote from the settlement in the northern embayment. The impenetrable tangle of vegetation combines with a large number of biting sandflies to restrict access to the interior. On the cleared, low-lying areas, such as the northern peninsula, prostrate creepers and grasses (Euphorbia, Sesuvium, Sporobolus) are most important. Ambrosia hispida also covers considerable areas. Round the exposed western margin of the sandy area, one finds, in addition to coconuts and tall grasses (Andropogon), Tournefortia gnaphalodes, Suriana maritima, Conocarpus erectus, and very infrequently Coccoloba uvifera. On the eastern shore, Coccoloba is much more widespread, though often stunted, and with Suriana and Conocarpus it is the dominant tree of the sand-cliff top. Rhizophora mangle, straying from the main mangrove areas, and Avicennia are found in places along the sand area margins, particularly close to the mangrove zones.

Because of lack of time, no detailed levelling could be done, except on the northern peninsula. As mentioned, this consists of a number of concentric ridges, the innermost vegetated with creepers and grasses, surrounding an internal area of vegetated fixed dunes. Much of the peninsula is cleared of all except ground vegetation, and the irregular steep hummocks of the dunes can be clearly seen. The line of section, through the middle of the peninsula from north to south, includes four dune ridges, rising respectively to elevations of 5, 5, $7\frac{1}{2}$ and $10\frac{1}{2}$ feet above sea-level. These are maximum elevations for the particular ridge; the fourth ridge is the highest on the peninsula, and it is unlikely that any higher point is found on the island. The outermost of the dune ridges has dammed up a small lenticular pool of stagnant water on its landward side. With the exception of Ambergris Cay on the Barrier Reef (not a true cay, in the strict sense, but a peninsula), this area of dune development at the northeast, windward side of the Northern Cay is unique on the British Honduras reefs, for dunes do not normally occur on these sand cays.

There are two or three small huts at the northeast side of the island, used by the cocal caretakers; one of these, near the pier, is in ruins, and this, combined with the unusual bare dune hummocks, gives a desolate, abandoned appearance at first sight. Well-water is available, but the men rely mainly on rain-water collected in drums and vats. The owner of the cay, Mrs. Ben Stuart of Belize, told us of historical remains in the form of large earthenware containers (?) about 4 feet tall on the cay, but unfortunately these were not seen during our visit. The possibilities for further work on this cay, both for physiographers and zoologists, are immense, and more than any other island on the three British Honduras atolls, Northern Cay would repay more detailed investigations than we had the time to make.

Saddle Cay

Saddle Cay is situated on the east reef of Lighthouse Reef, 2 3/4 miles north of Half Moon Cay, at the inner edge of the main reef-flat, here over 1500 yards wide. Its location is rather inexplicable, for there are no gaps in the east reef at this point, and no particular reason why a cay should form here. It may result from some irregularity in the rock floor dating from glacial times, and serving as a basis for debris accumulation. The present cay is now only a remnant of a former larger island,

and in fact is too small to be usefully shown on a map. It stands on a larger arcuate sand shoal, convex to the north, and as seen on air photographs over 200 yards long. The dry land area is roughly circular and has a diameter of 10 yards; it is sandy with some small shingle, and does not rise more than 2 feet above sea-level. There are two small areas of sandy beach, thickly covered with Sesuvium, and with mounds of dead Thalassia cast up at the limit of wave action. Sesuvium blankets the greater part of the cay area. To a very large extent the island consists simply of half a dozen mangrove trees, partly on dry land, partly in water. On the east and south sides these include Rhizophora mangle; and on drier land on the east side, tall gnarled Avicennia. The vegetation on the west side of the sand patch is lower and less dense--Avicennia and Conocarpus, with a ground mat of Sesuvium, and two tall coconuts. A third coconut only a few years old is growing near the shore.

The cay was formerly more extensive, and has been much eroded in recent years. Before 1931 it was some 50 yards long, but was reduced to half this length in the 1931 hurricane, and by half again in 1942. Other hurricanes have progressively destroyed the land area until only a clump of trees remains. A large hurricane passing over the cay now would probably destroy it altogether. It is still possible to trace the extent of the older cay in a submerged sand shoal. This extends for about 50 yards in a broad curve eastwards from the cay, and normally carries 6-12 inches of water. The bottom is very soft, covered with worm mounds, and one or two tree trunks are stranded on it. West of the cay there is a similar but much shorter submerged spit, a deeper scour hole, and one or two remnants of a submerged sand-flat beyond. On this western spit two large tree-trunks have been washed up, and ospreys had built a nest there and were breeding in 1960. The nest was nearly 3 feet across, built of sticks and some coral rubble.

One of the first accounts of the British Honduras cays concerns Saddle Cay, for it appears that Nathaniel Uring spent several days here after being shipwrecked in February 1720. He does not name the cay, and it is impossible to be certain, but Jefferys (1775) marks the wreck of Uring's ship, the Bangor, on Lighthouse Reef, and Saddle Cay is the nearest cay to this. Uring's account is here quoted; the cay on which he lived is thought to be Saddle Cay, and that visited for water Half Moon Cay. It is interesting to note that on Jefferys' map Saddle Cay is shown as an island comparable in size to Half Moon Cay.

Uring's account of Saddle Cay, 1720

> "When it grew light, we found ourselves upon a Shoal of Rocks about Two Miles from any dry Land, there being a small flat Island or Key at that Distance, and farther off we saw several more little low Islands. There was near a Foot Water upon the Reef where we were lost, the Surge of the Sea leaving it bare at time, some perched Rocks appearing above Water... the shoalest Part of it being about One Hundred and Fifty Yards broad, and then the Water deepen'd. ...

> We got ashore some Goods and Provisions, and put them into the Long-Boat, and carried them to the nearest Island. ... In the Morning, we searched the Island for fresh Water: and by the Footing of Birds we discovered a small Pool under the Cover of a Tree, at which we were exceeding glad; but it being only Rain Water, we drank it out in a very few Days. ...
>
> When we had been about Ten Days, and finding our Water grew scant, we went to the next Island, where we found Plenty, with which we fill'd our Cask; and we likewise found there several Cocoa Nut Trees full of Fruit; we gathered some of the Nuts, and returned to our Island again, where I planted several. We found one Tree growing on it when we landed, but too young to bear Fruit."

Tiring of his "desart Island", Uring decided to make a raft; "there being a great many dry Trees on the Island, we went heartily to work to cut them down; but being Mangroves which is hard and heavy, I suspected they were not fit for our Purpose, and therefore put one of them into the Water to see if it would float, and found it would hardly swim." He then used wreckage from the Bangor, completed the raft, and departed, "leaving on the Island five laying Hens and a Cock to breed, we set forward on the Afternoon, and by Night reached the next Island, where we remained all Night, and in the Morning set forward again, but found a good deal of Difficulty in passing between that Island and a Reef of Rocks, till we came onto the open Sea... (and) made Tournef." (Uring, 1726; from the 1928 edition, pages 234-240). Uring reached Belize safely, and in his book includes many useful tips on raft-building for mariners in similar distressing situations.

Half Moon Cay

Half Moon Cay (fig. 30) is the largest simple sand cay on Lighthouse Reef and one of the largest on the British Honduras coast. It is located on the almost unbroken eastern reef of Lighouthouse Reef, at the point where the reef turns sharply westwards in a prominent elbow, sweeping southwestwards to form the half-moon-shaped Southeast Bight. To the north of the cay the east reef extends uninterruptedly, with a smoothly scalloped plan, for 18 miles; immediately westwards, the east reef is broken by two gaps each a thousand yards wide. The cay lies with its long axis parallel to the reef forming the northern edge of the southeast bight, and hence transverse to the main eastern reef-flat, here some 2,000 yards wide. Immediately southeast of the cay, the bank is prolonged by a submarine spur, visible on air photographs (CAE-6-176), carrying 7 fathoms of water, but the vigorously growing reef on this spur does not reach the surface as a continuous reef.

It has been visited by the ornithologists Salvin and Verner on account of its pink-footed booby colony, and Verner in particular (1959, 3-8) has given a fairly full and valuable description of it, with particular reference to vegetation. He also produced a sketch-map of the cay on a scale of 1:6000, showing the location of broadleaf forest and the booby colony. Vermeer also visited the cay in 1957, and gives a brief general description (1959, 97-103). Ten days were spent on this cay in April 1960, and a similar period in May-June 1961. The cay was mapped in detail, 32 lines of levels were surveyed across it, and subsequently used for a contour map, plants were collected on both occasions, mainly from the area outside the high broad-leaf forest, and 130 sediment samples were taken for later analysis. Reef transects made near the cay have already been described (transect C, Section IV). Much of this material, especially the sediments, has yet to be studied, and this account is thus a general one, similar in purpose to the other cay descriptions in this paper. It is hoped to produce a more detailed report on Half Moon Cay at a later date. The cay was photographed from the air in July 1961.

While the island may be thought of as forming a crescent or halfmoon shape concave towards the lagoon, it may be described more easily in terms of two units. The southwest segment of the cay consists of a quadrilateral 700 yards long, with a uniform width of 200 yards. The south, west and north shores of this quadrilateral are linear in plan. Extending northeastwards from this part of the cay is a tapering peninsula 650 yards long and over 250 yards wide where it adjoins the first segment. This peninsula trends northeastwards for all but the last 200 yards of its length, where it curves towards the east, and comes to an end in a series of steep shingle ridges overlooking the eastern reef. While these two segments are distinguished primarily for ease in description and imply no physiographic or structural distinction, they are clearly evident to the student of vegetation: the first, rectangular segment is covered with dense low broadleaf forest and coconut thicket, while the second peninsular segment has been completely cleared for coconut plantations.

Beaches

The cay is highest along its south and southeast shores, fronting the ocean, and both of these shores overlook expanses of beachrock and conglomerate (fig. 31). Of these shores, that facing southeast (forming the south shore of the peninsula) is most exposed to the prevailing easterlies; while the shore facing slightly west of south (forming the south shore of the main body of the cay) is accessible only to the southeasterlies and to waves refracting round the east reef elbow. The least exposed southern shore is hence lower than the southeastern. At the same time, since it overlooks fairly shallow water immediately offshore, with a profuse growth of rough water corals (Acropora palmata, A. cervicornis, Millepora), on which short period waves continually break, the lower shore is built of coarser material than the higher southeastern shore. The effects of exposure are also clearly visible in the changing nature of the shingle ridge along the shore itself, for wave action is strongest at its eastern end, and decreases westwards. Most observed waves on this southern shore approached from the southeast at an angle of 45° to it, and had lost much of their force by the time they reached the western end. Thus, while the whole south shore is built of shingle, it rises to a height of 7 feet near the eastern end and declines eastwards to heights of 4 feet and less. At least three "populations" of sediments constitute the ridge: an upper zone of blackened, pitted coral blocks, 6-15 inches in diameter; an intermediate zone of white, relatively unweathered, finer coral debris, 1-6 inches in longest diameter; and a lower zone with many larger blocks, often 1-2 feet across, of yellow broken coral, lying at and above sea-level. These zones are distinguished, not only by size differences, but by colour, for the yellow, white and black zones occur constantly. A fourth "population" consists of small pockets of coarse sand at the foot of the shingle ridge, the largest being located near the middle of the south shore. The corals of the white zone are all relatively fresh and unbroken and include A. cervicornis, A. palmata, Montastrea annularis, M. cavernosa, Diploria strigosa, D. labyrinthiformis, D. clivosa, Siderastrea radians, S. siderea, Porites porites and Meandrina meandrites, with still-segmented Halimeda and many Strombus shells. These figures and composition data refer to the eastern section of the ridge; westwards, the proportion of coarser material lessens, and the species-composition of the ridge changes, presumably reflecting changes in the offshore reef. A. palmata, for example, becomes less important, and the smaller corals (Siderastrea, Porites, Favia) more so. The upper part of the ridge throughout its length is covered by a low, spray-swept "hedge" of broadleaf trees. Inward from the vegetation margin the ridge rises to a crest, and slopes gently backwards; the uppermost section of the ridge, and the backslope, consists mainly of coarse grey sand and scattered large blocks.

Sediment composition of the more exposed southeast shore varies from coarse sand through small coral shingle to coarse shingle and large blocks several feet across. The floor of the southeast bay shelves steeply to depths of more than a fathom, and a few hundred yards from shore reaches constant depths of 7 fathoms on the southeast submarine spur. Coral growth in the bay is patchy, though locally profuse. Most of the bay is sand-floored, and the water nearshore is so turbid with suspended sand that visibility is nil; the nearshore reef patches, which are concentrated near the western end of the bay, consist mainly of Acropora cervicornis, massive A. palmata and Porites astreoides; while seawards in deeper water the reef consists of very large tree-like A. palmata. The absence of a continuous fringe of reef, in contrast to the south shore, probably results from the amount of sand in suspension. Sediment distribution on the beach is largely controlled by the distribution of beachrock at its base; generally, where beachrock is well-exposed, the beach consists of sand and small shingle; where it is not developed, the waves have access to the beach itself and have thrown up ridges of larger shingle. In places the beachrock itself has been torn up and thrown up the beach in large blocks. The distribution of these types of sediment is shown on the map. The sediment composition reflects that of the reefs: the finer shingle is overwhelmingly short, cylindrical sticks of A. cervicornis, the larger shingle slabby plates of A. palmata. In places Strombus shells form 30-40% of the larger-shingle ridge. Taken as a whole, however, the beach is sandy, especially at the southeast corner of the cay, where a double sand ridge rises to a maximum height of 9 feet above sea-level. According to Vermeer, "the cay rises to a height of from 15 to 18 feet along the seaward face" (1959, 97), but this is only an estimate. The southeast ridge-crest is almost everywhere more than 7 feet above the sea, and towards its southwest and northeast ends everywhere above 8 feet. From this general crestline isolated mounds rise higher, and can clearly be seen in profile from the backslope of the ridge. Two areas rise above 9 feet (a third is located at the extreme southern point), and the highest part of the island, 10.5 feet above the sea, is found on one of these, approximately 120 yards west of the lighthouse.

At the eastern end of the island, exposed to the easterlies and fronting the eastern reef, three concentric shingle ridges (yellow, white and grey-black zones) rise to a height of 6 feet above the sea. This shingle complex extends for 80 yards from the east point along the southern shore of the peninsula, and for 250 yards along its north shore, reflecting the unequal exposure of north and south sides. The full suite of three ridges is found only near the east point itself: along most of the north shore, the ridge is a single feature gradually being pushed back across a lower sand shore; it has a height of $2\frac{1}{2}$-3 feet only. The size of the shingle at the east point is broadly comparable with that on the south shore, and may have similar origins. It is thought that the white zone consists of small material continually thrown up by day-to-day wave activity and storm action; the larger blocks of the yellow zone consist of dead corals torn loose by larger waves which can roll them across the reef-flat but lack the power to throw them up the beach; while the large eroded fragments of the black zone are cast up beyond the reach of day-to-day waves by exceptional storms and hurricanes, and subsequently are exposed to weathering and degradation.

With the exception of the low shingle ridge along its extreme eastern end, the northern side of the cay is formed by a wide, gentle sand beach, overlooking a bay with 1-2 fathoms water. This bay continues northwards as the main eastern reef-flat, across which strong currents flow transversely. Except in time of northers, when material is thrown up along the beach, the bay is calm and sheltered. Most of its floor is covered with thick Thalassia, with abundant scattered colonies of large Manicina areolata, and very occasional Porites furcata and Siderastrea radians. Holothurians are numerous toward the east side, near the main reef. The most abundant reef in the bay, paradoxically, is at its west side, where waves refract round from the south side of the island. Here small reef-patches are developed, consisting of Porites astreoides, Montastrea annularis, M. cavernosa and Siderastrea siderea. The water in the bay itself, where circulation is restricted, becomes much overheated, and in places near the shore is scum-covered and rather stagnant, with luxuriant bottom growths of green algae. The beach round the bay is everywhere low and sandy, and no beachrock is exposed. The northwest-facing shore of the bay (most protected) appears to be prograding; but the northeast-facing shore, though also low, is suffering wave erosion, for it is fringed by fallen and dangerously leaning coconut trees, the beach is narrow, and a cliff has been formed about a foot high.

Finally, the western shore, exposed only to refracted waves produced by the southeasterlies. It is highest at its south end (2-3 feet), where it is formed by the tapering end of the south shore ridge, and declines northwards. The shore forms a slight bay, containing a broad beach of fresh, unconsolidated sand, on which vegetation is just beginning to encroach.

Cay surface

In view of the height of the seaward ridges, the greater part of Half Moon Cay lies at a surprisingly low level; the narrowness of the belt rising above 6 feet is apparent from the map--it generally forms less than one quarter the width of the cay. It is perhaps misleading to term the slope of the cay surface "gradual", as Vermeer does, as this may imply straightness. The backslope of the ridges is in fact concave: large areas on the leeward side lie below 3 feet, and the surface rises steeply from this lower level to the ridge crest within an average distance of 30 yards. The contouring of the cay surface, while liable to error in the vegetated areas, shows a pattern of alternating lobes, extending back from the ridges, and intervening depressions; though it is probably too simplified a view to regard the lobes simply as growth stages in the lateral extension of the cay, as in the evolution of sand spits. The intervening depressions often form closed basins, cut off from the northern bay by the low sand mound along its shore. One of these depressions, locally known as "mudhole", permanently holds wet soil and water; another (near the middle of the main segment of the cay) contains water only after heavy rain. Verner (1959, 4) maps both as mudholes, but at the time of our visits the western one was dry. On the other hand, small areas of standing water have been seen in other parts of the leeward side of the cay, but persist for only a short time after rain. The main mudhole is now some 10 yards long and 6 yards wide, and it seems that an effort has been made to fill it in in recent years with coconut trash and husks. The "soil" in the hole is an extremely black organic material (in American usage, a "muck"), which augering in several places showed to be only 6 inches in thickness, underlain by rather evil-smelling, white, unaltered coarse sand.

The cay surface, apart from the sediment variations on the beaches, consists only of coarse coral-algal sand, with greater or less admixture of fine coral debris (see Section VIII for notes on quantitatively unimportant non-limestone constituents). A distinction may be made between the eastern cleared area and the western wooded one. The east end is under coconuts with no ground cover; the soil is a scarcely altered coral sand with added humus, forming a brown layer 25-30 inches thick, gradually grading into coral sand with no added humus. The soil loses much of its colour on drying, and seems comparable to the Shioya Series of the Pacific (Stone 1951, Fosberg 1954). The soils of the western end have a higher humus content and contain more large coral debris. In places this is sufficient to form an actual ridge. The pattern of surface shingle on this part of the cay cannot be traced until the higher vegetation is removed, but it must either relate to an earlier period in the cay's development and mark a former shoreline, or be a form of "rampart wash". Its distribution is shown as far as possible on the map; it lies at 3-5 feet above the sea.

Specimens of the more humic soil were taken on the north and south sides of the vegetated area and await analysis. Near the geographical centre of the cay occurs yet a third main soil type. Here, under a small area of high thicket, the soil is a rich brown humus, in places only a few centimetres thick. Wherever excavated, it reveals an irregular surface of yellow, speckled, seemingly rather decayed rock of uncertain origin. This layer seems continuous and solid; it is impossible to delimit it because of the very dense vegetation, but it probably covers an area of at least 100 yards in length and 50 yards in width. The matrix of the rock includes a number of recognisable corals similar to those scattered over the adjacent cay surface, mainly Montastrea annularis, M. cavernosa and a Diploria. The cay surface here lies at approximately 4 feet above the sea. The hardpan is either the upper surface of a block of upraised reefrock, in which case it would have important implications for the history of the cay, or it is a subsequent alteration product of the cay surface itself. In this connection it bears at least a superficial resemblance to Fosberg's Jemo Series (Fosberg 1954, 101-106), where the induration results from phosphatic cementation, associated with surface guano staining. The western woodlands on Half Moon provide a nesting ground for many thousands of birds, and the ground is stained over large areas with guano. However, in areas where guano staining is heaviest, no cementation is found. Verner comments (1959, 8): "The Hermit Crabs and Soldier Crabs figure prominently in the booby colony... They eat everthing... as well as the excrement of the birds. This latter activity combined with the porous substrate and high annual rainfall on Half Moon Cay, accounts for the absence of guano accumulation in the booby colony." Analyses of this rock are awaited with interest.

In the cleared eastern part of the island, wind erosion of the sand surface seems important. Many of the boles of the coconuts are exposed on the surface, and stand above its general level, and in many places a mat of fine coconut roots can be seen. A moderate ground cover would probably halt this, though it would undeniably detract from the great beauty of the cay itself.

Coast beachrock and conglomerates

The areas of beachrock and conglomerate on the seaward side of the cay are shown in detail on the map. They were noted by Vermeer (1959, 99-100), who distinguished

(a) "a coral platform (which) extends for as much as 100 yards (to windward of the cay). On the platform, pieces of reef rock are exposed at low tide, and in some cases broken pieces of reef rock thrown up on the platform and in other cases an exposed part of the platform itself. None of these pieces is more than six or eight inches above the water level"; and

(b) "five separate areas of a greyish sandstone or beach rock ... (which) consists of separate slabs of poorly cemented but clearly stratified beds of sandstone. Individual slabs of beach rock are generally from 4 to 6 feet long and about a foot thick and compare in hardness to a poorly cemented sandstone."

These are illustrated in Vermeer's Figures 24 and 22, 23 and 26 respectively. In this section the exposures will be described, and the difficulty of drawing very clear distinctions will be apparent. Seymour Sewell, among others, has stressed the importance of clearly differentiating between several types of lithified material on reef islands; and it is one of the more vexing problems of Half Moon Cay that (with the exception of the more extreme members of the spectrum of rock types) it is difficult, if not impossible, to do this.

The most extensive area of rock is at the southernmost point of the cay, where it extends in a continuous exposure for over 200 yards, and projects for 75 yards seaward of the cay shore itself. It here forms a platform, with a maximum width of 30 yards, its upper surface slightly above low tide level, on which waves break heavily. It is separated northwards by channels at least 5 feet deep from similar areas of rock, lying at the same level, again pounded by waves. This is the exposure described by Vermeer as the "coral platform" and shown in his Figure 24. The upper surface of the rock is deeply pitted and eroded into sharp ridges and depressions; it is coloured yellow-green and is slippery underfoot. Its outer edges, in the zone of wave action, support a profuse growth of orange, brown and green algae. Vermeer mentions the "pieces of reef rock... six or eight inches above the water level", but in some cases these are considerably higher. One such patch is found on an isolated platform north of the main exposure. Levelling showed that the upper surface of this remnant was 1.8 feet above low water level, and in detailed structure it consists of a slab of blackened, well-cemented calcarenite, dipping seawards, overlying a slightly undercut layer of finer calcarenite rising from the general level. The interface between the upper block and its basement dips seawards some 2 inches in 2½ feet. A second example is found rising from the main platform itself on the southwest side of the cay close inshore. This too rises 1.8 feet above low tide level, and consists of a seaward-dipping block of hard rock overlying a slightly undercut base rising from the general level; again the seaward dip is about 2 inches in 2½ feet. These remnants both consist of very well indurated sands, similar to beach sands, in which some alteration of constituent grains has taken place. The rocks of both the relict beds and the platform is distinguished by its strength; it rings to the hammer, and very heavy blows are necessary to secure specimens. Several other pinnacles approach close to the level of the tabular outcrops, but do not show seaward dip. The platform itself, however, is not entirely horizontal, for where it projects from the cay three distinct low escarpments, 2-4 inches high, can be seen parallel to the present outcrop, with apparent dip to seaward, in the same direction as that of the second tabular remnant described.

Is this then an exposed reef conglomerate, or a beachrock, now degraded, properly so called? The dipping structures might suggest the latter, though there is a remote possibility (especially for the small scarps of the platform itself) that they result from jointing and tilting. The high tabular relicts are almost certainly a beachrock—they consist of beach sands and dip seawards (on the southwest shore to the southwest, on the southeast shore to the southeast). The widespread evidence of erosion shows that formerly the whole surface must have stood at a level close to that now represented by the beachrock remnants: was this surface wholly formed of thick beachrock, or did it overlie reefrock at no great depth? The surface of the lower platform bears a very great resemblance to raised reefrock surfaces seen by the writer on the north coast of Jamaica, but the example stresses the importance of precision and care in applying labels to lithified outcrops on cays. The rock itself consists of much-recrystallised detrital material, with *Homotrema*, similar to that now found on the beaches, together with larger fragments, mainly broken Strombus shells (usually worn) and corals. Many of the smaller pinnacles are formed by out-weathered coral heads and are still identifiable, though it is impossible to say whether they are in the position of growth. The inclusion of corals, often relatively numerous, in the rock does not necessarily have much bearing on its origin, for equal amounts of coral material are found in rock which is demonstrably beachrock, elsewhere on this cay.

Much of the southwest shore is fringed by a narrow outcrop of similar rock to that at the south point, forming a low ridge 1-2 feet wide, rising slightly above low tide level (though continually wetted by breaking waves), and often separated from the shore by a narrow shallow moat. The presence of this moat in places gives the rock an apparent surface dip to landward, where it is obscured by the shingle ridge; but excavation in the ridge shows that the rock reappears there for at least a small extent, at a slightly higher level than to seaward, and hence the true dip (if such exists) is from land to sea, the moat being erosional. The crest of the exposed ridge carries a very luxuriant growth of brown and green algae, which give it a distinctive appearance; on the seaward side it is undergoing severe erosion by grooving and potholing. It is impossible to speculate on the origin of this exposure, except to say that it is probably linked to that at the south point, and is not now in the process of formation.

The southeast bay contains a number of outcrops of lithified material, mostly intertidal, though descending at their outer edge below low tide level, and in one or two cases rising landward above high tide level, but still within the reach of swash and spray. These include Vermeer's "five separate areas of a greyish sandstone or beach rock", comparing in hardness to a poorly cemented sandstone, and "composed not only of cemented sand but contain(ing) shells, pieces of coral and coral rock" (Vermeer 1959, 99). Much of the rock is very much harder than Vermeer suggests; this is particularly so of the cemented beach conglomerates, but even finer beach calcarenites are consistently so well lithified that repeated heavy blows are needed to secure specimens. The best general view of the rock is obtained from the top of the lighthouse at the east end of the island. There are two main outcrops: the first, along the north shore of the bay, is mainly a calcarenite; the second, along the west side of the bay, also includes calcarenites, but with a large proportion of conglomerates. Generally, the proportion of purely sandy beachrock is greater in the middle of the bay than towards its extremities. The coarsest material is found close to the south point, where it has been much disrupted by wave action, and now lies in a jumble of slabs up to 10 feet long, some obviously inverted, piled on the steep beach ridge. Immediately seaward and to the north, enough of this rock remains in its original seaward-dipping intertidal location to identify it as a true beachrock. Strombus shells are very prominent in the rock, as in the beach deposits of this bay, together with identifiable corals (mostly Montastrea and Diploria), and sticks and plates of Acropora). The slabs have a maximum thickness of about 18 inches, they are extremely tough, and compare in hardness to the south point rocks.

Northward the proportion of coarse material decreases, and several distinct layers of rock (up to 5) outcrop on the beach, dipping seawards, forming miniature escarpments up to 9 inches in height. They often show a distinct variation in content, layers of fine calcarenite alternating with layers of conglomerate, containing few recognisable corals but much cobble material. Some sorting is also to be seen within the individual calcarenite layers, between fine sands with Homotrema, and coarser sands with much Halimeda. A layer of pure Halimeda sand about half an inch thick often tops the calcarenite layer, much as on uncemented modern beaches. In general the coarser sands tend to be less well lithified than the finer. The beachrock in this bay reaches a maximum thickness of 10 yards.

The exposures along the north side of the bay are narrower, but similar in composition. The rocks are more sandy, with scattered patches of coarser fragments within the sand layers. Distinct conglomerate layers are found occasionally. The beachrock round the whole bay is being eroded by the formation of miniature groove-spur systems on its seaward side, and these often develop into potholes containing large cobbles. The outer lower parts of the beach rock are covered with a rich growth of green and brown algae, distinctly zoned (the identifications are awaited); the inner zones are free from larger algal colonists, but are coloured blue-black or yellow, presumably by encrusting microscopic algae. At several places along the shores of the bay, iron bars can be seen incorporated in the rock, and are now much rusted and decayed; at least 5 examples were seen. Hence the induration dates from later than about 1700, when this coast first began to be colonised and visited, and quite probably since 1830, when the first lighthouse came into operation. Apart from these bars, no inorganic material, such as pumice, was seen in the beachrock.

But perhaps the most interesting fact about the southeast bay beachrock is that thirty years ago none of it was to be seen. Prior to the 1931 hurricane, the seaward beach of this part of the cay stood 20-30 yards further seaward than it does now, and was sandy throughout. The hurricane destroyed this sand beach, and in effect bodily pushed the cay back that distance, exposing the present beachrock virtually overnight. The amount of this exposure seems to have been greatest in the centre of the bay and least towards its ends: northeastwards the beachrock still passes under the cay sands, but in the middle of the cay the rock has been subsequently obscured by a covering of fine soft, constantly shifting sand. The pre-1931 sandy shore seems to have been in existence for many years. Jefferys in all his maps (1775 and later) marks a prominent "Sandy Bay" on this side of the island, with, it is significant to note, a conspicuous southern lobe along the line of the present rock platform at the south point. Owen's 1830 MS chart, too, shows a similar configuration. It is at least possible, therefore, that all the rock now exposed developed during a previous more seaward extension of the cay, and has been relatively recently exposed. One would give much for detailed maps of this cay in 1930 and earlier!

No beachrock is found on the northern shores of the cay.

Evolution of the cay

It is thus impossible to understand the present physiography of the cay without reference to the 1931 hurricane. At certain places along the south shore, blocks of beachrock and conglomerate are found perched on the beach ridge 809 feet above the sea, and some are even found a short distance down its backslope. Residents describe seeing these blocks being rolled up the steep seaward beach at the height of the storm in 1931. The orientation and depth of the southeast bay gives large waves access to the beach itself, and these normally break heavily in great clouds of spray on the beachrock, or where this is absent, on the beach itself, the swash wetting the sand for some distance above high water level. In times of violent storm and hurricane, the swash is so great that it overtops the ridge crest (7-9 feet high), depositing fresh sand there and on the upper part of the backslope. This occurred recently during the comparatively minor hurricanes Abby in 1960 and Anna in 1961. Sediment also accumulates in the northern bay by refraction chiefly round the east point, but whether the aggradation has yet made up the 1931 net losses is not known. The continuing progradation of the lagoon shore may account for the apparent or real absence of beachrock on this shore.

Verner makes the point that the present brick lighthouse base was built in 1845 "midway between the north and south sides". If this is so, then as he says "hurricanes have actually moved Half Moon Cay northward while not affecting the position of the Lighthouse" (1959, 9, 12). The base of the lighthouse now rests immediately overlooking the seaward slope of the ridge, and any further retreat will lead to its undermining, though this is unlikely without the intervention of another major hurricane.

Vegetation

Our knowledge of the present vegetation on Half Moon Cay is fairly full, while of its development, though data are meagre in the extreme, we at least know more than for any other cay. In the account of Saddle Cay it was shown the coconuts were already established on Lighthouse Reef in 1720, and it seems that Uring found a number on Half Moon Cay in that year (Uring 1726; 1928 edition, 236). Alone of the British Honduras cays we have an early sketch of Half Moon, made in 1828 or 1830 from the south. This is redrawn and given here (fig. 32); it shows the absence of all except low bushes and shrubs at the eastern end of the cay, while fully two-thirds is occupied by high forest. Only half a dozen or so coconuts are indicated in this sketch at the margin of the high bush and cleared area. (I am indebted to Chart Branch IX, Hydrographic Department, Admiralty, for allowing me to search their volumes of views and finding this sketch for me; it is in Volume 1, No. 362). The sketch was made in 1828-9, shortly after the building of the first lighthouse; the Honduras Almanack for 1830, reporting this event, describes (on p. 150), a "luxuriant growth of the wild plum and salt-water palmetto, over which the cocoa-nut tree may be seen towering in majestic grandeur."

Mr. George Young, resident on the cay since 1928, informs me that when he first came, the high bush extended to a point half way along the northeastern peninsula, and thus it cannot have been much less extensive in 1928 than in 1830. During the four decades since 1928, Mr. Young and his family have slowly cleared the high bush from the whole of the peninsula (fig. 33), and it is now restricted to the western portion of the cay, especially along its southern side. Nearly all the peninsula is now planted to coconuts and is devoid of ground vegetation; while the high bush area is surrounded by a fringe, particularly on its northern side, of low ground vegetation and bushes, intermixed with coconuts. It is interesting to note that as the lagoon beach builds outwards, Mr. Young is planting additional rows of young coconuts in line with the old, so that as one approaches the lagoon shore from the crest of the seaward ridge, the coconuts become lower and younger. It cannot be too strongly emphasised that the existing pattern of vegetation on inhabited cays like Half Moon is ephemeral, and indeed the vegetation of some cays visited in 1961 was almost unrecognisable as that seen fourteen months earlier (e.g. Tobacco Cay, Barrier Reef), simply because of the activities of man. The vegetation is periodically cut back, and sometimes rooted out altogether. Mr. Young's programme of systematic clearing is at present being continued by Mr. Philip Young, who is cutting out the *Cordia* bush at the southern point, and the mixed *Cordia*-*Conocarpus* bush behind, for *cocals*. The vegetation of this middle part of the cay was in 1961 covered only with low bushes and ground vegetation, whereas in 1960 when first seen, it was a confused tangle of tall *Conocarpus* and other bushes. A small amount of vegetation still covers the shingle ridges at the east end of the island.

Verner gives a description of the composition of the broadleaf area, as follows (1959, 3-8):

> "The principal tree, both in numbers and in utilisation by the boobies, is the red-flowered *Cordia sebestena*. It is the only tree that occurs in all sections of the (booby) colony, and the only one growing next to the shore. Most individuals are about twenty to twenty-five feet high, but some attain thirty-five feet. *Bursera simaruba* occurs generally in all areas of the colony except along the shore, and *Bumelia retusa* occurs in all areas except along the the shore and in approximately the eastern fifth of the colony. *Ficus* sp. is distributed like *Bursera* but is much less common. *Pithecellobium keyense* grows only in the central portion of the colony. ... *Neea choriophylla* is a very rare species in the colony... I was aware of not over five individuals of the species on the island, and all but one of these were in the eastern fifth of the booby colony. *Ximenia americana* is also rather uncommon, and is restricted to the northwest corner of the colony. *Pouteria campechiana* is one of the principal species along the north border of the eastern half of the colony, where it occurs in association mainly with *Bursera* and *Ficus*. Those three species reach heights of forty to fifty feet in that section of the colony,

and they are the principal species composing the remainder of the broadleaf grove where the boobies do not rest."

He also noted the abundance of the night-flowering bush Capparis flexuosa, forming "dense tangles of stems throughout most of the central section of the nesting colony."

I can add little to this account. The whole of the south shore of the cay is lined with Cordia sebestena, forming a low, spray-swept hedge, most noticeable (till cleared in 1961) at the south point. Verner (1959, 57) thinks this shearing is due to birds collecting nest materials, and he quotes Mr. George Young as saying "he had seen a number of boobies practically strip a small bush to the trunk before leaving it to gather sticks elsewhere." He considers frigate birds and ospreys, as well as boobies, to be the culprits. I consider that the shearing results from salt spray and wind-trimming (Boyce, 1954), rather than from the birds. Verner states that "neighbouring cays exhibited no such trimming of shoreward vegetation", but this is true only of the cays lacking broadleaf forest (the majority). Wherever one still finds cays with broadleaf forest on the windward side, then one finds shearing even in the absence of birds. Examples are seen on Northeast Cay and other cays on Glover's Reef, and several of the Sapodilla Cays, Barrier Reef.

Most attention in my visits was given to the lower vegetation cover surrounding the broadleaf forest, and 30 plants were collected here and sent to Dr. Fosberg for identification. A map (fig. 34) has been constructed showing the distribution of the main species in this area. Tournefortia gnaphalodes occurs around the cay margins on both shingle and sand, particularly in exposed places. It is dominant on the extreme eastern shingle ridges (with stunted Cordia, some coconuts, Hymenocallis and Sesuvium), and also occurs on high ground at the south point, near the northwest corner of the cay, and intermittently along the southwest shore below the Cordia hedge. Sporobolus virginicus is a sand-binding grass found in similar exposed locations on sand beaches: again it is important near the south point, along the south shore, at the northwest corner, and along the beach ridge of the lagoon shore. Suriana maritima is another shrub of exposed shores, rather oddly restricted here to the northwest point. Other colonising strand plants such as Sesuvium and Ipomoea are not well developed on the Half Moon beaches, except at the west end of the island.

The area surrounding the high bush falls into three vegetational zones: the eastern zone, the central zone, and the western zone. Wedelia trilobata, with Cakile lanceolata and Ipomoea, forms the ground cover in the west zone, behind a fringe of Tournefortia and Suriana; and Verner records Calonyction aculeatum from this area also. The central zone, round the western mudhole, is composed mainly of Wedelia, scattered Stachytarpheta jamaicensis, low bushes such as Rivina humilis, and, shorewards, a broad belt of the lily, Hymenocallis littoralis. The eastern zone extends along the east side of the high bush zone from the south shore to the north. In the south, on the crest and backslope of the windward ridge, there is a narrow zone of Tournefortia, succeeded inland by a broad belt with little but Hymenocallis. The middle of the cay in this zone, south and west of the main mudhole, is covered with extensive patches of Wedelia trilobata, Cyperus planifolius, Alternanthera ramosissima, Eragrostis ciliaris, Ageratum maritimum (recorded by Verner), Sida acuta (Verner), and bushes such as Rivina humilis, Ernodea litoralis, Hamelia patens, Erithalis fruticosa, and Conocarpus erectus. According to Verner, Sida and Hamelia "are confined to the moist, shady areas bordering the broadleaf tree stands". The mudhole itself stands in the middle of an almost exclusive mat of Wedelia trilobata, while to the north, between the Wedelia stand and the Sporobolus-covered lagoon beach-ridge, is an area of mixed Wedelia, Euphorbia, Cyperus and Sporobolus.

Almost one-third the area of the cay is still covered with high bush, but it is clear that the period of extensive clearing from 1928 onwards is coming to a close. First, much of what is left is a protected booby colony and cannot be cleared, and much of the remainder is underlain at very small depths by hardpan or reefrock and cannot support coconuts. Were the vegetation cleared here, the surface humus would soon disappear and a barren pavement would be exposed. The main change to be expected is the complete ground-clearing of the coconut undergrowth on the fringes of the high bush, involving the partial disappearance of species such as Wedelia, Stachytarpheta, Euphorbia and the grasses.

Occupance and land use

The giant lizards (Iguana and Ctenosaura) and the smaller anolids and the rats on this cay have already been mentioned, as have Verner's ornithological records. In his study of the colony of boobies (Sula sula sula) in 1958, he counted 1389 nests (more than a half in Cordia sebestena, about 85% in Cordia, Bursera and Bumelia combined), averaging rather more than two nests to the tree, containing about 3500 pink-footed boobies, of whom 500 were immature birds. Two percent of the boobies were brown, but each of these was mated with a white (1959, 15, 53). Much information on the habits of these boobies is given in Verner's thesis, which should be consulted by those interested.

The Young family has a thriving settlement near the middle of the north shore, where they carry on boat building. George Young builds boats from imported timber of up to 15 tons wholly by eye, without the aid of drawings or models, which is unusual even among British Honduran fishermen. Several houses are associated with the lighthouse at the east end of the cay, together with a number of sheds and rainwater vats. The lighthouse keepers do not long remain at any station, but in 1961 one of them was also building a fishing boat on the cay. The lighthouse houses are sturdy, hurricane-proof shelters, large and comfortable. The first lighthouse was built in 1820, and a light first shown on December 1st that year (Honduras Almanack, 1830, 76); it was replaced by another in 1845. The present brick foundation dates from this time. The present steel-frame tower was built on the old base in 1930, and was still unfinished at the time of the 1931 hurricane. Apart from the lighthouse, the main occupation of the dozen or so individuals on the cay is tending the cocals, taking the nuts to Belize, and fishing--for barracuda, grouper, snapper, jacks and others--and turtling. Turtles are taken in nets baited with small brightly painted wooden decoys, and are sold in Belize. A number of the coconuts are used on the cay for coconut oil and water, which is fed to the pigs. In addition to pigs, the fishermen keep chickens and dogs. The island is occasionally visited by the Harbourmaster and a Customs launch, but is otherwise rarely visited. It is said that an attempt was made a few years ago by an American syndicate to purchase the cay for development as a holiday resort, but permission was refused.

Little is known of the history of the cay, though the Honduras Almanack referred to (1830, 151) tells the story of a violent, bloody-visaged spectre haunting the island at night, presumably the ghost of some unfortunate pirate. The apparition has now ceased to appear, and has been forgotten.

Conclusion

Half Moon Cay has been described at greater length than any other cay, partly on account of the length of time spent there and mass of data collected (much of it still unsifted), partly because of the great natural beauty of the island, partly because of the problems which it raises. Several conclusions emerge from the study, including (1) the importance of major hurricanes, even on so large a cay as this, in the evolution of the present physiography; (2) the great practical difficulty of distinguishing in the field between various types of lithified material and hence the difficulties of drawing conclusions from them; and (3) the constantly changing nature of cay vegetation, even over so short a period as 30 years. When as much information is available on other cays as there is now on Half Moon, there is little doubt that features which now seem simple and easy to explain will be revealed as more complex and enigmatic; for even such small and apparently insignificant features as sand cays are beset with difficulties and problems, few of which can yet be solved.

Long Cay

The great German geographer Carl Sapper visited Long Cay in the 1890s but published no account of his observations, and no further attention seems to have been paid to it until 1958, when Vermeer called there and later published a short description. The island (fig. 35) is located near the southern end of Lighthouse Reef, on its long, narrow "half-moon" extension, $2\frac{1}{2}$ miles west of Half Moon Cay, and some $3\frac{1}{2}$ miles from the southern end of the reef. The situation of the cay is somewhat peculiar: it does not stand on the windward reef-flat, here about 700 yards wide, sandy and strongly rippled with flourishing reef on its outer edge; nor does it lie on the leeward reef-flat, which strictly speaking does not here exist. Living reef is in fact absent on the whole of the western, leeward side of the cay, and the gap continues some distance north of it, forming the main entrance to the atoll lagoon. The cay occupies an intermediate position, almost in the centre of the "lagoon", here at its narrowest and shoalest; the water round the cay averages $1-1\frac{1}{2}$ fathoms in depth. The deeper channel between the windward reef-flat and the east side of the cay may be due to subsequent current scour of the bottom, as water surges across the reef, piles up against the cay obstruction, and is diverted southwards.

Long Cay is a narrow island, with its long axis parallel to the trend of the reefs and lagoon at this point. Its maximum length is approximately 3640 yards, and its width varies from a minimum of less than 300 yards in the south to a maximum of 1200 yards in the north. Vermeer's description of the cay is here quoted, since he found here features which he ascribed to a recent eustatic fall of sea-level:

> "A sand cay with a swampy, depressed centre, this cay has been almost completely planted to coconut palms. Long Cay appears similar to Ambergris Cay on the coastal shelf block in that it also gives indication of greater age and stability than the other cays" (1959, 97).

After finding a "raised beach" on Ambergris Cay, Vermeer described another from Long Cay:

> "....the elevated beach was manifest not only on the windward side but on the leeward side as well. Long Cay has an enclosed elongated lagoon toward the centre of the island. From this lagoon there is a rise to the ridge which surrounds the lagoon and which is the highest part of the cay. From this high part of the cay, there is a drop to the elevated beach terrace. The maximum width of the raised beach on Long Cay is similar to that on Ambergris Cay, being no more than about 20 yards, but displays less variation in width. From this elevated beach-level there is a drop of 5-6 feet to sea level. The elevated beach on the leeward side of Long Cay is much more clearly defined and illustrated than it is on the windward side of the cay and than is the case on Ambergris Cay" (1959, 51-2). "The contrast in colour of the soil between the raised beach level and the higher portion of the cay is not as striking as that found on Ambergris Cay, but it remains very evident. As has been noted previously, the raised beach level is best evident on the leeward side of the cay but can also be observed on the windward side" (1959, 97).

The "raised beach" is shown in Vermeer's Figure 21.

Long Cay was visited in June 1961 and the dry sand areas mapped; both Murray and I are convinced that no raised beach at the levels described by Vermeer can be demonstrated. In the first place, his description of the island as " a sand cay with a swampy depressed centre ... almost completely planted to coconut palms" gives a misleading impression of its physiography. The total area of the cay is approximately 2,525,000 square yards (525 acres); of this, only 8% is dry land. The rest is mangrove swamp and standing water. Its physiography is basically similar to that of Northern Cay: a small sandy area at the north and northwest corner, covering 22 acres, with a vast mangrove swamp to the south, with a narrow fringe of sand on its windward side. Like the mangrove rims of the Turneffe lagoons, this swamp is "hollow". From the sea one sees an unbroken wall of tall, bushy _Rhizophora mangle_, but much of the interior consists of open lagoon, mud, and dead and dying trees. Some of the lagoons can be seen on air photographs, and one extensive lagoon area near the middle of the cay covers about 158,000 square yards (larger than the main sand area, and 6% of the total cay area). It is thought that the area of open water is considerably greater in the interior than is suggested by the air photographs, especially in the northern part, where, as seen from the sand area margin, there is more open water with dying trees than flourishing mangrove. A distinction is made in the map between high mangrove and more open bush; but the most flourishing high mangrove is probably restricted to the coast, and inland contains innumerable pockets of dead trees, open water and mud.

The northern sand area was traversed and mapped. It has an area of 22 acres and is trapezoidal in shape: the northwest shore, 200 yards long, parallels the southwest edge of the sand area, where it adjoins the mangrove (700 yards from shore to shore). The northeast shore is a little over 400 yards long, the west-facing shore 300 yards in length. The northeast shore is low and sandy; north of the pier there has been a little undercutting, producing a sand cliff less than a foot high. A few yards offshore there are linear banks of sand, covered with Thalassia, drying at low tide, similar to those on the west coast of Northern Cay. South of the pier the slight cliffing continues for a few yards, but is then succeeded by a broad beach of fresh white sand less than a foot above sea-level, planted with young coconuts. The northwest shore of the cay is very low-lying and fringed with a belt of Rhizophora mangle several yards wide and 200 yards long. The western shore extends from this minor belt of mangrove to the main area which forms the southern part of the cay. A substantial pier has been built midway along this shore. North of it the beach is sandy and rises to a crest $2\frac{1}{2}$ feet above the sea, covered with Sporobolus virginicus. South of the pier the beach ridge reaches a maximum height of $3\frac{1}{2}$ feet above the sea, and then declines southwards towards the mangrove. The average height of the sand ridge round the northern part of Long Cay is thus between two and three feet above the sea, and the maximum height not more than 4 feet. Nowhere does the surface rise to Vermeer's 5-6 foot level, and on no part of the island was the existence of "a drop of 5-6 feet to sea level" from the edge of the "raised beach" confirmed. From the low peripheral ridge the cay surface declines southwards to the mangrove and swamp areas; near the mangrove there is a fringe zone, at or near sea-level, of spongy water-soaked ground. Over most of its length, the sand area/mangrove boundary is lined with open water, forming a narrow channel separating the mangrove bushes from the sand.

Nothing was seen on the cay surface to indicate the existence of a raised beach. The surface is uniformly sandy—a coarse sand with much Halimeda, similar to that now accumulating on present beaches, and near the northwest corner, sheltered by the mangrove fringe, it is thrown up in a series of arcuate low ridges convex landward. The view of the "raised beach" in Vermeer's Figure 21 seems simply to be an area under cocal, and similar views can be seen at many points throughout the island. There is no marked break of slope on the cay surface (such as an old undercut cliff line), no raised lines of pumice or raised beach-rock, and no indication in the vegetation of such a raised beach. If such a beach can be demonstrated, then it certainly does not lie at 5-6 feet above sea-level; 2-3 feet would be its maximum elevation. I strongly doubt the existence of this raised beach and hence the conclusions drawn from it. There is nothing at Long Cay which cannot be explained by sand accumulation and mangrove colonisation at present sea-level.

The vegetation of the sandy area is of little interest. Most has been cleared for cocals, and apart from a few patches of Hymenocallis littoralis, Euphorbia, Sesuvium and mangroves, there is little but grasses (mainly Sporobolus, but some taller grasses). In the shallow water adjacent to the beach there is an abundant growth of green algae --Halimeda and Penicillus on the west side, Halimeda and Acetabularia on the east.

With a single exception there is no dry land in the mangrove area, but the exception is important. Owing to its proximity to the eastern reef, a narrow fringe of dry sand has been thrown up along a large part of the east coast, with a total length of about 1800 yards. This was traversed for most of its extent; it nowhere rises more than 2 feet above the sea, and is generally between 1 and 2 feet high. It varies in width from 20 to 40 yards, and averages 25 yards. The sand is coarse, with many shell fragments and Halimeda, and abundant white pumice. Much of the calcareous material probably derives from the wide eastern reef-flat, is thrown up in time of storm, and suffers little wave-sorting and abrasion, hence the number of little-damaged shells. At one point on the shore is a pile of large vertebrae of some unidentified marine animal. The ridge is planted to coconuts, with an undercover of Sporobolus and Euphorbia. It declines westwards to the mangrove swamp, and is lined at its inner edge by Conocarpus, Avicennia, and tall ancient Rhizophora. At many places on the seaward shore small Rhizophora seedlings are abundant. Sophora tomentosa and Suriana maritima were noted at one point.

A similar seaward sand ridge extends for a very short distance southwards along the east shore from the northern sand area, but because of a wide gap between it and the main sand ridge it is not possible to walk along the east coast of the island. Near the south end of the cay the eastern sand ridge disappears, and vigorous Rhizophora have built eastwards towards the reef: the possibility that this mangrove section formed a separate cay in the middle eighteenth century has already been mentioned. The island was circumnavigated, and nowhere else was a coastal sand ridge seen fringing the mangrove: but there are two large pockets of sand near the south end of the western shore, not large enough for coconut colonisation.

The cay has a wooden pier 55 yards long on the west side of the main sand area, with a warehouse at the end, giving anchorage in rather more than 1 fathom of water. The pier is used for the export of coconuts to Belize. The caretakers live on the northeast shore of the cay, where there is a smaller, older pier for fishing boats. Long Cay is currently owned by an American, who has built a large house with a concrete rainwater vat near the latter pier. There are two small houses on the narrow eastern sand ridge, occupied only during the cocal harvesting.

A note on the map

The map of this cay (fig. 35) has been largely constructed from air photographs CAE-6-178-179 and 188-190, from which derive the outline of the cay and details of the interior mangrove area. The scale of this derivation is correct by comparison with other land areas surveyed on the same photographs (Half Moon Cay). The dry land areas were mapped by traverse in 1961, and maps drawn up on a scale of 1:2,000. These were then reduced to a common scale with the airphoto plots. In the case of the eastern sand ridge an excellent fit was obtained. The northern part of the cay on the photographs is, however, obscured by cloud, and no part of the main sand area can be seen. Hence the location of this ground map on the airphoto plot is a best-fit approximation, based on the straightness of both east and west mangrove coasts. The probable error in location of the northern surveyed portion with reference to the rest of the cay is probably no more than plus or minus 150 yards.

Hat Cay

With the single exception of Saddle Cay, only recently diminished in size, Hat Cay (fig. 36) is the smallest island on Lighthouse Reef. Speer called it "a very small round Kay" in 1771, and the description still applies; according to local informants there has been no marked change in its size or appearance for over thirty years.

It is located about 2500 yards south of the southern end of Long Cay, at the inner edge of the leeward reef-flat, here less than 500 yards wide and less than 3 feet deep. Again, like Saddle Cay, there is no clear reason for its situation at this point. The island is rectangular, and aligned NE-SW; it is 70 yards long and 55-60 yards wide. The surface is low and probably does not rise more than 2 feet above sea-level; it has a slight ridge of *Acropora cervicornis* shingle at the eastern end. At its eastern and western ends there are large banks of *Rhizophora*, partly standing in water. The rest of the cay margin is clothed with *Suriana maritima* and *Borrichia arborescens*, except for a narrow southern sand beach with *Sesuvium*. The cay interior contains a number of large black mangroves (*Avicennia*), *Conocarpus erectus*, and dead unidentified trees, chiefly at the northern end. There is little open ground, and what there is is covered with *Sesuvium* (near the sea), and *Hymenocallis* and *Sporobolus*. The area immediately to leeward of the low shingle ridge is low and marshy, though without standing water, and colonised by *Avicennia*.

The cay was uninhabited and devoid of wild life when visited in 1961. Pelicans are said to breed here.

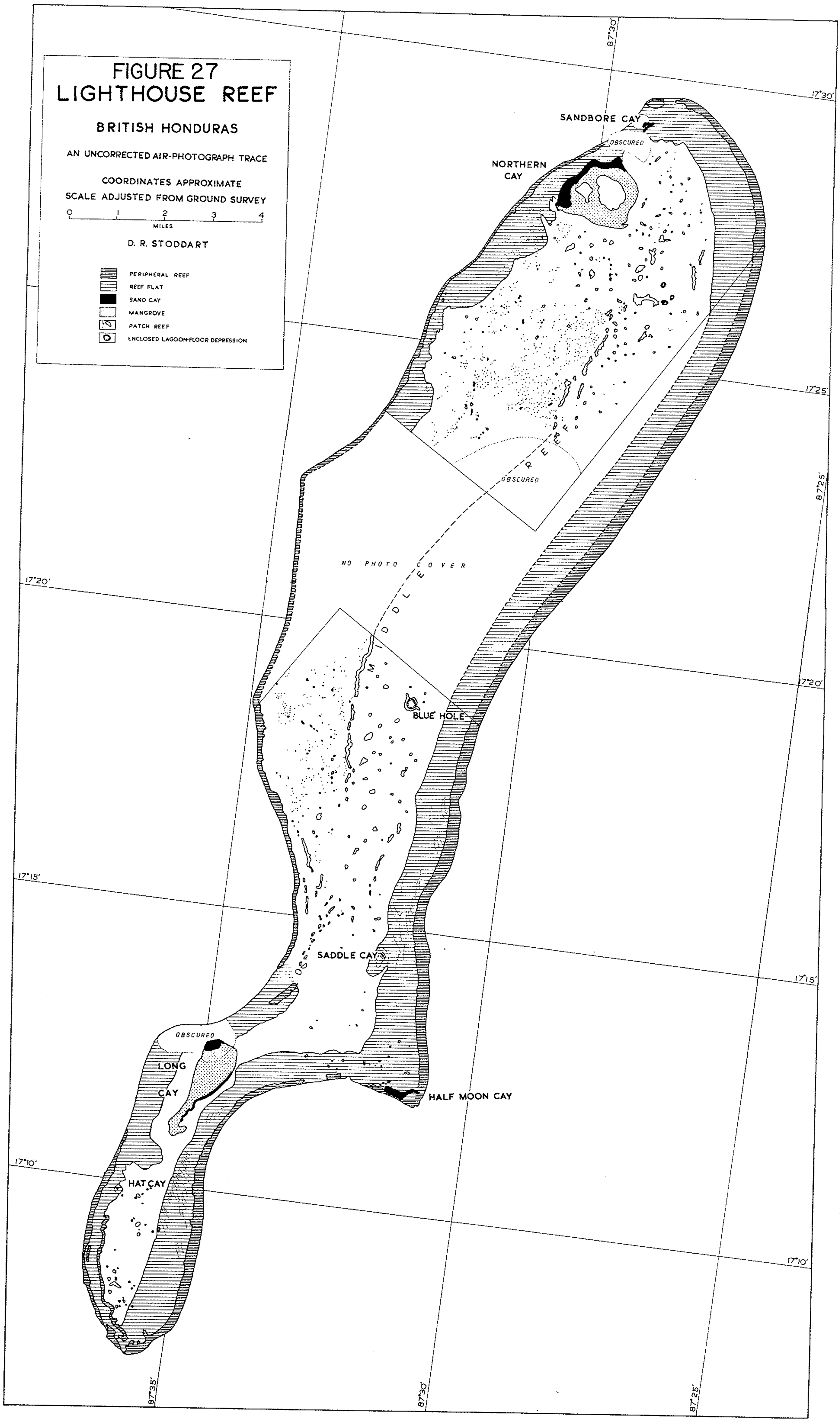
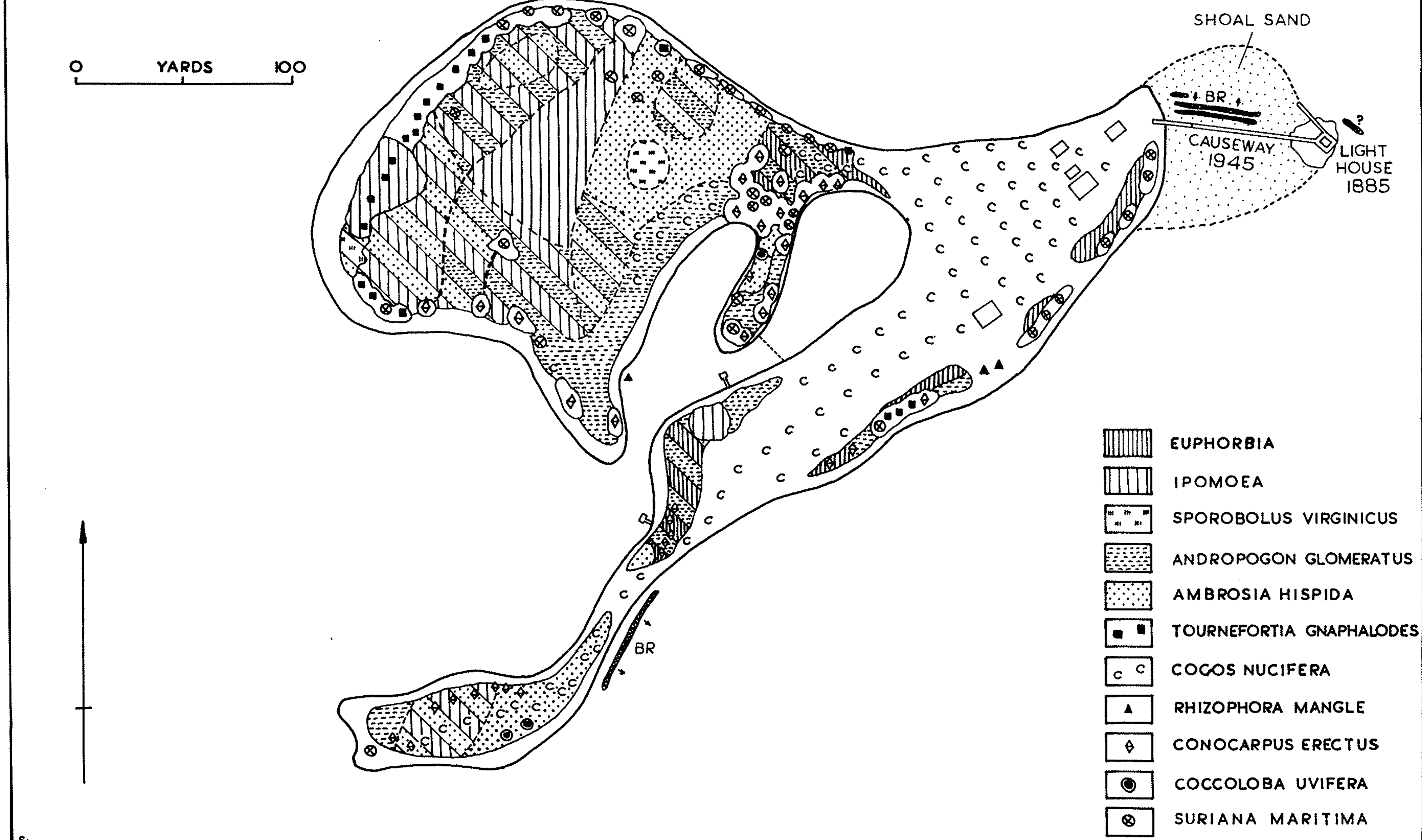


FIGURE 27
LIGHTHOUSE REEF

FIGURE 28
SANDBORE CAY



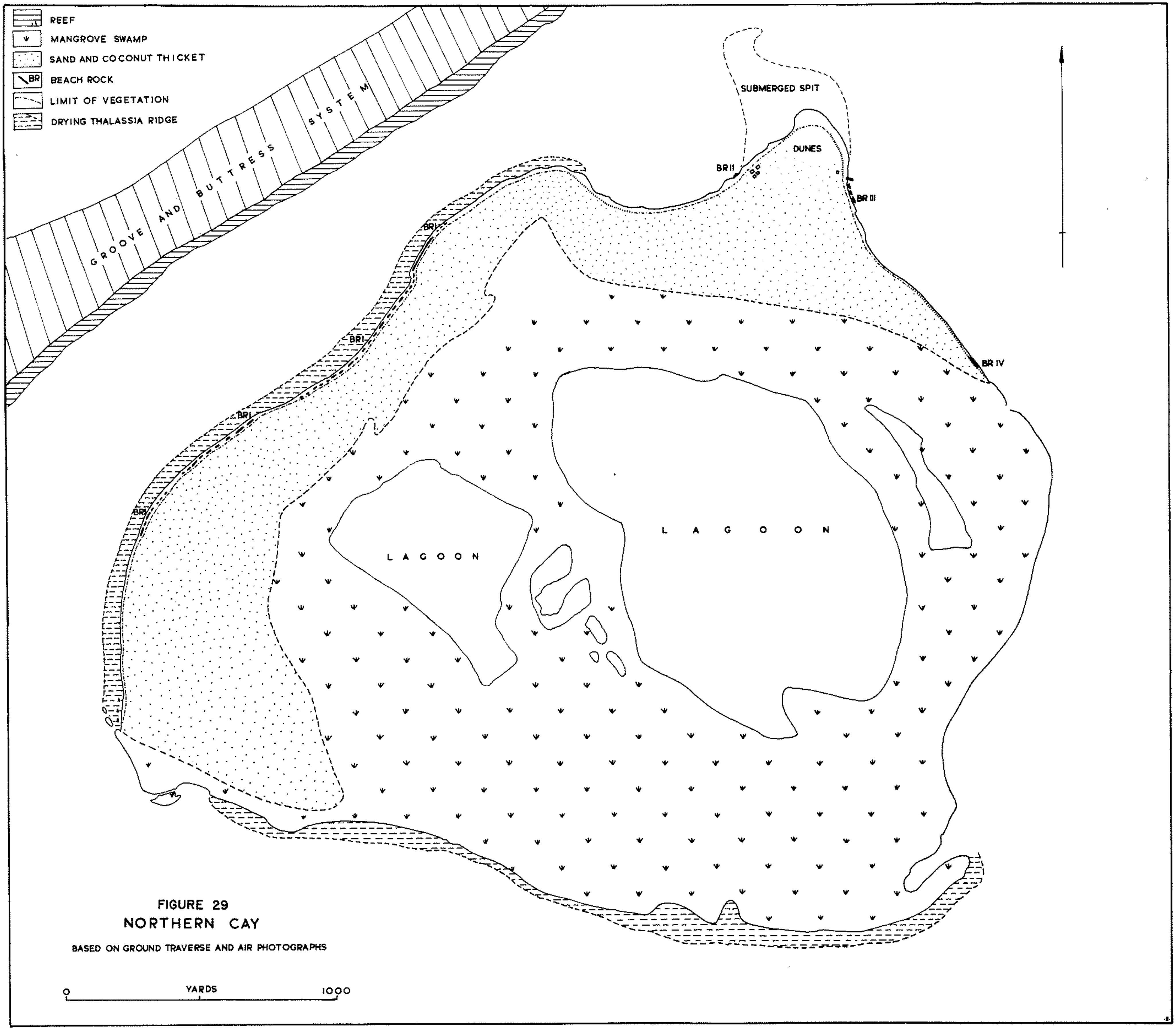


FIGURE 29
NORTHERN CAY

BASED ON GROUND TRAVERSE AND AIR PHOTOGRAPHS

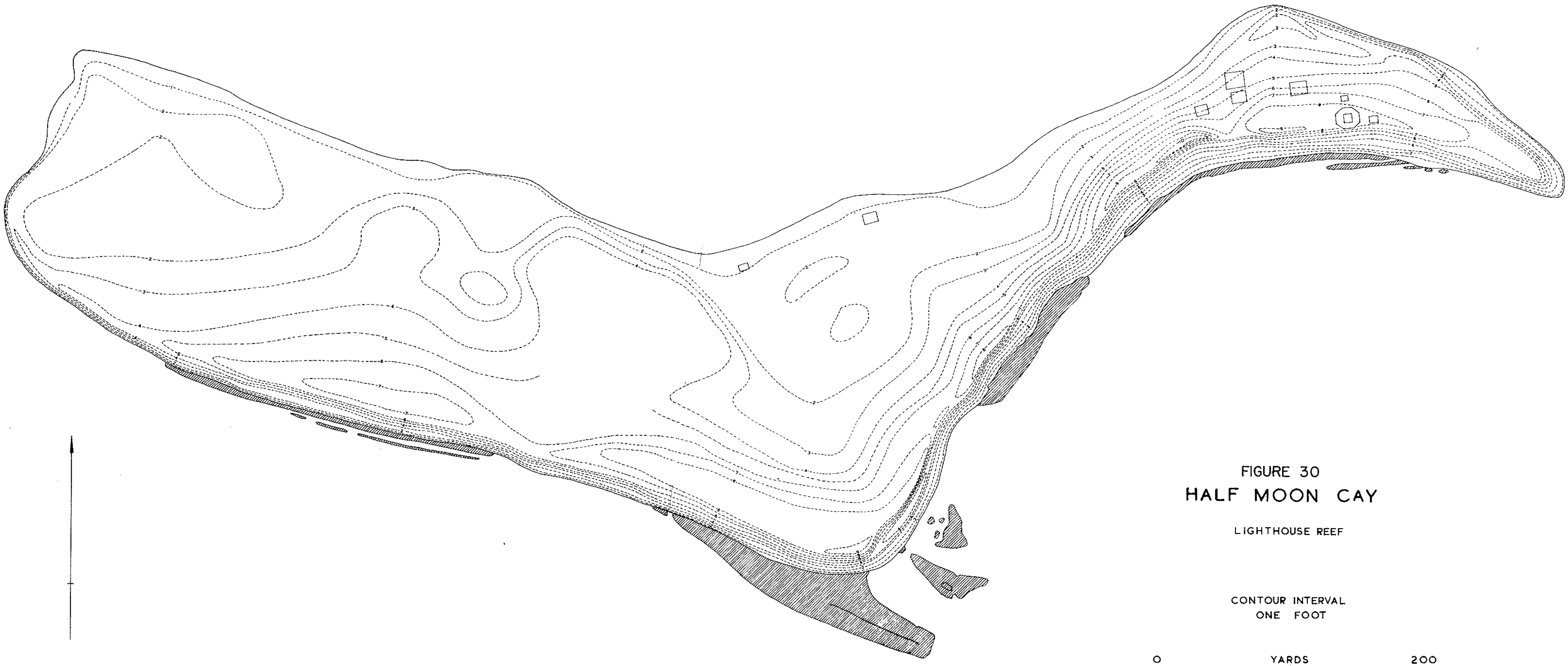


FIGURE 30
HALF MOON CAY
LIGHTHOUSE REEF

CONTOUR INTERVAL
ONE FOOT

0 YARDS 200

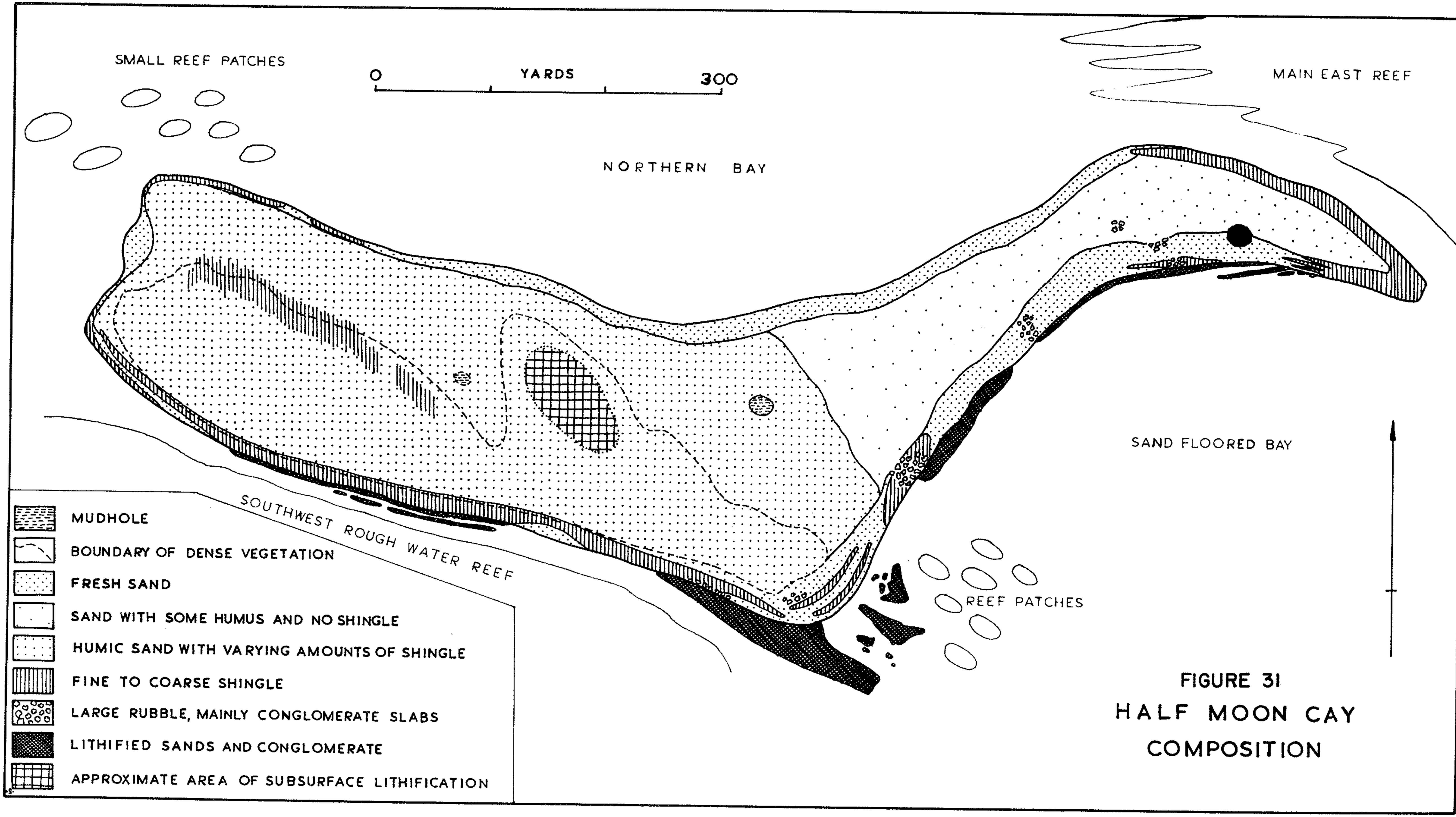
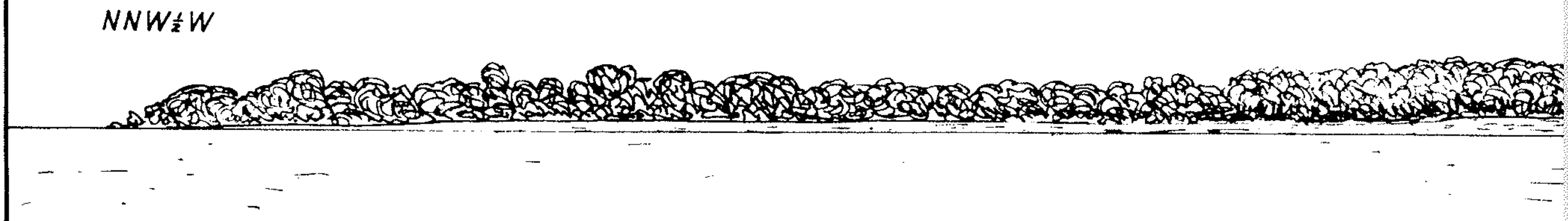


FIGURE 31
HALF MOON CAY
COMPOSITION

HALF M

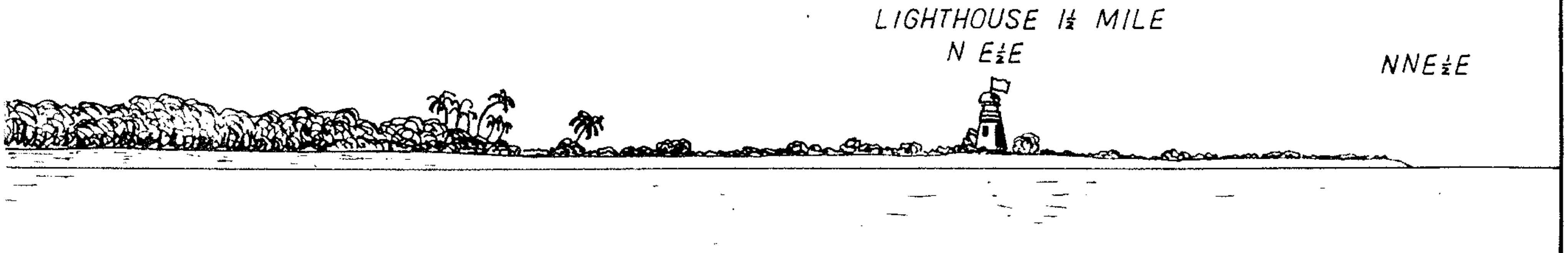
FIGU



FROM A SKETCH PROBABLY MADE BY ANTHONY DE MAYNE, HMS KANGAROO, IN 1828

OON CAY

IRE 32



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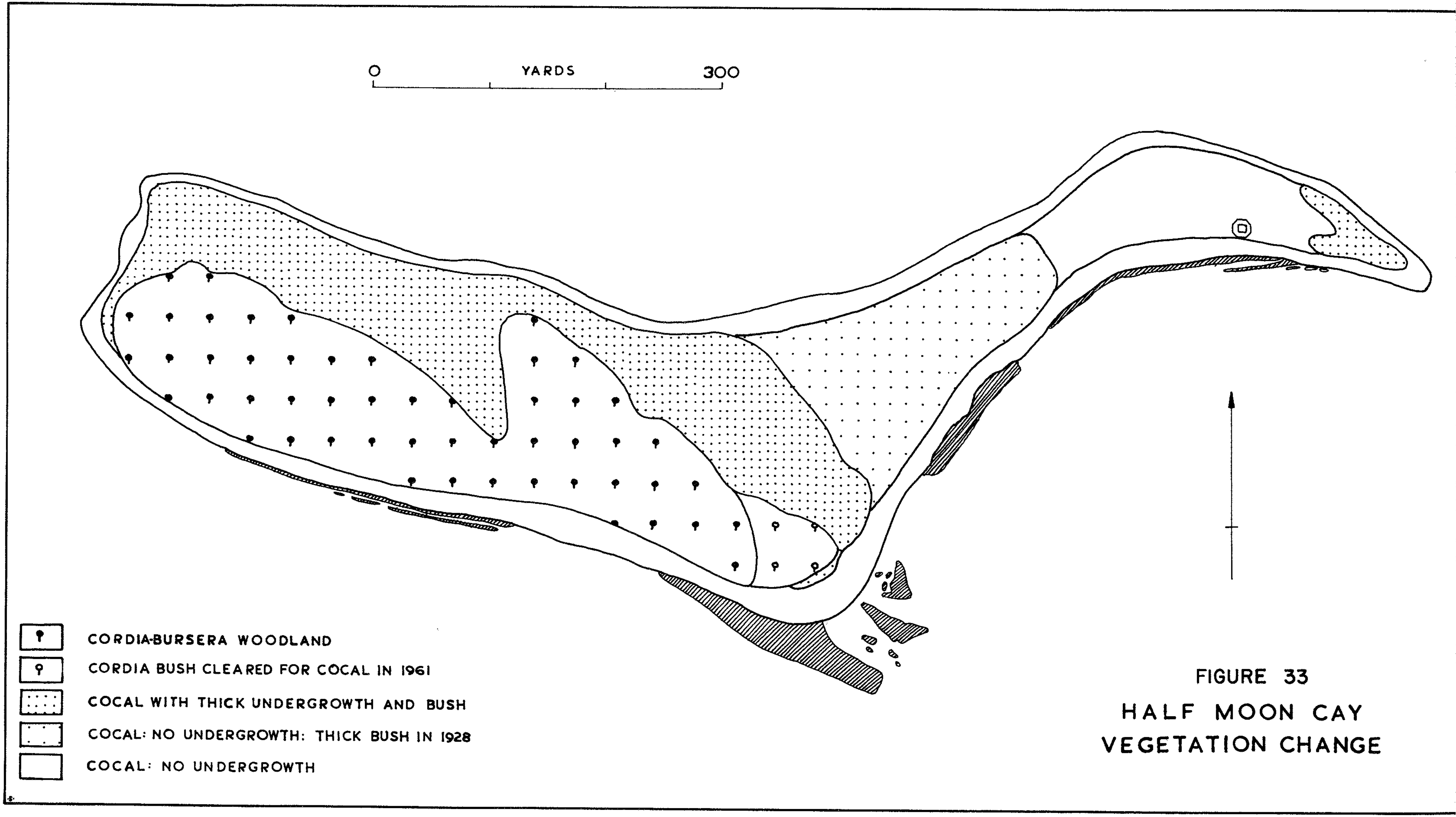


FIGURE 33
HALF MOON CAY
VEGETATION CHANGE

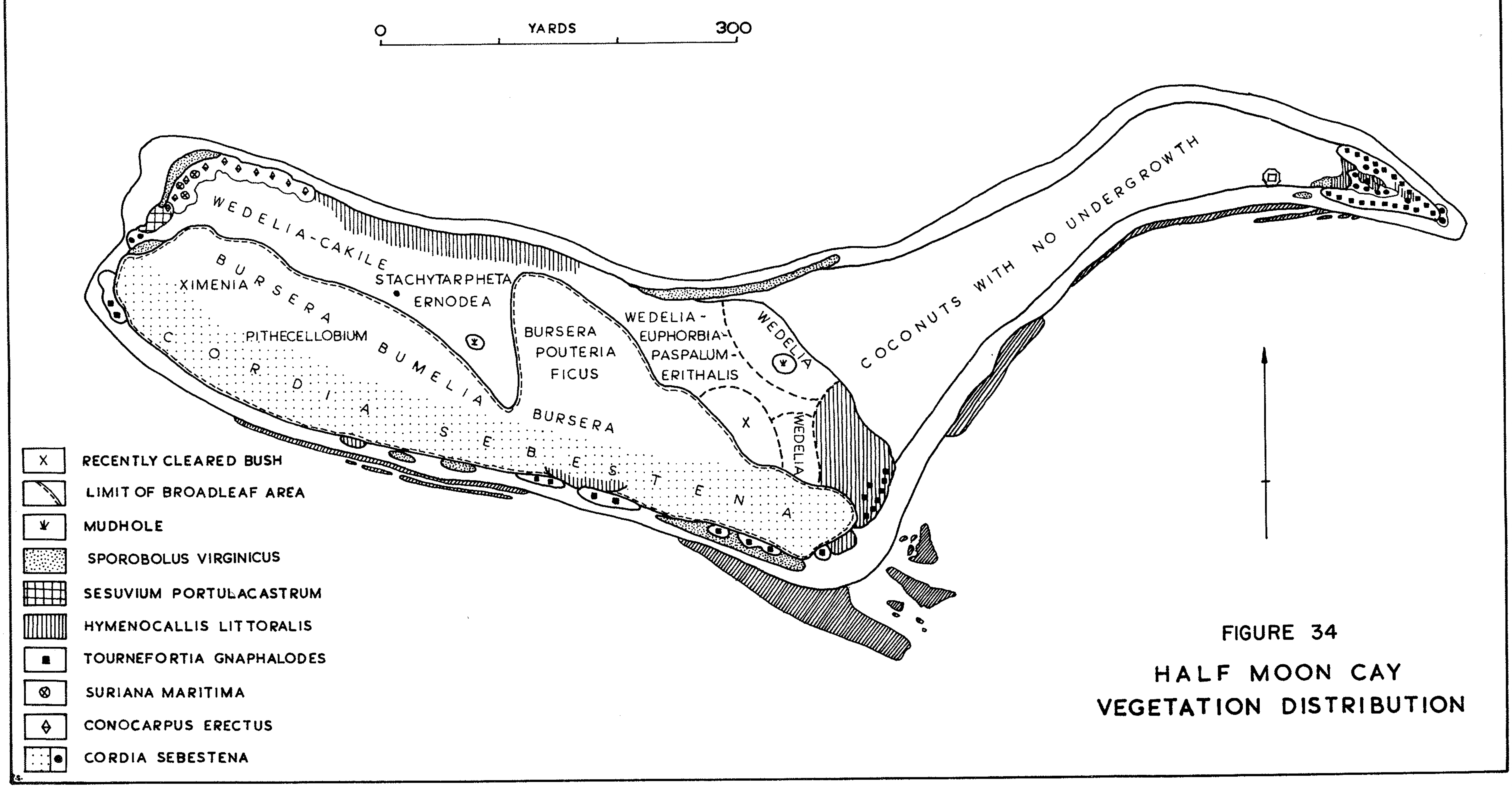
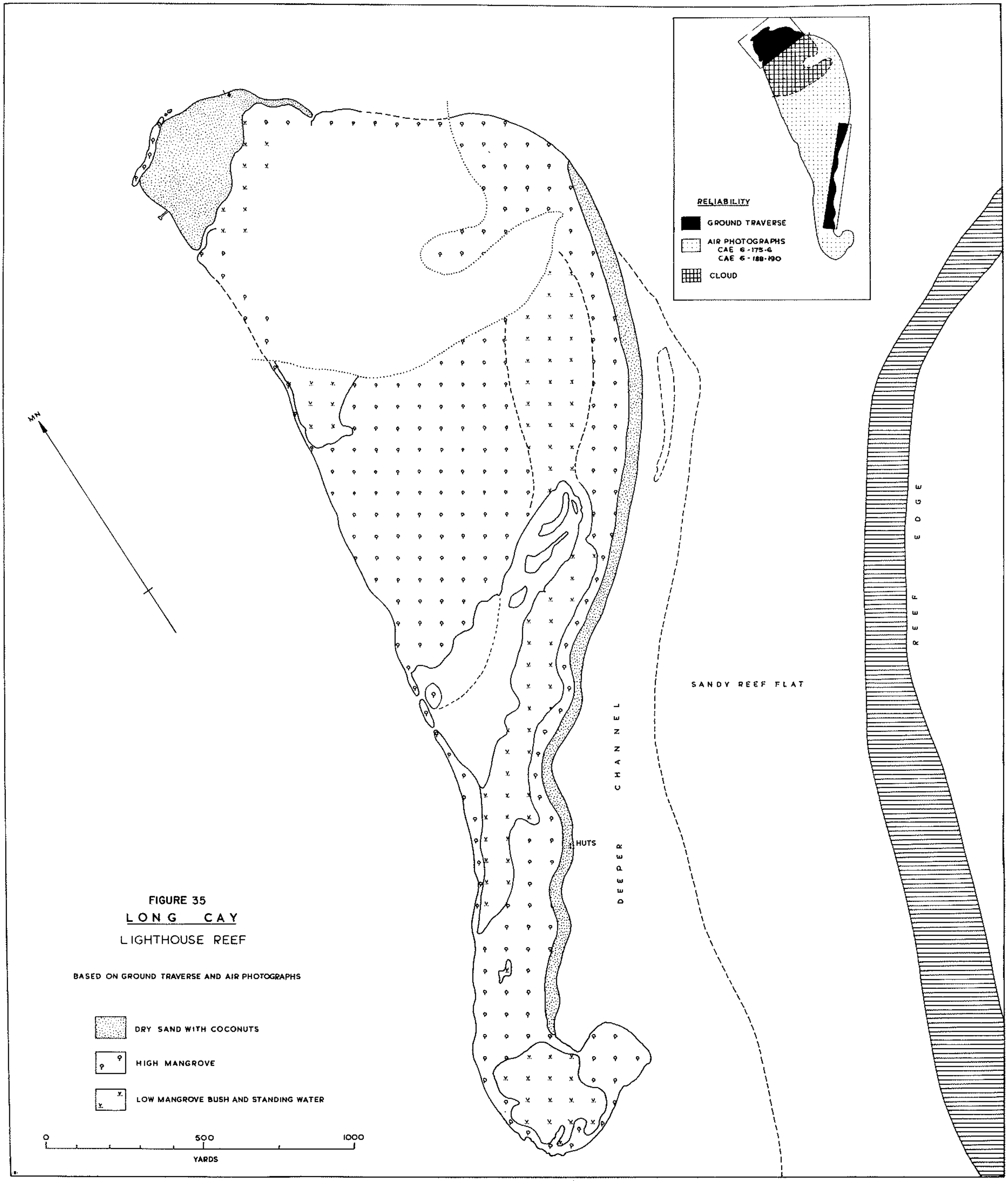


FIGURE 34

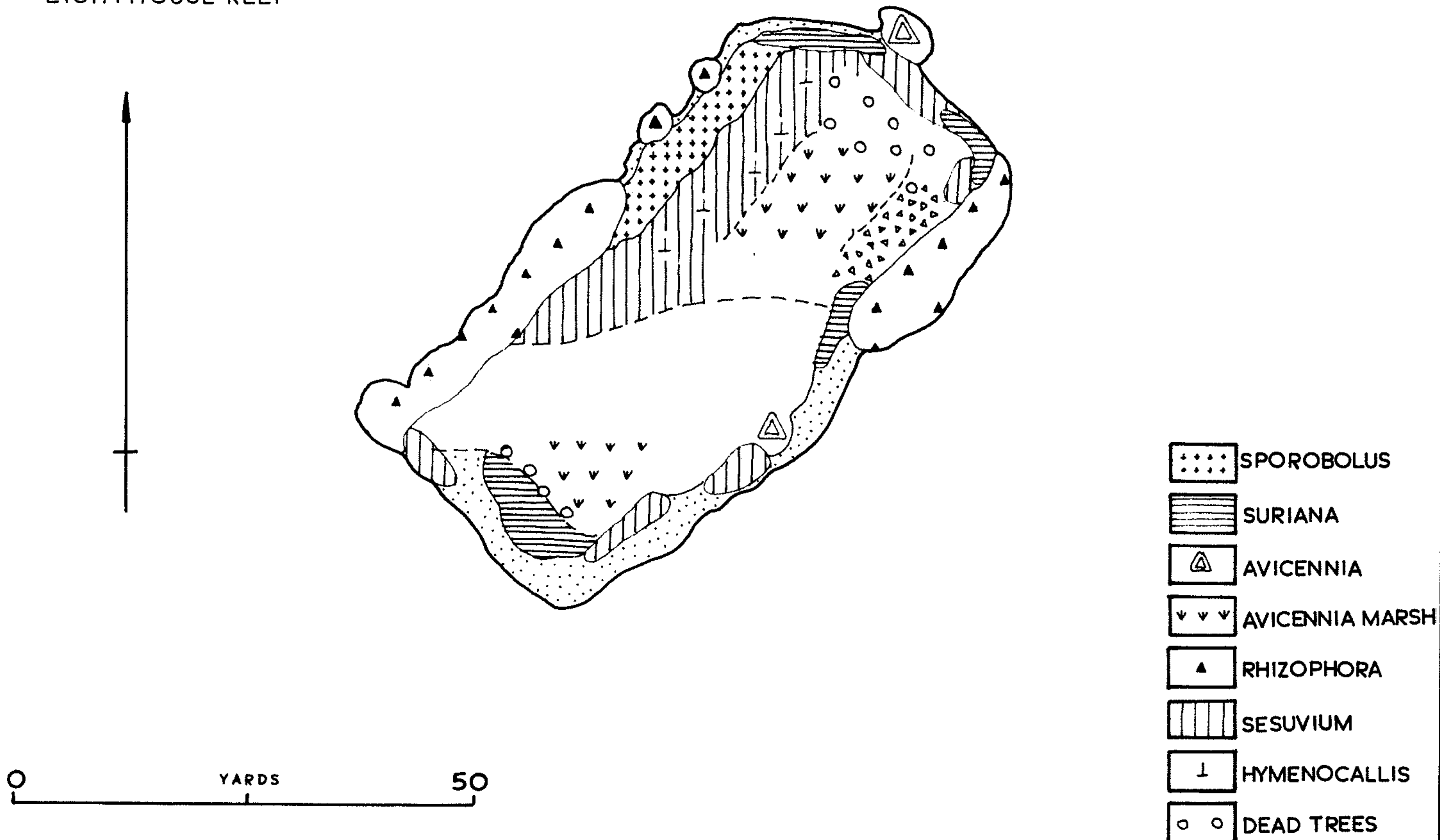
HALF MOON CAY
VEGETATION DISTRIBUTION



RELIABILITY
GROUND TRAVERSE
AIR PHOTOGRAPHS
CAE 6-175-6
CAE 6-188-190
CLOUD
MN
SANDY REEF FLAT
REEF EDGE
DEEPER CHANNEL
HUTS
FIGURE 35
LONG CAY
LIGHTHOUSE REEF
BASED ON GROUND TRAVERSE AND AIR PHOTOGRAPHS
DRY SAND WITH COCONUTS
HIGH MANGROVE
LOW MANGROVE BUSH AND STANDING WATER
0
500
1000
YARDS

FIGURE 36
HAT CAY

LIGHTHOUSE REEF



VII. GLOVER'S REEF

The greatest length of Glover's Reef (cf. Vermeer, 1959, 19-20) is 15 miles and its greatest width $6\frac{1}{2}$ miles. With an approximate total area of 81.6 square miles it is slightly larger than Lighthouse Reef but much smaller than Turneffe. The atoll (fig. 37) is surrounded by broad, well-defined reefs of living coral breaking surface (transects C and F), interrupted by three prominent gaps. The largest of these is Southern Entrance, one mile wide and carrying 1-2 fathoms water; it provides good anchorage for small boats. Northern Entrance, on the windward side of the atoll near its northern extremity, is some 1400 yards wide, with similar depths, opening into an extensive shoal area with numerous coral heads. The third and smallest entrance, also on the windward side, lies between Northern Cay and Long Cay. It is only a quarter of a mile wide, and a heavy swell surges through it continuously; no information can be given as to its depth. As already noted, small fishing boats can thread their way between coral heads to cross the leeward reefs in one or two places, but there are no interruptions of the reef platform on the leeward side. This restriction of the gaps to the windward side is anomalous; on many Pacific atolls there is a strong negative correlation between wind-direction and reef-gap location, though this is not perhaps as widespread as might be supposed (Emery, Tracey and Ladd, 1954, 142-143; Newell, 1956, 326-327). According to Newell, "The passes mark old gaps in the atoll rim where organic accretions evidently have not kept pace with the general upward growth during subsidence....the distribution of passes may in some way be controlled by prevailing winds." (1956, 326-327). As shown in this paper, there is no necessity in the case of the British Honduras atolls to invoke subsidence, though this is far from denying that it may have taken place; and it has been shown that subsidence on a large scale has taken place on many Pacific atolls (Emery, Tracey and Ladd, 1954, 74-91; Ladd and others 1953), and in the Bahamas (Spencer, 1951). The interpretation followed here is that the reefs have grown up in post-glacial times on structurally-controlled foundations. The reason why the gaps should be confined to the windward reefs, during such development, while the leeward reefs are virtually continuous, remains unknown.

On one point, however, the reefs agree with general atoll experience, in that the zone of living coral on the reef-flats is wider on the windward than the leeward sides. The reefs of Glover's Reef may be considered to fall into four groups, on the basis of width and orientation:

(a) the northern reef, facing north: the reef-flat here has an average width of about 500 yards, and judging from air photographs it is coral-covered for one-third of its width.

(b) the eastern reef, between Northern Entrance and Northern (or Northeast) Cay, facing east: the width of the flat varies here from 500-1400 yards, and averages some 1100 yards. The width of the zone of growing coral remains fairly constant at about one-third of a mile.

(c) the southeast reefs, from Long Cay to Southwest Cays, facing southeast: the flat there is much narrower, from 200-500 yards wide, with a fringe of coral 100 yards wide at its outer edge.

(d) the leeward reefs, facing WNW, with a fairly constant reef-flat width of 4-500 yards, increasing to 6-700 yards in the south.

The width of zones (a) and (b) is clearly related to the prevailing north and east winds. The southwest reefs are narrow, in view of their windward location, but this may be explained by the fact that they are aligned sub-parallel to the winds, rather than transverse to them. Ecologically they are more comparable to the main east reef (transect C), rather than to leeward reefs of similar dimensions (transect F). The reef-flat back of the zone of living reef sinks lagoonward and carries 2-6 feet of water. Wherever seen, its surface consisted of loose foraminiferal, algal and coral sand, sparsely covered with green algae and Thalassia. No rock platforms were seen back of the living reef area.

The bathymetry of the lagoon enclosed by the reefs is very inadequately known, though some soundings were made in the southern third of the lagoon in 1961. Plans to sound down the centre of the lagoon were abandoned because of adverse weather. Taking the soundings, air photographs, and local information together, the following picture emerges. The reef-flat is bounded lagoonward over most of its extent by a submerged platform with an average width of one mile. The limits of this platform can be well seen on air photographs, and are shown on the atoll map. The platform appears sharply bounded lagoonward by a steep slope to the lagoon floor, and seaward by a steep rise to the present reef-flat. Line soundings in the southern part of the lagoon showed that on both windward and leeward sides it has a depth of 3-4 fathoms. The significance of this platform at such a depth will be discussed later, but attention is here called to the presence of a very similar feature, hitherto undescribed, along the British Honduras barrier reef. Here a platform extends 1-4 miles lagoonward of the present reef-flat at depths of 2-4 fathoms. No comparable submerged platform is seen on Turneffe or Lighthouse Reef, since the lagoon floors do not fall below these depths.

The lagoon itself is unique in the three atolls because of its depth and the very numerous patch-reefs and pinnacles rising to its surface. On the very limited data available, the lagoon appears to be basin-shaped, with depths of 10-12 fathoms near the sides and 17-20 fathoms in the centre. Local informants, found in all other instances to be accurate, stated that the maximum depth of the lagoon, found near its geographical centre, is 24 fathoms. Some 700 reef patches rise to the surface from the lagoon floor, not counting those on the 2-4 fathom shelf or the reef-flat proper, and some of these are as much as 500 yards long. Most are roughly circular, with coral growth on the east and north sides (transect G); a number are elongate, with apparently random orientation, but similar living-reef distribution. The basin-shaped lagoon shoals towards its northern and southern parts, and the greatest concentration of patches is found in the deepest central area. This is in apparent contradiction to the fact that in the Pacific most reef patches are found in the shallowest lagoons (Cloud, 1957; Nugent, 1946, 744-745). The number and density of reef patches in the Glover's Reef lagoon is much higher than on Lighthouse Reef. Attention may be called to the 'chain' of large patch-reefs orientated north-south near the lagoon centre, which recalls some of the north-south chains of patch-reefs in the Barrier Reef lagoon, the north-south Middle Reef of Lighthouse Reef lagoon, and the north-south "ranges" of cays in the Turneffe lagoon.

There is no information on the nature of the lagoon floor. For some reason (possibly the depth of the floor) the conspicuous downwind attenuation of patch-reefs by debris trails found, for example, by Newell on Raroia (1956, 353-355, Plates 29-30), is not seen on Glover's Reef (though Raroia lagoon reaches greater depths than Glover's Reef). In no single instance was a patch-reef or outer reef seen with dry elevated reef-rock, similar to that found intermittently on Lighthouse Reef, which suggests that whatever cause gave rise to the Lighthouse Reef drying patches was limited to that Reef alone.

Land fauna of Glover's Reef

Schmidt (1941) records only two reptiles from Glover's Reef, collected by the Field Museum Mandel Caribbean Expedition in 1940, but gives no location details. They are Anolis sagrei Dumeril and Bibron, and the wish-willy, Ctenosaura similis. Ctenosaura was seen frequently in 1961 on Northeast Cay, Long Cay and Middle Cay. Iguana iguana, known on Half Moon Cay, Lighthouse Reef, was not seen during our brief visits to Glover's Reef.

Salvin appears to be the only ornithologist to have visited Glover's Reef, in 1862, and he recorded (1864) Columba leucocephala (bald-pate pigeon) on Middle Cay, and Pelicanus occidentalis (brown pelican), Sterna antillarum (lesser tern), and Thalasseus regius (a larger tern) from Long Cay. On Southwest Cay II, he found "Noddies everywhere....many thousands in all", while eggs of Sooty Terns "might be gathered by the basketful" (1864, 383). The nesting birds on this cay are named as Anoüs stolidus and Anoüs minutus by Bond, who did not however visit this reef. He comments: "I was told that this colony had greatly diminished in size. Since this islet is the only known breeding ground of A. minutus in the entire Caribbean area and the only locality where A. minutus americanus Mathews has been reported, it would seem advisable to establish a bird sanctuary here" (1954, 6). This has not so far been done. At the request of Dr. G.H. Lowery of Baton Rouge, we confirmed the existence of this colony of white-capped brown noddies (A. stolidus?) on this cay in 1961, but certainly not in the profusion described by Salvin. The whole cay is under coconuts, and the noddies appear to nest in their crowns. They are seen in large numbers flitting over the water at dawn and dusk, but it is difficult to approach them on the cay. According to fishermen they vary greatly in number throughout the year.

Other birds seen in 1961 included a few brown pelicans at Northeast and Middle Cay, a single osprey (Pandion haliaetus) at Northeast Cay, and a pair of frigate birds (Fregata magnificens) at Middle Cay. Salvin recorded the brown booby, Sula leucogaster leucogaster Boddaert, between Glover's Reef and Cay Bokel. There are two specimens of the flycatcher Elaenia martinica chinchorrensis Griscom from Middle Cay in the Carnegie Museum, Pittsburgh (known from Lighthouse Reef and Chinchorro Bank), and specimens of the hummingbird Anthracothorax prevostii prevostii from Middle and Northeast Cays, also in the Carnegie Museum (Todd, 1942, 294). One species (a small white gull?) was seen nesting on the small island northeast of Long Cay in May 1961, laying its eggs in small excavations on bare sand about two feet above the sea, at the leeward end of the cay. There were two eggs to each nest, each about 3/4 inch long, silver-grey in colour and speckled dark brown, extremely difficult to see against the sand background. Seven species of birds were thus seen by Salvin (the seventh is the mockingbird Mumus gilvus leucophaeus Ridgway); Elaenia and Anthracothorax make nine; and the osprey and frigate birds seen in 1961, eleven.

Of domesticated animals, there are some black pigs and chickens on Long Cay, and pigs on Middle Cay. Hermit crabs are found in large numbers, especially on Northeast Cay, but it is not known whether rats are a common pest to coconuts on any of these cays.

The cays of Glover's Reef

There are at present six cays on Glover's Reef, all on the southeast side. Five of these (Northeast, Long, Middle, and Southwest I and II) are of a large size, ranging from 330 to 1100 yards in length; while the sixth, Long Cay North, is a smaller island 160 yards long north of Long Cay. All are formed of clastic reef material, and no solid rock, apart from beachrock, outcrops on any of them. Some confusion has been caused by the insertion on published Admiralty charts of a further cay lying within the lagoon on the west side of the reef, 4 miles from the northwest corner of the atoll (Chart 1797 of 1929); it is described as having trees 20 feet tall. This cay is mentioned again in the West Indies Pilot, 1956, 459-60. According to Vermeer, who "viewed it at a distance from the air", "towards the centre of the lagoon a solitary cay, which appears to be covered with mangrove, rises from the bank to breach the otherwise continuous expanse of water" (1959, 19). This cay does not now exist, and has not existed for many years. No local fisherman with knowledge of these waters can remember seeing it, though the location of the island is known (bearing Northeast Cay 130°, Southwest Cay II 180°, uncorrected compass bearings), near a small gap in the leeward reef. The site was visited in 1961, and carried 3-4 feet of water; occasionally an ephemeral sandbore breaks surface. The site is known as "Bushy Spot" or "Bushy Cay". It is interesting that Owen in his MS chart of 1830 (H57) shows no cay at this point: so that the cay marked on the charts must have accumulated, been vegetated, and swept away, some time between approximately 1830 and 1930. It should be erased from charts.

Detailed maps were made of the cays on the southeast rim, and descriptions of each of these cays are given here. It might be noted that in Owen's 1830 MS chart, two small sandbores are marked between Middle Cay and Southwest Cays which have now disappeared. Vermeer (1959, 19) describes seeing "at the northern edge, two sand ridges, visible at some distance"; these do not break surface, though they may occasionally form ephemeral strips of dry land, as in fact happens in similar circumstances along parts of the Barrier Reef, for example north of Tobacco Cay.

Northeast Cay

Northeast Cay (fig. 38) is situated at the southern end of the unbroken east reef of Glover's Reef, on the north side of the entrance between Northeast and Long Cays. The cay is semi-circular in shape, 330 yards long along its near-straight northern shore, and with a maximum north-south width of 200 yards. The physiography of the island is basically simple: a shingle ridge rises steeply on the south and southeast sides, protecting a gently-sloping surface of sand and gravel, which falls away to the north shore. The shingle ridge begins in a few yards from the shore on the east side of the cay, about 100 yards from its northeast corner. Small coral-blocks and white rubble top the sand beach on this side of the cay, but the sand beach gives way southwards to a shingle shore. The shingle ridge on the southeast side is a double feature: grey and blackened older shingle and small coral-blocks form a layer one foot and more in thickness, overlying an undercut and eroded formation of grey sand at least $1\frac{1}{2}$ feet in thickness. In front of this lies a fresh ridge of white, relatively unworn coral fragments, heavily encrusted with Homotrema rubrum. The newer ridge is 3-4 feet wide, and rises to a height of 2 feet; it can be traced without interruption round the base of the older shingle ridge for over 300 yards. It is separated from the older ridge by a slight depression, and there is an undoubted difference in composition between the two ridges. The older ridge consists mainly of grey and blackened sticks of Acropora cervicornis, slabs of A. palmata, and small individual coral colonies, generally more than 4-5 inches long. The new ridge consists of smaller coral fragments, chiefly A. cervicornis sticks comparable to those in the older ridge, though fresher, together with large quantities of Halimeda, including still-segmented fronds, a considerable proportion of Lithothamnion nodules, well-preserved conch shells (Strombus sp.), and tests of echinoids.

The whole shingle ridge complex averages 5 feet in height, with an estimated maximum of 6-7 feet nearest to the living reef at the southeast corner of the island. Along the south shore it is somewhat lower, decreasing to 5 feet in 150 yards westwards, and then more rapidly, to 3-4 feet, along the southwest shore. With the decrease in height, the size of the constituent material decreases, and the newer ridge becomes less important. The shingle section at the southeast corner seems to show considerable erosion at this point after the formation of the old ridge and before the formation of the new. The greater part of the old ridge has here been removed, leaving only its landward feather-edge overlying sand, across which the shingle ridge had been advancing at the time of its destruction.

At two places on the south shore, beachrock extends seaward from beneath the shingle ridge. Both outcrops are sandy, poorly consolidated, and dip seawards, indicating a slight shift of the shore northwestwards, away from the reef. Small blackened, rotten coral blocks and slabs of small size litter the reef-flat along the base of the shingle ridge on the southeast side.

The evidence of shore retreat shown by the shingle section and the beachrock is further reinforced by the character of the northeast shore, immediately north of the end of the shingle ridge. The sandy shore here consists of small bays separated by bluffs 1-2 feet high, outjutting 2-3 feet, and generally carrying individual coconut palms. The small headlands are being gradually undercut, and in some cases, at least on the surface, appear to consist now of a tangle of roots with little clastic debris at all, all the finer material having been flushed out by the waves. Many of the coconut trees have fallen, with a remarkably constant direction normal to the shore (compass bearing 55-65° east of north), which may suggest hurricane damage. Undercutting on this scale is limited to this segment of the cay shore.

The other shores of the cay, to north and northwest, are low and sandy, with intermittent scatterings of fine coral shingle. Vegetation approaches close to the sea, and no active progradation or degradation seems to be in progress. A submerged sand-spit is building out from the northeast point into the shallow northern bay, the bottom of which is largely covered with Thalassia. Short choppy seas are found in this bay during moderate easterlies.

The interior of the cay has little of interest physiographically, with the exception of a mudhole toward the east side, located in the lee of the higher shingle ridge. No standing water was seen in this hole in 1961 (May and July), and the black soil was largely covered with a ground mat of Wedelia trilobata. The greater part of the cay surface consists of dirty grey sand and some fragmented coral colonies. The windward shingle ridges form a band some 10 yards wide on the south and southeast shores, and immediately landward there is another zone, 10-15 yards wide with an indefinite landward edge, of what McKee (1956, 8-9) would term "rampart wash", or a surface layer of shingle-size debris.

The vegetation of Northeast Cay is of interest. Most of the island is covered with coconuts, with a ground cover of Wedelia, Euphorbia, Ambrosia or grasses, but near the southeast side is an area of tall broadleaf woodland, comparable to that at Half Moon Cay, Lighthouse Reef. Near the shore this consists of Coccoloba overlooking Tournefortia, but inland, in addition to Coccoloba, there are tall trees of Bursera simaruba, Ficus ovalis (?), Neea choriophylla, and a palmetto (Thrinax parviflora(?)). The undergrowth in this area consists of Ambrosia, Wedelia, and the grass Eragrostis domingensis, which here reaches a height of 6-7 feet. The seaward-facing shores of the cay are lined mainly with Tournefortia, with a little Suriana and a number of small trees of Cordia sebestena; the leeward shores are covered with low Sporobolus and Sesuvium, with Conocarpus and Erithalis bushes at the northwest point.

Long Cay North

Between Long Cay and Southwest Cays the southeast reef of Glover's Reef extends without break in a NE-SW direction. Long Cay and Long Cay North are located at the northeast end of this reef, south of the gap between the southeast reef and Northeast Cay. Looking towards Long Cay from Northeast Cay, one sees the coconut covered area of Long Cay proper, with two low, bush-covered areas in front. One of these is a peninsula extending from the northeast corner of Long Cay; the other is an island, here designated "Long Cay North", separated from Long Cay by a narrow deep channel which allows heavy seas to roll in from the reef-flat. This smaller island is known locally simply as "sandbore".

Long Cay North (fig. 40) is approximately 160 yards long, widening reefwards to a maximum width of over 50 yards. The main body of the cay is prolonged westwards (lagoonwards) by a narrow, curving 50 yard long spit of brilliant white sand. Water 2-3 fathoms deep is found within a few yards of the northwest point on both its north and south sides. The greater part of the cay is built of ridges of coarse, unconsolidated white sand. There are no hard-packed shingle ridges, but fresh white shingle is scattered over the sand surface, and forms a ground cover, particularly at the east end. There are no large blocks, either on the cay or immediately offshore. The beach ridges are not more than 2 feet high, and the maximum height of the cay is probably not more than 3 feet at any point. The western sand-spit decreases in height lagoonwards until it is washed over by waves approaching from each side at high tide. The whole spit is probably awash in storms. The shape of the cay is adjusted to wave-refraction patterns in the two adjacent gaps, as shown by the sketch-map of observed patterns. At the extreme east end of the island, the interior is formed by small rubble, fringed by a new white sand beach a few feet wide. This in turn is margined seawards by a low ridge of fine white debris comparable to that described at Northeast Cay. The island bears no sign of great antiquity, and was not noted by Owen in 1830 (MS chart H57).

The main body of the cay at the eastern end is covered with a compact thicket of vegetation, of which the bay cedar, Suriana maritima, is the dominant member, forming bushes 10 feet high, which in places are wind or spray trimmed. The only other trees are a number of Conocarpus erectus bushes, and one or two small coconuts on the southeast shore. At the exposed east end of the cay, and intermittently along the north shore, are clumps of Tournefortia gnaphalodes, and in May 1961 a a number of tiny Tournefortia seedlings were advancing westwards along the sand spit. The ground beneath the Suriana, and round the fringes of the vegetation thicket, is covered with Sesuvium portulacastrum, some grasses, and Euphorbia. A single specimen of Sophora tomentosa was seen on the south shore, but not in flower.

No beachrock is exposed round the cay margins.

Long Cay

Long Cay (fig. 41) is situated near the northeastern end of the southeast reef; it is a long, narrow island, aligned with its long axis parallel to the reef, and has many features of interest. The cay is 680 yards long along its main axis, which ranks it among the largest sand cays on this coast, and is roughly hour-glass shaped: the width decreases from a maximum of 130 yards in the west to 70 yards in the centre, increasing again to 160 yards near the eastern end. The addition of a low, bush-covered peninsula, similar in appearance to Long Cay North, at the northeast end of the cay, gives a maximum north-south width of nearly 250 yards at this end of the cay. The south shore is fairly straight and overlooks a shallow, boulder-studded reef-flat, with waves breaking on living reef only 30-40 yards from the shore. The north shore forms a broad, arcuate embayment, terminated by lagoonward projections at both ends.

The dominant physiographic feature of this cay is the massive development of shingle ramparts on the seaward side, which cannot be matched on any other island on this coast. The main features of the rampart can be seen from the map and section. The ridge begins at the southwest end of the island as a mound of small shingle and scattered coral blocks up to 2 feet in diameter. Already at this point the ridge is a double feature—an inner mound of blackened debris, and an outer lower ridge of glistening white, Homotrema-encrusted small coral and nodular Lithothamnion. In the slight intervening depression there is a cover of Hymenocallis littoralis growing directly on the shingle. The whole ridge system rapidly rises to a height of 5 feet on the southeast shore, where again the seaward face of the inner ridge is formed of grey-white interlocking shingle, chiefly Acropora cervicornis sticks and A. palmata slabs, with a fresh white ridge at its base. From its crest the surface dips slightly inland, and presents a barren expanse of rough, blackened coral blocks, generally between 6 inches and 2 feet in diameter. Some 30 yards inland (20 yards from the first major crest) a second blackened ridge of coarse, broken blackened blocks rises above the backslope of the first (fig. 43). The material composing it seems coarser than that composing the first ridge, and much coarser than that composing the depression between the two crests. It is also considerably older, as shown not only by the degree of blackening of the constituent coral (Teichert, 1947), but also by the breakdown of the coral blocks themselves. Many of these, notably Montastrea annularis, are breaking down by subaerial radial fracture, first into large segments of the original colony, then into cuboidal fragments averaging 1 inch across, and then into constituent limestone grains.

As these two ridges are followed eastwards the crests move together and the intervening depression becomes less pronounced; the two ridges can, however, be clearly traced along the whole length of the shore, both topographically and by debris characteristics. The outer ridge has a fairly constant altitude of 5-6 feet at its crest; the inner ridge at the line of section reaches nearly 9 feet and may exceed 10 feet near the eastern end. North of the second crest the debris decreases in size fairly rapidly and gives way to grey sand. In places, there is a distinct step-like margin on the north side of the inner ridge, as though the shingle had been pushed back over a pre-existing sand surface. The total width of this shingle complex averages 50 yards, and in places is nearly twice that figure. Locally it occupies one third or even one half the width of the cay. Along the east shore, the ridge sinks rapidly to 2-3 feet above sea-level, and the calibre of the material comprising it also decreases.

Along most of the length of the cay the surface falls relatively rapidly from the shingle zone to the north bay, and is composed of dark sand and small fragments of rotted coral. At the east end, however, protected by both the eastern and the southern shingle ridges, a depression has been formed in the center of the island, occupied by a sheet of still, stagnant water approximately 80 yards long and 40 wide. This pond is surrounded by an apron of soft, rich brown humic soil, which may at times be flooded. The whole of the depression containing the pond, which lies approximately at sea-level, is 120 yards long and 80 wide; it was impossible to survey it in detail or to excavate because of the intense mosquito infestation.

Northwards, as has been noted, the island is prolonged by a low peninsula similar in appearance and size (120 x 50 yards) to Long Cay North. Long Cay has been inhabited by a single aged negro for 31 years, and according to him the peninsula is only intermittently connected to the cay, but nothing was seen in the physiography to support this. It is formed mainly of coral rubble, with a ridge structure on the east side, sheltering an area of white sandy beach to the west. The maximum height of the ridge is 2-3 feet. Coconuts are not found on this peninsula, and the vegetation (fig. 42) consists of a thicket of Suriana maritima, Conocarpus erectus, and low bushes of Tournefortia gnaphalodes. Again, the resemblance to Long Cay North is striking. A small pond has been dammed up at the northern extremity of the peninsula by the shingle ridge.

The whole of the north shore is low and sandy, fronting a shallow bay, the floor of which is thickly carpeted with Thalassia. With the exception of the shingle ramparts and the northeast peninsula, the natural vegetation has been removed from the whole of the cay for coconut plantations. Over much of the island, beneath the coconuts, there is now only a sparse and intermittent ground cover of Euphorbia and grasses. Much of the shingle area is completely barren, except for clumps of Tournefortia gnaphalodes and Coccoloba uvifera on the seaward side, and some patches of Hymenocallis littoralis. The more diversified vegetation of the northeast peninsula has already been described. Even the stagnant water and marshy flat at the east end of the island has been cleared of distinctive vegetation, except for some small Conocarpus round its edges. The whole of the cay, with these exceptions, is covered with dense cocal, with much coconut trash forming a patchy ground cover. A couple of palmettoes were noted near the south end.

There is an outcrop of beachrock at the southeast corner of the cay, where a rock promenade extends for over 100 yards along the shore and continues beyond the cay shoreline for another 40-50 yards. The exposure here is strikingly similar in distribution to that at the southeast corner of Half Moon Cay, Lighthouse Reef. The rock dips to the SSE, and varies in width from 3-5 feet. Along its landward edge there are a number of erosional remnants rising above the general level (which is close to mean sea level) for 6-9 inches. There are two lines of this beachrock, parallel to each other, with water 2-3 feet deep between.

There are several huts on the cay, which is permanently inhabited by a caretaker who keeps the cocals cleared. Fresh vat water is available.

Middle Cay

Middle Cay (fig. 43) is located near the centre of the southeast reef of Glover's Reef, without any marked reef entrance or gap nearby. The island is of fairly simple outline, and aligned NE-SW, parallel to the reef. It is 450 yards long, and increases in width from 120 yards near the southwest end to 240 yards in the northeast. Recurved spits are found at both northeast and southwest ends of the island, projecting lagoonward.

The seaward shore rises above a narrow, shallow reef-flat, extending outwards from the cay for 30-40 yards to living reef; it is littered with blackened uprooted blocks of coral, most of them of small size. The seaward shore itself is formed by a steep shingle ridge, which rises northeastwards to a maximum height of 5-6 feet above sea-level (fig. 44). It is formed of white to grey coral rubble, in which Acropora sticks and slabs and small Montastrea and other globular colonies are abundant. Banked along the seaward side of this ridge is a lower bank of fresh fine debris, much encrusted with Homotrema, and containing abundant nodules of Lithothamnion up to 6 inches long. Lagoonward of the crest of the main ridge, blackened and decayed rubble extends for 60-70 yards, before giving way to sand and fine debris. Along the foot of the ridge there is an extensive outcrop of beachrock. This begins near the northeast corner of the cay, in the form of several yards of incipient beachrock at about mean sea level; the beachrock here is little more than an indurated crust on fine sand. Following the rock southwestwards, it appears after a short interval as a distinct seaward-dipping ridge of more consolidated rock, forming a platform 1-2 feet wide, with a broken, pitted surface, from which rise several higher fragments 6-9 inches above the general level. These projections appear to be coral colonies weathered out of the general beachrock matrix. The beachrock trends parallel to the reef, and maintains this parallelism when the shore ridge begins to trend away from the reef-edge southwestwards. The total length of this more indurated rock is about 250 yards.

Near the southwest corner of the cay, the seaward shingle ridge becomes lower, and finally is replaced by a gentle sand beach scattered with coarser debris. Beginning at this point, and extending northeastwards in the lee of the shingle ridge, is a zone of swamp and intermittent standing water 200 yards long. In May 1961 there was no connection between the sea and the swamp area, because of the low sand ridge colonised by a stand of mature Rhizophora 25-30 feet high. This colony now stands on dry land 2 feet above sea-level round the southwest margins of the swamp area, and by its attitude appears to have been advancing seaward for some time. This evidence of outbuilding appears to conflict with the evidence of shore retreat at this point shown by the beach-rock. In May 1961 the depression enclosed two mudholes with standing water, surrounded by extensive flats at about mean sea level, with rich brown humic soil, probably at one time under mangroves. Lagoonward of this depression rises a broad low sandy mound forming the lagoon shore. Elsewhere the cay surface sinks gradually from the edge of the shingle zone to the lagoon beach.

Sedimentation appears active at both NE and SW ends of the island. At the southwest end a small unvegetated sand-spit has built out 25 yards into the lagoon, and is continued by a broad submerged spit, with several Rhizophora seedlings growing on it. At the northeast corner a hook-like spit has built out westwards into the lagoon, to enclose an extremely sheltered bay, containing a near-stagnant shallow pool of water. There is no evidence of undercutting round the cay margins, except for one or two fallen coconut trees on the northeast shore.

As with the rest of the Glover's Cays, most of the vegetation (fig. 45) has been removed for coconut plantation. At the northeast end of the cay, and along most of the sandy lee side, there is an extensive ground cover of Ambrosia hispida and Stachytarpheta jamaicensis. The shingle area supports a few small bushes of Tournefortia gnaphalodes, whose seedlings have invaded the sand area to the northeast, and more extensive carpets of Hymenocallis littoralis, scattered bushes of Conocarpus erectus, and coconuts. Large red mangroves (Rhizophora) and Conocarpus are found round the mudholes, especially on the seaward side, but most of the vegetation round the island margins has been cleared. The lagoon beaches are colonised only by low grasses, Stachytarpheta and similar plants in places, and occasional Conocarpus bushes. The greater part of the island is covered with coconuts, with little ground cover. The bottom of the northern bay is thickly covered with Thalassia.

There are several huts on the cay, which is generally inhabited, and a single poor quality well.

Southwest Cay I

Southwest Cays are situated near the southwest extremity of the southeast reef of Glover's Reef, and are the most southerly cays on this atoll. There are two islands in the group (Admiralty charts dubiously mark a third small one to the north of the two large islands); and these are here termed, for convenience, Southwest Cay I (the northeast cay) and II (the southwest cay, Salvin's "Southwest-of-all Cay"). To some extent these two cays form a unit, but as they have very diverse characteristics they will be separately described.

Southwest Cay I (fig. 46) is located 2½ miles southwest of Middle Cay. It fronts a shallow reef-flat, 60-70 yards wide, studded with blackened coral blocks, much pitted and eroded, and is aligned with its long axis parallel to the reef. The island is trapezoidal in shape: it has a maximum length of almost exactly 500 yards, and decreases in width fairly regularly from 330 yards along its southwest shore to little more than 100 yards along its northeast side. The same physiographic units are present on the island as on the other Glover's Reef cays, but their degree of development differs and their pattern is more complex. Essentially the cay falls into three parts: a seaward rubble and shingle area, an interior swamp zone, and the leeward sand area. The seaward shingle and rubble zone does not form a continuous distinct ridge, as on the other cays. It consists of large, deeply weathered, jagged blocks of coral, forming a low rubble carpet, gradually becoming sparser seawards and more continuous landwards. Many of the blocks are no longer identifiable on casual inspection; there are hardly any fresh blocks, and most of those exposed are coloured yellow, grey or black, presumably by surface algae. Near the seaward edge of the rubble zone, the blocks stand in water 3-4 inches deep, and the floor here consists of pitted, eroded yellow and grey rock. The width of the reef-flat and shallowness of the water make it likely that considerable variation in temperature, salinity and pH take place near the shore. A number of marine molluscs are very noticeable in and around the blocks. The rubble zone over the greater part of its extent (i.e. for some 300 yards from the northern end of the cay) does not rise more than two feet above the sea: the blocks simply become more crowded landward, and are covered with dense vegetation, through which one catches glimpses, from the seaward shore, of the interior swamps. Toward the middle of the seaward side of the cay, however, a number of large Avicennia trees have advanced across the rubble zone almost onto the reef-flat, and southwest of this point, the seaward shore changes in character. The amount of rubble in front of the shore decreases, the shore itself steepens, and is formed by an arcuate shingle ridge 5 feet high, overlooking a small sand beach containing much Halimeda. This true shingle ridge is about 150 yards long; it consists of white to grey small coral shingle, similar to that on the other cays. From the crest of this ridge the cay surface declines rapidly at first, then more gently, to the leeward shore.

The seaward shore does not trend parallel to the reef for its whole extent: for the greater part it does, and is here fringed either by the rubble zone or shingle ridge, but towards the southwest the shore turns westwards, while the reef continues along its NE-SW axis. As the shore swings away from the reef, the reef-flat widens and deepens, the fringe of blackened boulders disappears, and the shingle ridge gives way to a narrow sand beach.

From this account and the map, it is apparent that the seaward shore is backed by a zone of swamp and standing water, divided into two parts. The first extends from the northeast side of the cay, in the lee of the rubble zone, and is some 280 yards long and up to 120 yards wide. The second extends inland from the southwest side of the island for distances of 120-180 yards. It is interesting to note that the marsh zone is interrupted immediately in the lee of the true shingle ridge, where dry land extends across the whole width of the cay, but it is impossible to state with certainty whether this is due to sedimentation and drying out of the mudhole at this point, or to higher upbuilding of the original cay surface. The two swampy areas are rather different in character. The larger one includes a number of pools of standing water, but the natural vegetation has been cleared, and an effort is being made to colonise almost the whole of this low-lying area with coconut palms. These are planted out in rows as young seedlings, several yards apart, and banked up with fresh sand from other parts of the cay. There are several dozen of these conical mounds of sand, each with a young coconut palm, often rising out of shallow stagnant water. Along the seaward margin of this larger swamp, and along the northeast shore, are a number of Rhizophora and Conocarpus trees.

The southwest swamp area is wilder; there is less standing water, but the ground is very soft and muddy. There are many coconut trees in the swampy area, which do not seem to have been planted, while along the southwest shore and in places throughout the swamp are trees of Conocarpus and Rhizophora. From the seaward side the southwest shore presents an unbroken fringe of red mangrove, 10-15 feet high, rising out of water up to 2 feet deep. There is, however, no general connection between the sea and the swamp, for on scrambling through the Rhizophora rim one reaches a low sand ridge some yards back from the seaward edge, forming a barrier between sea and swamp. Isolated clumps of Rhizophora extend reefward from the main body of mangrove, to partially enclose a small bay on the seaward shore; this bay is very sheltered, has a low sandy shore, and is floored with Thalassia and Penicillus.

The area between the two swamp zones, and along the north shore of the cay, is built of grey sand with little relief. Much of the lagoon shore is undercut, and in plan consists of a number of small bays and promontories, the latter often topped with leaning or fallen coconut trees. Near the northeast end of the lagoon beach, a large number of trees have fallen landward, and now lie in a roughly north-south direction, probably indicating storm action. The bottom is generally shallow on the lagoon side, with a Thalassia bottom, and there is much fresh white sand accumulation at the foot of the undercut cliff. At the southwest end of this shore, a small spit is building out into the lagoon, and several weed-covered sand-banks are exposed at low tide.

Much of the vegetation (fig. 47), especially of the sand and swamp areas, has been removed for cocals, and much of what remains is mangrove --Rhizophora mangle on the southwest and northeast shores, Avicennia nitida and Conocarpus erectus along the seaward side, and associations of these three in the swamps themselves. There are a number of Tournefortia gnaphalodes bushes on the high shingle ridge, and a little Tournefortia and Coccoloba uvifera on the drier parts of the rubble zone. The greater part of the sand surface, under the cocals, is covered with Euphorbia, grasses (including Sporobolus virginicus), and coconut trash.

There are four houses on the cay, which is generally inhabited. There are no freshwater wells, and only small tanks for rainwater.

Southwest Cay II

Southwest Cay II (fig. 48) lies immediately south and west of Cay I, but is very different in physiography. Unlike Cay I it is not aligned parallel to the reef-front, but at an angle of some 45° to it, the cay trending slightly east of north and the reef NE-SW. Immediately west of Cay II is the main southern entrance of Glover's Reef. Cay II is rather longer than its neighbour (total length 580 yards), is widest in the south (nearly 250 yards), and decreases in width northwards. The northern half of the cay maintains a fairly constant width of 80-100 yards.

Only at its southern end does the island approach the reef, and thus shingle is absent except on the south and extreme southeast shores. Nor is the swamp zone found on every other large cay on Glover's Reef represented here. The cay is built mainly of white to grey sand, with much Halimeda and small unrecognisable coral fragments, with an admixture of larger pieces of broken coral, Strombus shells, nodular calcareous algae and other calcareous material, giving a strongly bimodal sediment distribution. The shingle ridge at the southeast end does not rise higher than 3-5 feet above sea-level, and consists of small coral fragments, mostly less than 6-9 inches long. The ridge overlooks a reef-flat 25-30 yards wide, littered with blackened blocks and coral rubble. The rest of the cay margins are built of sand, which rather anomalously forms a higher ridge on the leeward side than on the windward. The windward beach is generally low, and shallow offshore, with in places a number of Rhizophora seedlings colonising within 5-10 yards of tide mark. The leeward shore is also sandy, but narrow and steep; and the floor of the northern bay falls rather steeply to depths of 4-5 feet. In part this difference is due to more severe undercutting on the north shore, but it probably results to some extent from greater exposure of the lagoon shore. The seaward shore lies from 100-250 yards from the reef-edge, the only source of abundant coarse and sand-size debris. Further, the flat is shallow, so that only in times of exceptional wave activity will material from the distant reef be thrown up on the seaward shore. The lagoonward shore, trending slightly east of north, is protected, it is true, from the prevailing easterlies and northeasterlies, but is exposed both to northers sweeping down the deep lagoon, and to large waves refracting through the southern entrance.

The undercutting referred to affects much of the cay margins---along the lagoon shore, and along the central part of the seaward shore. On the lagoon shore, undercutting extends for 280 yards from the north end of the cay, and has produced a low, grey-sand cliff between 1 and 2 feet high, capped by vegetation and roots, and overlooking a very narrow white-sand beach. In plan the shore forms a series of minor embayments, with coconut boles on the promontories. Many trees have fallen into the sea; others lean at perilous angles. Further evidence of recent retreat on this coast is found in relict beachrock offshore. There are three separate areas of this, comprising respectively from south to north, two lines, one line and four lines of rock. The rock itself is a well-cemented coarse sand, now rather eroded and pitted on its upper surface and cavernous beneath. All the exposures show in some part a recognisable dip lagoonward. Each of the lines trends nearly north-south, some a little west of north; the coast itself trends almost NNE, and is clearly retreating eastwards. The amount of this retreat seems, from the extent of beachrock in each place, and its distance from the present shore, to increase northwards, and in fact, south of the southernmost beachrock outcrop there is no evidence of coast erosion at all on this side of the island. This pattern probably results from the refraction of waves round the south end of the island, through the southern entrance. Along the southern part of the lagoonward shore the waves are further refracted and advance transverse to it: in the south the shore is static or even aggrading, in the north it is retreating, and the degree of retreat increases northwards.

The southern part of this lagoon shore is of interest. Immediately south of the undercut zone, the shore is formed by a beach of hard-packed white sand, some 20 yards wide, and rising 2-3 feet above sea-level. Vegetation begins at the crest of this beach, though a few bushes of Conocarpus in places occur below it. At the extreme southwest corner of the cay, aggradation is now active. The line of the "core-island" can be traced as an undercut low cliff of grey sand, capped with coconuts, and partially obscured below by fresh sand accumulation. This fresh sand extends lagoonward for 20-30 yards from the old shore, and is thrown up in three main ridges, approximately equidistant, with a fourth much smaller ridge very recently built round the present shore. That this whole accumulation is not seasonal is demonstrated by the vegetation. On the "core-island" above the cliff, there is little but coconuts and some lilies. The succeeding depression is either bare or has a sparse cover of Sporobolus virginicus, but on the first sand ridge from the cliff there are a number of young coconuts, probably less than 5 years old. The backslope of the second ridge is covered with typical strand pioneer colonisers, forming a low mat, chiefly of Ipomoea, Sesuvium and Euphorbia, with occasional Conocarpus. The third and most seaward of the ridges is yet unvegetated. Thus the long-term erosion farther north is balanced by aggradation in the south, extending back over several years at least. Between this zone of aggradation and the windward shingle ridge is a further short extent of undercut shoreline, with a bay-promontory plan, cliffs 1-2 feet high, and some fallen coconut trees.

The seaward shore possesses many points of interest too, but is more enigmatic. North of the shingle ridge (where there is no sign of either erosion or aggradation), the shore is retreating for a distance of 200 yards, as shown by undercut and outstanding coconut boles. But the erosion is not so rapid as that on the west side; the offshore area is gentle and colonised by many mangrove seedlings. Erosion is clearly caused by waves traversing the wide reef-flat almost normally. Beachrock is exposed on this side of the cay also, along the present shoreline. There are several patches of poorly to moderately well-cemented sand with Halimeda, the longest extending for 15 yards. There is only one line of the rock, about 2 feet wide, passing under beach sands, not eroded on its surface (which is covered with a rather slimy grey coating), and dipping lagoonward. This is the only example of beachrock with reversed dip on a seaward shore noted on this coast; though examples in other parts of the world are numerous. The reverse dip of exposed surfaces was confirmed by pit-digging 1 and 2 yards up the beach, when the rock was found in both pits at slightly lower elevations than its seaward exposure. If the beachrock now stands in its position and attitude of formation, then it seems that the whole cay has migrated bodily at least 100 yards away from the reef-edge and towards the lagoon since it was formed, in spite of the relatively clear evidence of present erosion on the west, lagoonward shore. In this case the unweathered appearance of the rock is explained by its protection beneath the cay sands. Alternatively, the islandward dip may result from some at present unexplained anomaly, and may have formed recently along the present seaward shore.

Farther north, the evidence of erosion is less, and the shore is margined by a belt of tall Rhizophora 2-3 yards from it, and comparable to the similar belt on the southwest shore of Cay I across the bay. Between the Rhizophora belt and the north end of the island the shore is low and sandy, with very numerous brown sea anemones in shallow water offshore, and some surface induration of sands on the beach itself, presumably almost contemporaneous in age and too friable to collect. The sheltered state of this site might be noted. At the north end of the cay, where it approaches closest to Cay I, a narrow sand-spit some 40 yards long, exposed at low tide, is developing, growing outwards towards a similar spit at the southwest end of Cay I.

The natural vegetation of the cay has been very largely removed for cocals, which now cover almost all the island. One or two Conocarpus bushes are found around the cay margins, especially at the north end, but otherwise vegetation is restricted to a ground cover of climbing plants and grasses, chiefly Sesuvium portulacastrum, Euphorbia sp., Ipomoea sp., and Cakile lanceolata. Sporobolus virginicus is widespread, with much Andropogon glomeratus at the northern end. Towards the southwest end of the cay, the cocal has an undercarpet of the lily, Hymenocallis littoralis.

The colony of brown noddies (Anoüs stolidus) on the island has already been mentioned; the number of these birds contrasts sharply with the relatively birdless appearance of most other sand-cays. Pelicanus occidentalis and Fregata magnificens were seen here in July 1961. There are two houses on the cay, for cocal caretakers, and a tank rainwater supply.

It is interesting to speculate on the relations between Cays I and II, and their very different appearance. They have certainly existed in their present form for at least 2 centuries (cf. Owen, H57, 1830). The wide, sand-floored bay on the seaward side, between the two islands, is generally placid, and probably not more than 3 feet deep in any part. The channel between the two cays is kept open by tidal currents, which will probably prevent the two spits, now advancing toward each other from the southwest end of I and the northeast end of II, from meeting. A lobate sand delta, shown on air photographs, has developed on the lagoonward side of the gap between the cays, and will build further lagoonward as more material is supplied from the reef-flat. Whether the two cays were ever connected is a difficult question; Cay I in particular looks like a cay in the process of growth and consolidation rather than a remnant of a larger island. On the other hand, If Cay II formerly stood 100 yards further seaward, as perhaps indicated by the lagoonward-dipping beachrock of its seaward shore, then the two cays would be appreciably closer together, and the bay much smaller. It is difficult to envisage a bay of this size being eroded under present conditions. One may expect a progressive attenuation of the northern part of Cay II, by erosion on the lagoon side, which may ultimately widen the gap between the two cays, while at the same time the southern part of II increases in size. The consolidation of Cay I, much of which is--or was--standing water, will be largely the result of human activities.

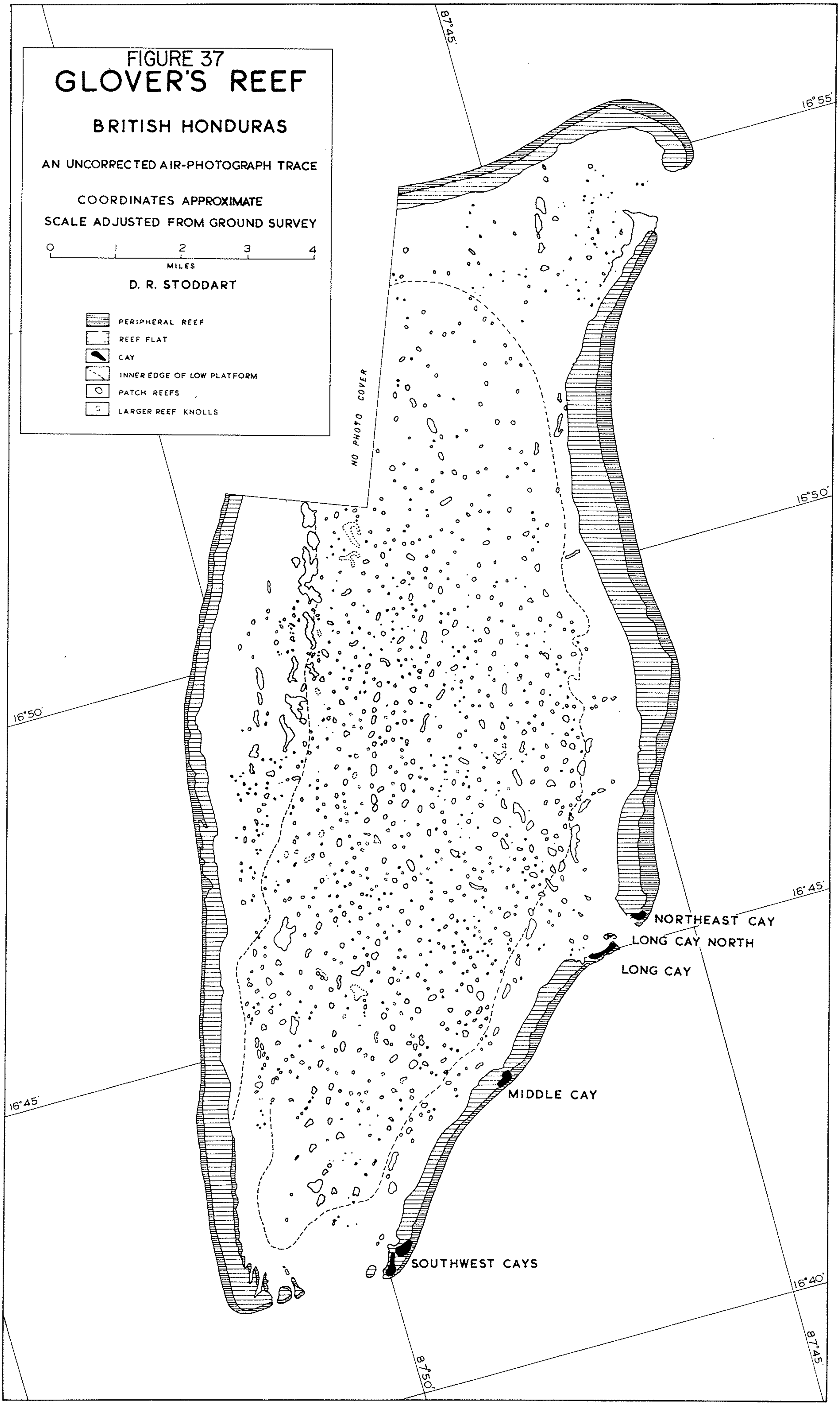
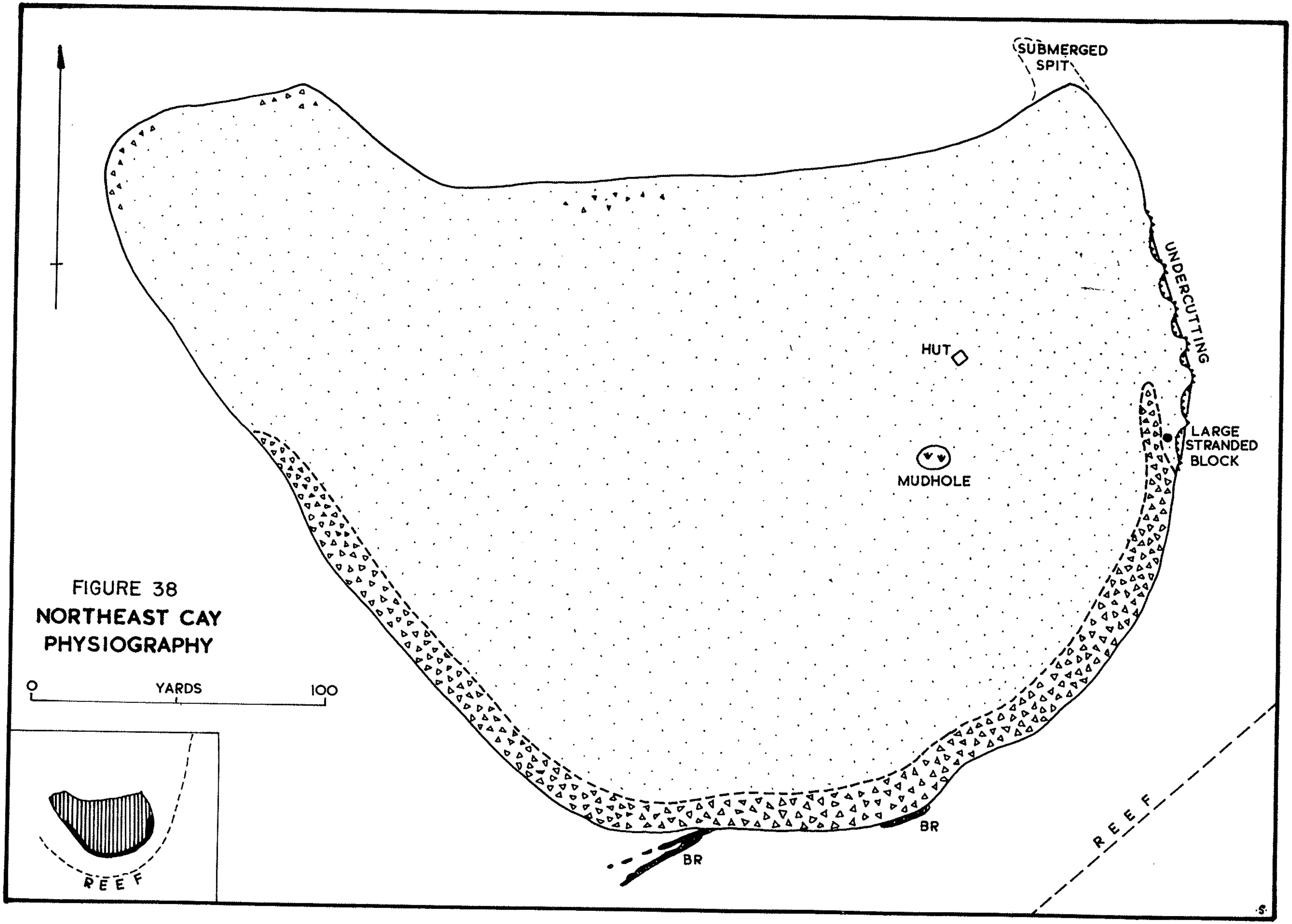


FIGURE 37
GLOVER'S REEF
BRITISH HONDURAS
AN UNCORRECTED AIR-PHOTOGRAPH TRACE
COORDINATES APPROXIMATE
SCALE ADJUSTED FROM GROUND SURVEY
0 1 2 3 4
MILES
D. R. STODDART
PERIPHERAL REEF
REEF FLAT
CAY
INNER EDGE OF LOW PLATFORM
PATCH REEFS
LARGER REEF KNOLLS
NO PHOTO COVER
87°45'
16°55'
16°50'
16°45'
16°40'
87°50'
NORTHEAST CAY
LONG CAY NORTH
LONG CAY
MIDDLE CAY
SOUTHWEST CAYS


SUBMERGED
SPIT
UNDERCUTTING
HUT
LARGE
STRANDED
BLOCK
MUDHOLE
FIGURE 38
NORTHEAST CAY
PHYSIOGRAPHY
0
YARDS
100
BR
BR
REEF
REEF

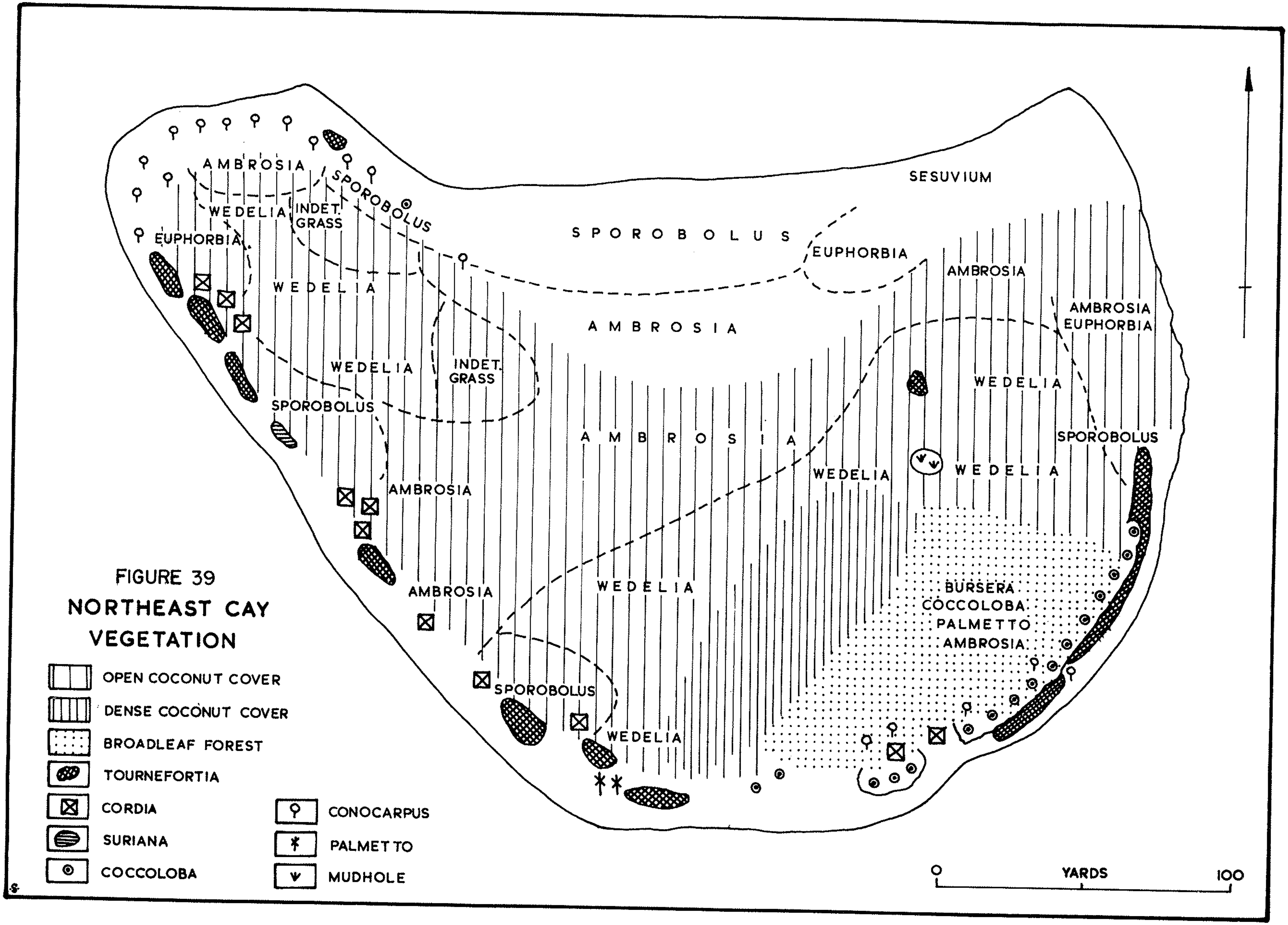


FIGURE 39
NORTHEAST CAY
VEGETATION

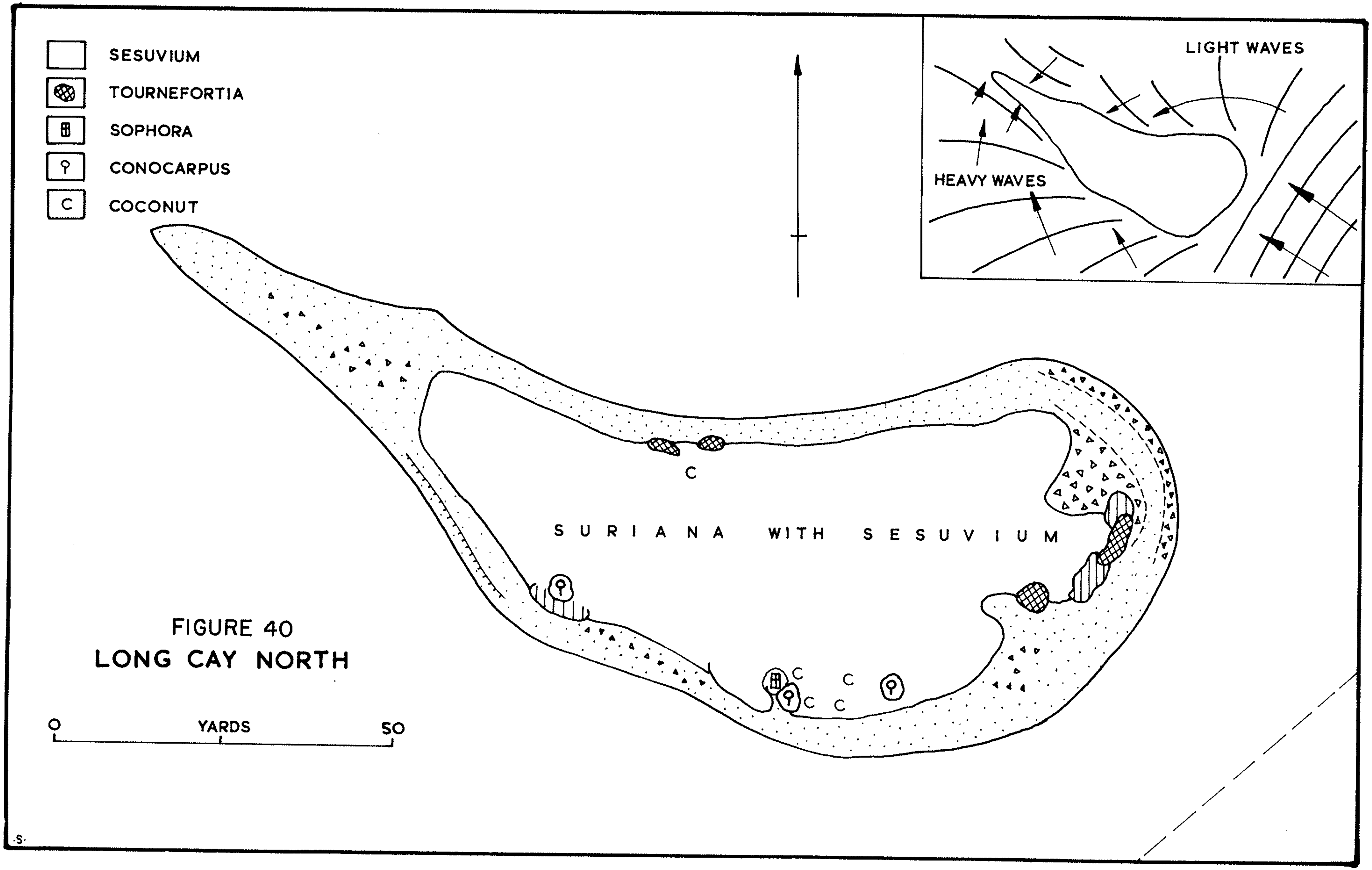


FIGURE 40
LONG CAY NORTH

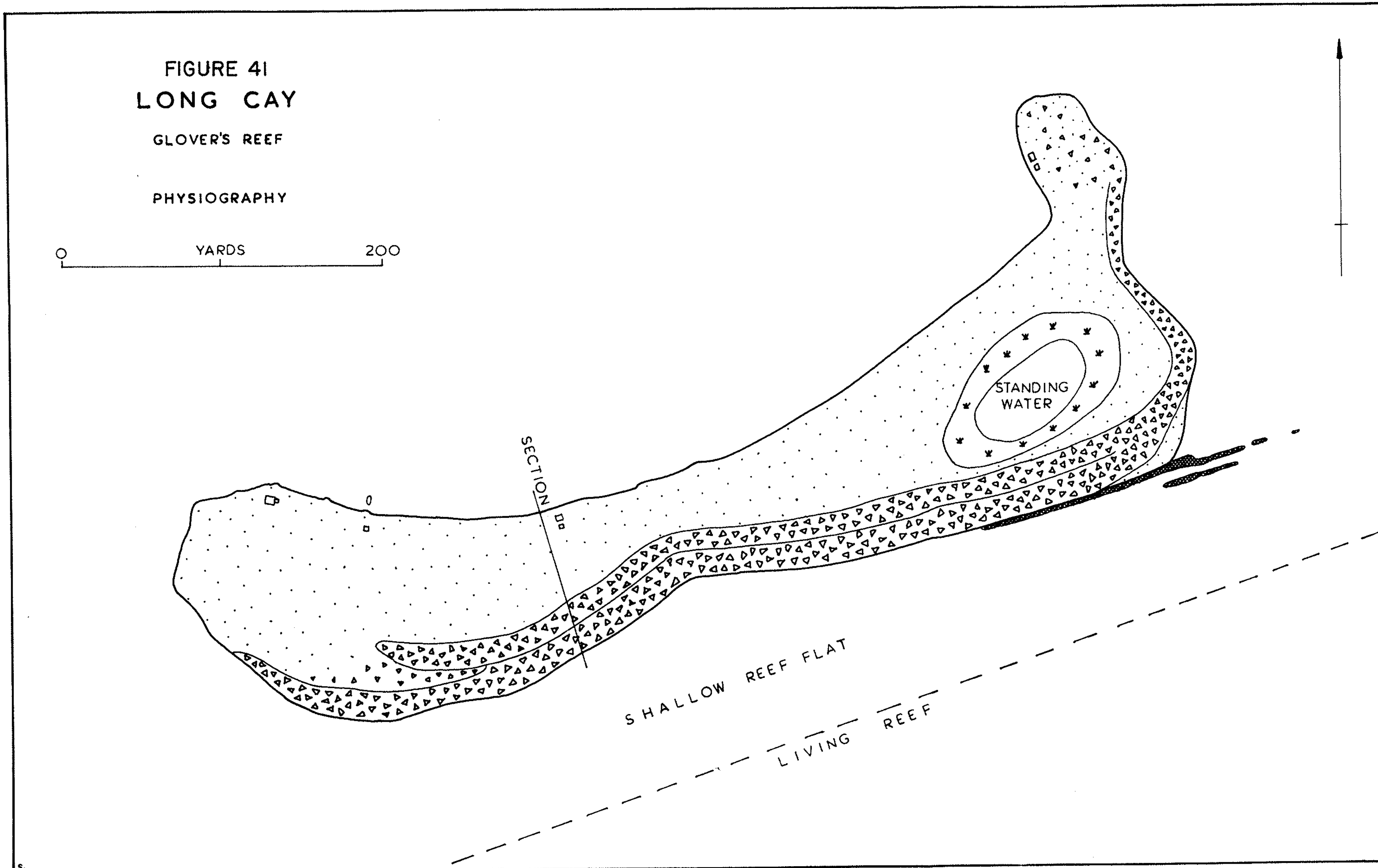


FIGURE 41
LONG CAY
GLOVER'S REEF
PHYSIOGRAPHY
0
YARDS
200
STANDING WATER
SECTION
SHALLOW REEF FLAT
LIVING REEF

FIGURE 42

LONG CAY

GLOVER'S REEF

VEGETATION

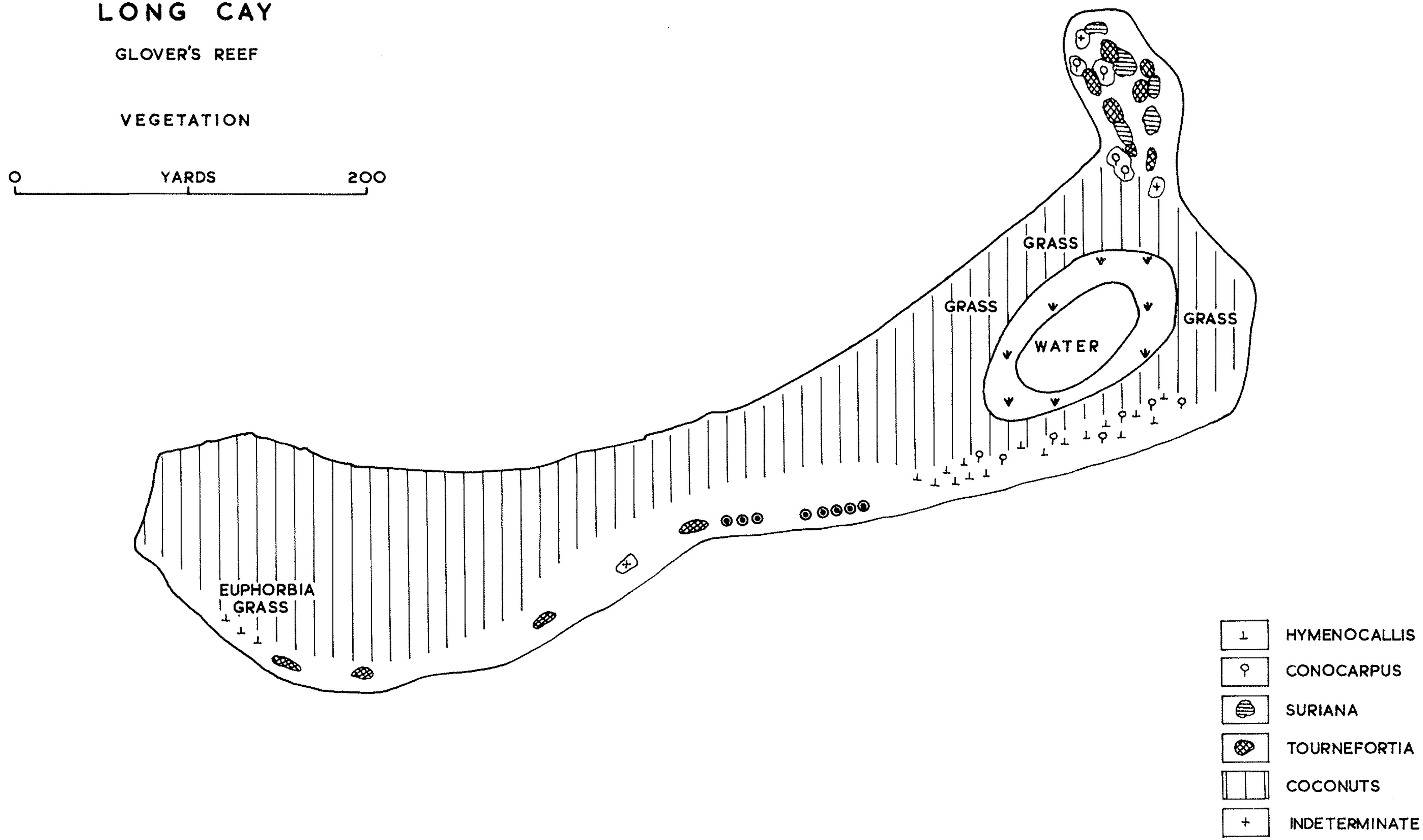


FIGURE 43

MIDDLE CAY: PHYSIOGRAPHY

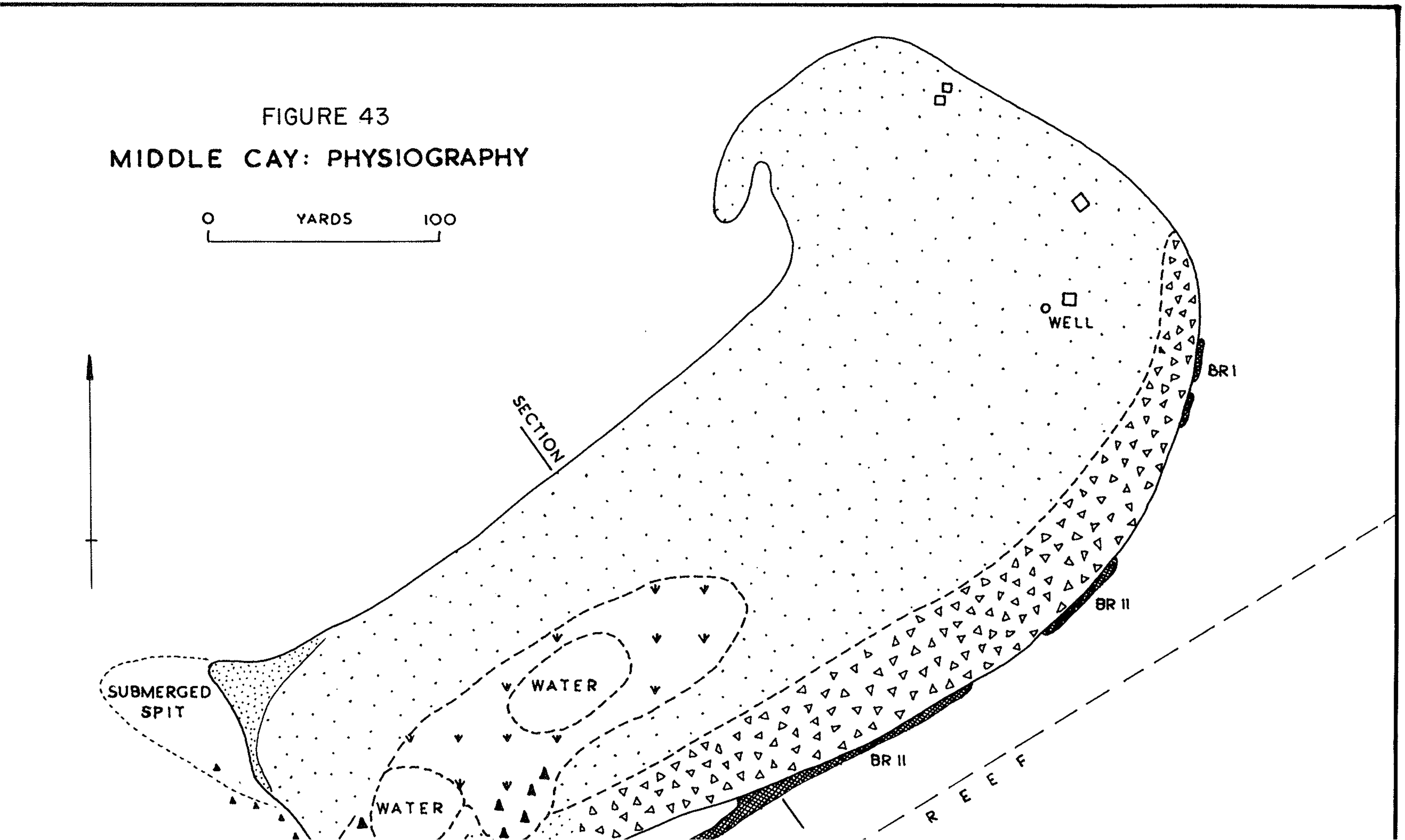


FIGURE 44
LONG CAY

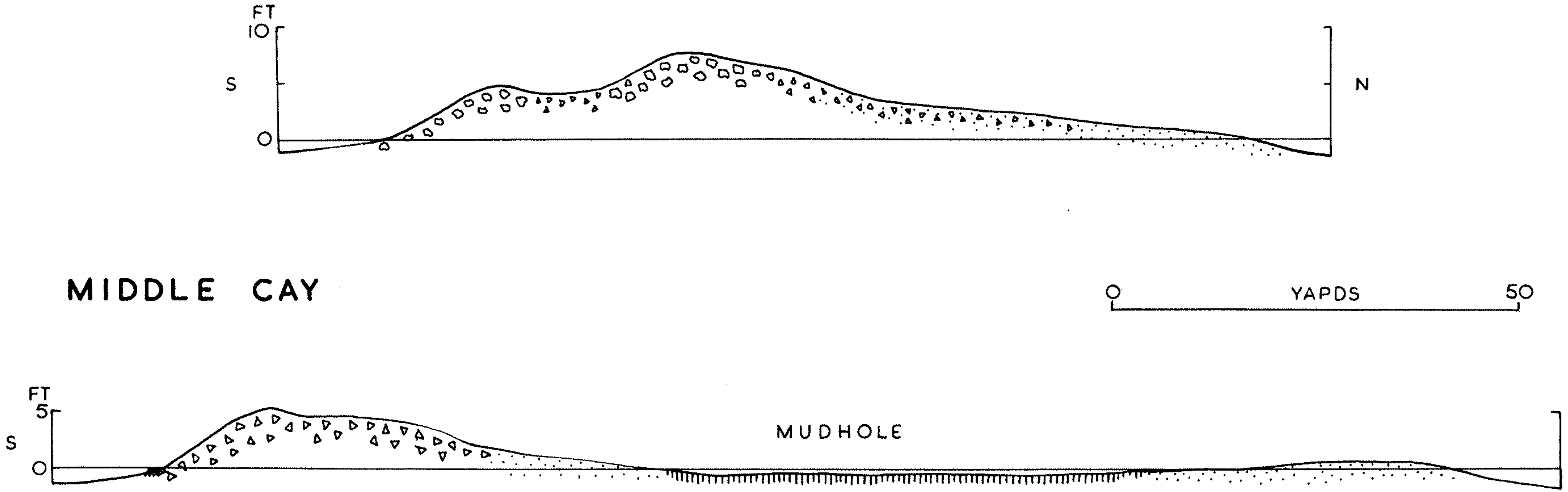


FIGURE 45

MIDDLE CAY: VEGETATION

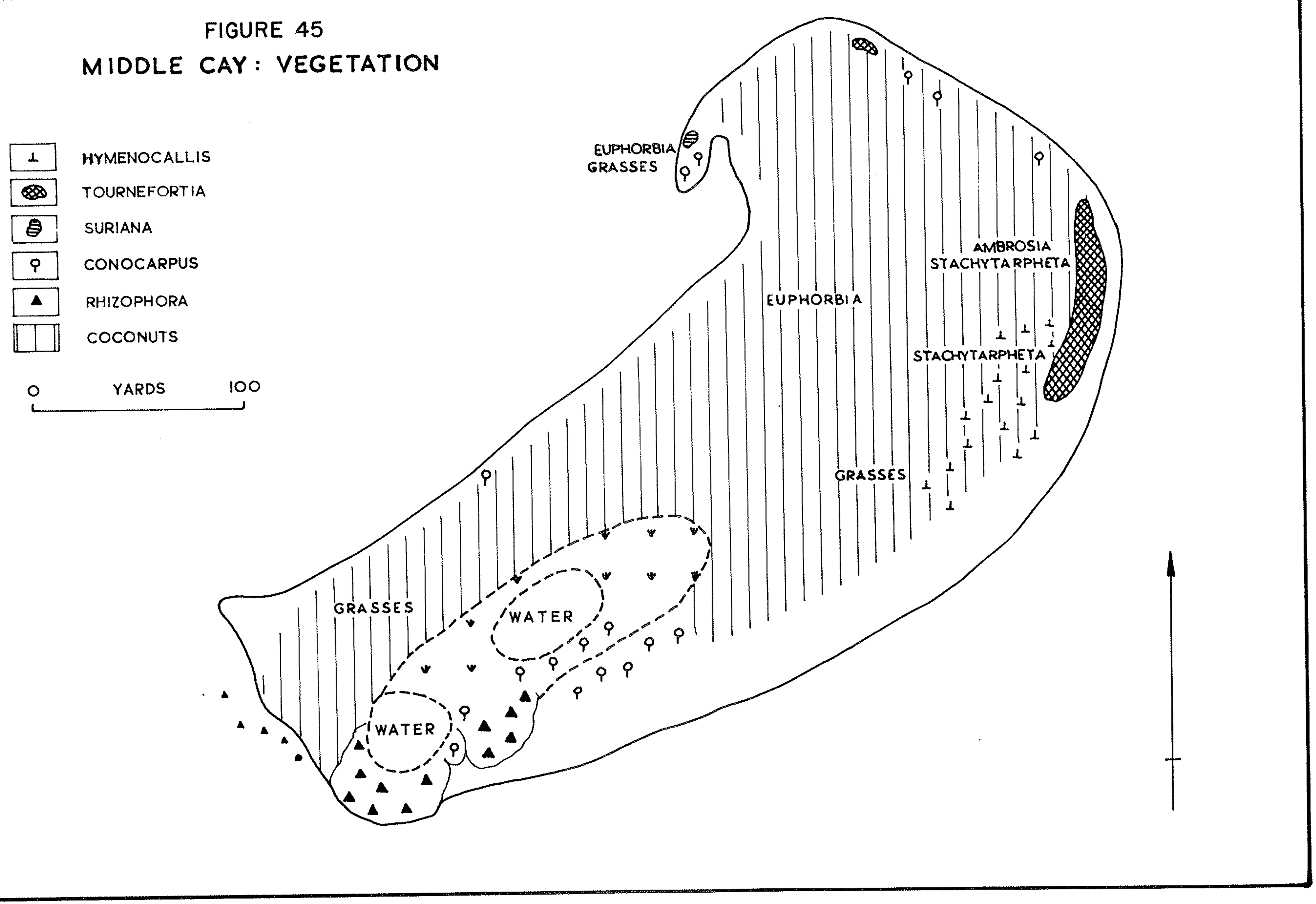


FIGURE 46

SOUTHWEST CAY I: PHYSIOGRAPHY

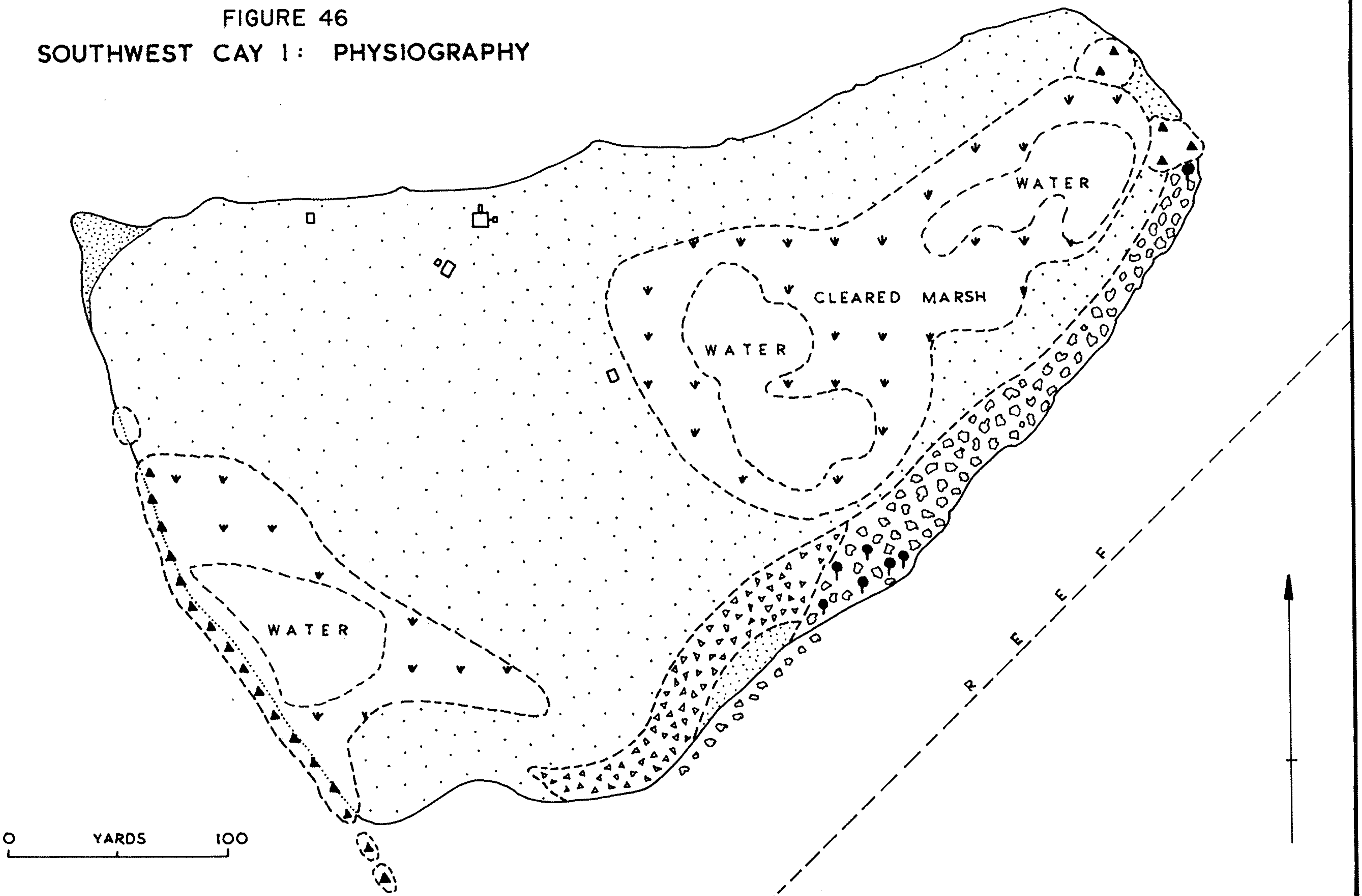
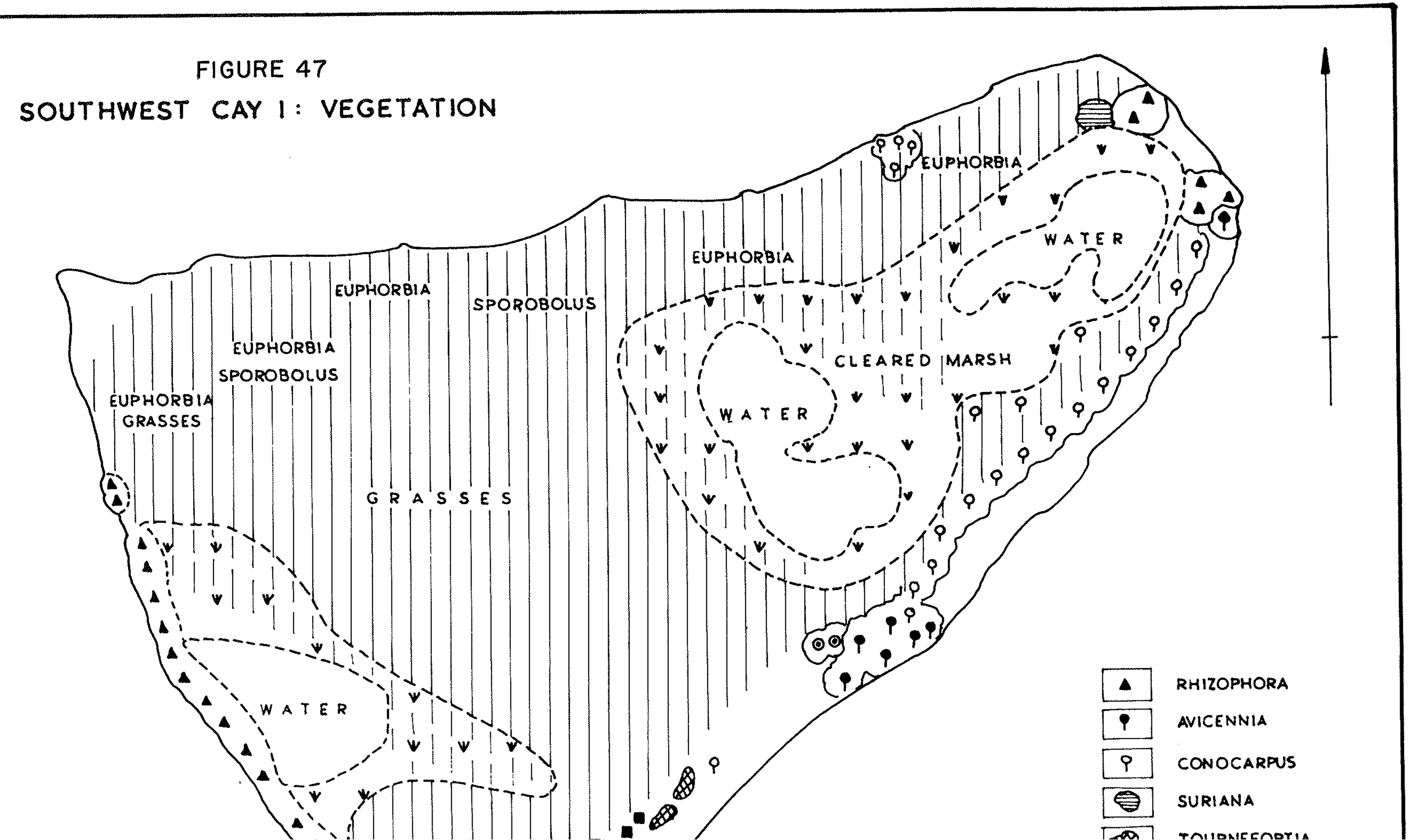


FIGURE 47

SOUTHWEST CAY I: VEGETATION



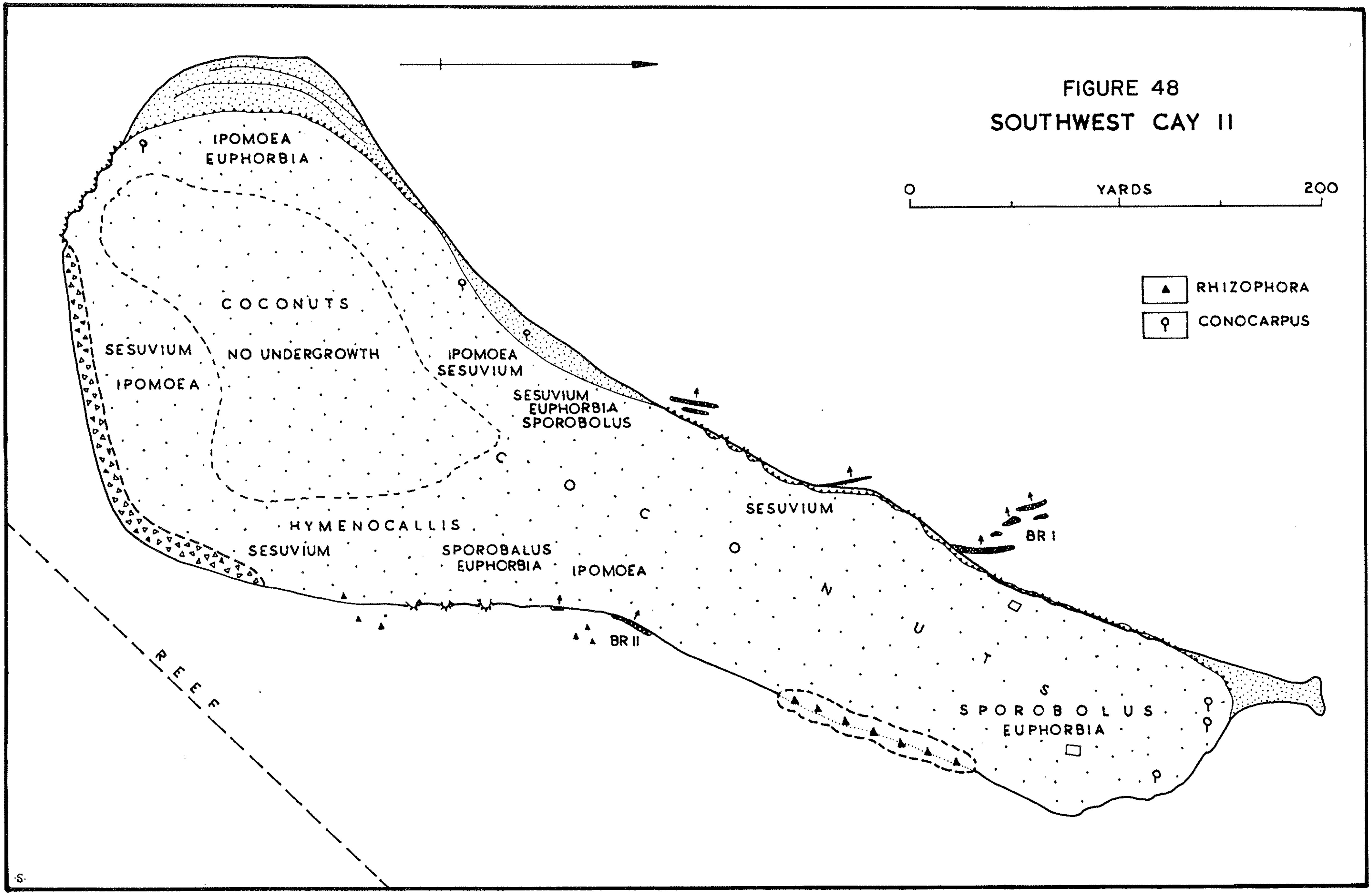


FIGURE 48
SOUTHWEST CAY II
0
YARDS
200
RHIZOPHORA
CONOCARPUS
IPOMOEA
EUPHORBIA
COCONUTS
NO UNDERGROWTH
SESUVIUM
IPOMOEA
IPOMOEA
SESUVIUM
SESUVIUM
EUPHORBIA
SPOROBOLUS
HYMENOCALLIS
SESUVIUM
SPOROBALUS
EUPHORBIA
IPOMOEA
SESUVIUM
C O C O N U T S
BR I
BR II
REEF
SPOROBOLUS
EUPHORBIA

VIII. FORM AND DEVELOPMENT OF THE CAYS

It is not proposed in this section to give a full review of the physiography of sand and mangrove cays: this must await the completion of work on the 45 barrier reef cays mapped during the two expeditions, when the results of both studies can be compared. Certain types of cays are unrepresented on the atolls; while conversely, some problems arising on the atoll cays find no counterpart on the barrier reef. This is not, therefore, a full analysis of cays and their problems; rather it is an interim report on the atoll cays, in which attention is especially directed to some of the main problems awaiting solution.

Vermeer in his study of the British Honduras cays classified them into "1. The coral sand cay. 2. The mangrove cay. 3. The mangrove-sand cay or transition type cay" (1959, 29). While this must be extended for the barrier reef cays, it is applicable to the atolls, where, as the detailed descriptions show, all three types are to be found.

A. The sand cays

Form of sand cays

Sand cays are developed near the inner edges of reef flats, generally on the windward reefs of atolls, and are usually--but not invariably--associated with reef-gaps. They are not found on the most exposed reefs, such as the east reefs of Lighthouse and Glover's Reefs, nor on the most protected. Ideally they are located at the northern or southern ends of linear eastern reefs, as on Lighthouse Reef, or on the more protected southeast reef of Glover's Reef. Turneffe is rather a special case, since its eastern reefs are protected from the prevailing winds by Lighthouse Reef; hence numerous small sand cays are found close to the reef-edge, in positions where they would certainly be destroyed were the reef more exposed.

Sand cays may range in size from small ephemeral unvegetated sand-bores a few yards in diameter, to forested islands several hundred yards in length. The largest on the atolls is Half Moon Cay, 1100 yards long; the sand cays of Glover's Reef vary from 150 to nearly 700 yards in length; while the Turneffe cays are much shorter, being generally less than 200 yards long. Most of the cays are regular in shape, their width being one-third to one-fifth their length: variations may be caused by shape of the reef basement (Half Moon Cay) or accumulation patterns (Sandbore Cay). The cays are highest on their seaward side, where they overlook a shallow reef-flat; their surface slopes from the crest of the seaward beach towards the leeward shore, which faces a sheltered bay carrying at least 1 fathom of water.

Three main classes of unconsolidated material are present in the cays: rubble, shingle and sand. Rubble includes coarse coral blocks, dark-coloured and deeply weathered, which are too heavy to be thrown up the seaward shore of the cay, and have accumulated at the foot of the seaward beach. In some cases (Southwest Cay I, some of the Deadman Group) it forms the beach itself. Generally, however, the seaward beach is formed of shingle, chiefly small globular corals, broken larger corals, and shells. The mean diameter of the material varies with exposure of the ridge, and varies from 1 to 6 inches. Shingle ridges may rise to a height of 10 feet above sea level, but usually do not exceed 5 feet. They are almost always single features, though two are described, one behind the other, at Long Cay (Glover's Reef). At the foot of each modern shingle ridge there is a smaller ridge of fine white shingle, 2-3 feet high, which contrasts strongly in colour and grain-size with the older, higher ridge against which it rests. The older ridges are thought to be storm and hurricane constructions, the small white ridges to be formed by day to day wave action. Finally, the area to leeward of the shingle ridge is formed of coarse coral-algal sand, often with a surface scattering of larger blocks and shingle ("rampart wash"). Fresh sand spits are frequently found building lagoonward from the ends of the cay, to enclose a sandy leeward shore. Where no shingle is found (some of the Turneffe cays, Sandbore Cay), the whole island is built from sand, rising to a crest on the windward side, and declining gradually to leeward.

Frequently the cay surface is not smooth, but descends to a central depression, containing a mudhole or lagoon, and rising to a leeward beach ridge. This feature is best developed on the most exposed cays, where the shingle ridges are highest, notably on Glover's Reef (where, however, the leeward beaches are exposed to considerable lagoon waves). The central depression is absent from most of the protected cays of the barrier reef. Soldier Cay, Turneffe, has a partly formed depression and leeward beach ridge at the north end of the cay.

Origin of sand cays

Sand cays are typically developed at gaps in linear reefs (Northeast Cay, Glover's Reef; Sandbore Cay, Lighthouse Reef), on small arcuate reef segments (many examples known from the barrier reef), or at prominent elbows or bends in reefs (Soldier Cay, Turneffe), but this relationship is not invariable. Some cays exist on unbroken reefs, and their origin demands an explanation (Cockroach and Deadman's Groups, Turneffe; Saddle and Hat Cays, Lighthouse Reef; Middle Cay, Glover's Reef). The presence of gaps or bends in reefs (i.e. variation in bottom topography) leads to refraction of surface waves (Munk and Traylor, 1947). Without refraction, waves simply sweep surface debris across reef-flats and into the lagoon, perhaps forming occasional short-lived linear sandbores, as reported along the north side of Glover's Reef. With refraction at gaps, however, and consequent opposed wave directions, waves both help to wash debris onto the reef-flat, and to keep it there. This was recognised in general terms by Charles Darwin (1842, 26), and later by Davis (1928, 13), but it was left to Steers to demonstrate it from field studies in Australia (1929, 250; 1930, 12; 1937, 13) and Jamaica. The effect of wave refraction on cay formation has been experimentally verified in the wave tanks at the Department of Geography, Cambridge. Here an arcuate 'reef' was built with bricks, its upper surface rising to water-level, and sand was fed in along the seaward edge of the reef. Waves approached normal to this edge and refracted strongly on either side. Sand was washed back across the reef and was halted by the refracted waves, to form an elongate drying 'cay' with its long axis parallel to that of the reef-patch. The stronger the

the waves striking the reef, the farther from the reef-edge is the cay formed, until with very strong waves all the material is washed off the patch into the lagoon. It is interesting that, given uniform wave conditions, no cay remains in existence perpetually: they tend to form and reform at 20 minute intervals until the lagoon is choked with sand. This series of experiments is proceeding.

Patterns of refraction in reef areas are well shown on a larger scale for Cocos-Keeling by Wood Jones (1910) and for Low Isles, Great Barrier Reef, by Stephenson and others (1931). The important point is the occurrence of refraction around the reef itself, rather than around the cay, and in theory the degree of refraction and hence the location of the cay on the reef-flat (the flat and bottom topography being assumed uniform) will depend on the degree of exposure and strength of wave action. All other conditions remaining the same, the cay will be formed further from the reef edge on exposed reefs than in less exposed areas, on deeper flats than on shallower ones. Thus Sandbore Cay, Lighthouse Reef, stands several hundred yards from the reef edge, whereas most of the Turneffe cays lie within a hundred yards of it. The fact that "all the sand cays are located at the back edge of the reef flat" (Vermeer, 1959, 113) does not in itself form evidence of refraction, as Vermeer argues: this condition is widespread but not universal, and simply indicates the degree of refraction involved, the size of the reef flat, and other complicating factors of cay evolution.

Cays are, therefore, accumulations of unconsolidated debris formed by the action of refracted waves. These wave patterns originate under the influence of prevailing winds, which on the British Honduras coast approach from the northeast, east and southeast, and, during the winter months, from the north (Section III). According to Umbgrove it is "the wind, and in a minor degree the breakers" which "forces the sand into a crescent-shaped sand bar" (1947, 734), but it is doubtful whether in British Honduras the wind plays any direct part in cay formation: it acts wholly through wind-generated surface waves. Much interesting work has been done in Indonesia on changes in cay physiography resulting from seasonal wind changes (Krempf, 1926, 1928; Umbgrove, 1929) and even longer-term climatic fluctuation (Verstappen, 1955), but it remains to be seen whether such changes can be demonstrated in British Honduras. Since the time of Hague, however, it has been known that relatively small seasonal changes in wind direction can lead to the growth of short-term sand-spits: some instances are given by Vermeer (1959, 114-115). Unvegetated cays, too, may appear and disappear seasonally: examples are known from the British Honduras barrier reef, and one is reported from Arrecife Alacran by Folk (personal communication).

There are three important factors limiting the influence of wave refraction, assuming an abundant supply of debris. One is the tidal range, here not more than a foot. Without such a small range many sand cays on exposed reefs simply could not exist, for the large waves crossing the reefs at high tide would wash all debris into the lagoon. Hence on the Australian Great Barrier Reef, where the tidal range may be over 10 feet, there are very few cays indeed on the outer reefs. High tidal range helps minimise it. In this connection British Honduras is an ideal area for cay study on both practical and theoretical grounds. Secondly, the existence of a cay depends fundamentally on its reef basement--its depth and its extent. Cays can only be formed on reefs which lie within the vertical zone of wave action (Vermeer, 1959, 110-112), and British Honduras experience suggests that few cays indeed are built on flats carrying more than 3 feet of water. In this connection, Spender attempted to show that the type of sediment accumulation on cays was connected with the depth of the reef-flat (1930, 285-287), shingle ridges only appearing on the highest reef-flats, and pure sand cays on much deeper ones. Colman (1937, 143) reached similar conclusions in the Dry Tortugas, but his paper was never published. In British Honduras, on the other hand, all the evidence seems to favour Steers's contention (1937, 137) that exposure is the main control. Vermeer (1959) outlined more evidence for this view, and more is given in these reports. The factors governing cay physiography are so complex and inter-relating that to isolate one as a general control is to invite error, but if one control is to be named, within the framework of wave refraction, then, with Steers and Vermeer, I would choose degree of exposure in its widest sense. The area of the reef patch is of importance as well as its depth: if the patch is so small that the locus of cay growth by wave refraction lies lagoonward of it, no cay will be formed. Experiments suggest that in exposed areas reef-patches need to be larger for cays to form than in protected areas--as is often the case. Yet a third limiting condition concerns the debris itself, which varies greatly in grain-size and ease of transport: coarse material is more difficult to transport than fine, and hence will accumulate closer to the reef edge, thus forming rubbly cays on even narrow reef-flats. The more easily wave-transported finer sands will be entirely washed off narrow patches and will accumulate only on wide ones. These principles indicate some of the factors affecting cay location under relatively static conditions; little so far has been done on either the geometry of cays and associated reefs, or on the processes at work on them, and the subject may benefit by more refined experimental work.

One major problem, already stated, concerns the formation of cays not located at gaps or bends, bearing in mind the greatly diminished, perhaps negligible role of refraction. It is a problem which cannot at present be solved. The cays of eastern Turneffe (Deadman's and Cockroach Groups) form one class, where it can be suggested that cay growth is largely random following the accumulation of great amounts of detritus, with no other outlet, between the reef and the mangrove rim. In the case of Middle Cay, Glover's Reef, however, there is no barrier to the washing of debris into the lagoon, and one can only suggest that in certain cases cay growth obeys no general rules, but depends on the chance accumulation of boulders on the reef-edge, followed by sand accumulation to leeward of the obstruction. Chance accumulation may also account for such apparently short-lived cays as Saddle and Hat Cays, Lighthouse Reef.

Where a cay consists of sand and shingle, there seems some agreement (Wells, 1951, 3; Zans, 1958, 21) that the shingle ridge appears first, and that the embryonic cay then grows lagoonward by sand accumulation, especially at the ends of the shingle ridge. Steers has asked whether, in the case of the Low Wooded Islands of the Queensland coast, the prior development of the shingle ridge might not derive the sand cay to leeward of its main source of debris supply, and this question is relevant also for some of the barrier reef cays of British Honduras. On the atolls, however, the sandy areas of cays are usually in such exposed locations that they could not survive without the protection of the shingle ridge, and hence could not have accumulated without its prior existence. No examples of shingle ridges without leeward sand areas are known from the atolls.

Constituents of sand cays

Having reviewed briefly the form and main reasons for development of sand cays, we may consider their material constitution. Since sediment analyses are not complete, this outline will be brief. The materials of sand cays fall into two groups: the loose, incoherent uncemented sediments, and the lithified rocks.

(a) Unconsolidated sediments.

On the atolls, unconsolidated sediments of sand cays range from fine sand to boulders, with coarse sands (0.5-2mm) and shingle (20-100mm) predominant. The sediments of all sizes are usually well-sorted, but sometimes bimodal. They are almost wholly organic in origin: and the mechanical properties of the sediment are closely associated with the type of organic materials which constitute it. Shingle consists largely of stony corals--small globular corals of the genera Montastrea, Siderastrea, Diploria, Meandrina and others, and broken fragments of larger branching corals, notably the Acropora and Porites. The grain size of the sediment depends largely on the proportion of particular corals in it; thus the first group are normally represented by abraded whole colonies, whereas the corals of the second group break down rapidly into "sticks" and "plates". Acropora cervicornis breaks down into cylindrical sticks 2-3 inches long and ½ inch in diameter, A. palmata into larger more slabby plates 6 inches and more in length. The shapes of these particles make cay sediments difficult to analyse by normal methods, since conventional mesh sieves bear little relation to actual size and weight of coral fragments. Other constituents of shingle areas are calcareous algal nodules, especially in exposed areas, roughly cylindrical in shape and up to 4 inches long; Strombus and other shells, which locally form up to 40% of shingle ridges; and of minor importance, horny skeletons of soft corals, clumps of calcareous green algae, sponges, and driftwood. Rubble differs from shingle in its greater size (often in excess of 50cm diameter) and more irregular shape. It consists chiefly of the more massive coral heads (Diploria, Montastrea), subject to weathering rather than abrasion.

Cay sands similarly derive their characteristics from contained organisms sorted by wave action. The most important single constituent is the green alga, Halimeda. In the Pacific this alga is a major sediment contributor on deep lagoon floors (Funafuti: David and Sweet, 1904, 151; Marshalls: Emery, Tracey and Ladd, 1954; Kapingamarangi: McKee, Chronic and Leopold, 1959), whereas in the Caribbean evidence seems to be accumulating that it is of greatest importance in shallow water as a beach constituent (Porto Rico: Van Overbeek and Crist, 1947; Jamaica: Steers and others, 1940). Sand analyses are not complete, but in British Honduras, Halimeda segments in places form small beaches containing no other material, and many beach sands, particularly near tide-levels, consist of 80-95% of this alga. This may result from the greater mobility of the flat, plate-like segments under wave-action, and their concentration in this zone, for away from the beaches, whole Halimeda segments form a lesser proportion. The segments range in diameter from 0.8-2mm; some are larger. A sand consisting largely of Halimeda will thus be concentrated in this size group, and have a very small standard deviation. In addition to whole Halimeda plates, cay sands contain broken Halimeda plates, Homotrema nodules in exposed situations, small amounts of tests and spines of echinoderms, sponge spicules, fish bones, shells and similar remains, and variable quantities of unrecognisable coral fragments.

The wide difference in characteristics and composition of shingle and sand on the cays is primary evidence of one most important factor in cay composition: the discontinuous breakdown of constituent organic material. The importance of discontinuous breakdown is well-known in fluvial landscapes, but is less studied with respect to cays. To take examples: A. cervicornis and A. palmata break down first into sticks and plates which vary in size within narrow limits, and then into constituent carbonate grains, with no intervening "fine gravel" stage. Halimeda breaks down into separate whole plates or leaves, each of which may split into two or three parts before disintegrating into fine particles. Larger globular coral heads in the zone of wave action seem to pass directly to the constituent particle stage. These changes are brought about mainly by mechanical abrasion of sediments, partly by chemical and biologic breakdown.

Many studies have been made (Otter, 1937; Bertram, 1936) of the breakdown of corals by boring algae, molluscs, fish, echinoderms and other organisms. On the atolls Scarids were frequently seen rasping the surface of coral boulders, and Holothurians were seen in great numbers excreting characteristic cylindrical rods of sand-size material, but we made no special studies on their role in rock comminution. However, attention may be drawn to one means of coral breakdown, active on cay surfaces beyond the zone of wave action, seen over wide areas. This is the splitting of globular colonies (single heads) by radial fracture, generally on heads 1-2 feet in diameter. It occurs mainly in Montastrea annularis, M. cavernosa, and Diploria clivosa, and was seen on one occasion in Colpophyllia natans. It presumably results from some form of chemical weathering, and specimens have been taken for analysis. The primary splitting is into perhaps half a dozen pyramidal segments, and the process is repeated, until the end products are cuboidal segments of rock $\frac{1}{2}$-3/4 inch long, which themselves disintegrate to coarse sand. Species can often be determined until the penultimate stage. Breakdown of this sort must be a major means of comminution away from wave action.

Clays and silts are not found on cays, at least not in significan quantities.

The British Honduras sediments agree in most essentials with those of Arrecife Alacran studied by Folk and Robles (I am much indebted to Dr. Folk for sending me a copy of his unpublished paper), but differ considerably in organic content from other areas. Thus at Bikini, beach sands contain up to 60% Foraminifera, including the large foram Marginopora reaching 5 mm in diameter (Emery, Tracey and Ladd, 1954, 36-37); while in the southern Carolines the orange foram Amphistegina forms up to 98% of lagoon beach sands at Kapingamarangi (McKee, Chronic and Leopold, 1959, 509-512). Foraminifera nowhere form an important constituent of beaches on the atolls, and those which do occur on the reef-flats and in the lagoons (Cebulski, 1961) are microscopic forms, which cannot long resist wave abrasion when mixed with larger material. Alcyonarians are not well represented in beach sands, in contrast with the dominance attached by Cary to them in the Dry Tortugas and Samoa (1918, 1931 and other papers), though they probably contribute to the large amount of small calcareous fragments which are no longer identifiable. Halimeda at Bikini is "usually rare" (Emery, Tracey and Ladd, 1954, 36), is absent in the Hawaiian Islands (Emery and Cox, 1956, 383), and is not mentioned in the Kapingamarangi beach sands (McKee and others, 1959), in contrast to its importance in the Caribbean. In sands, as opposed to shingles, fragments derived from stony corals and from calcareous algae are probably of nearly equal importance in British Honduras, especially in the lower grade sizes where identification is difficult.

Finally, a note on "erratic" sediments on atoll islands. These are of four types: pumice, lava, quartz, and brown limestone. Pumice is everywhere widespread on coral islands, and can often be used in dating when correlated with known eruptions. Miss Sachet has reviewed its distribution, and noted the lack of evidence so far from the Caribbean (1955, 27). Vermeer (1959, 121) mentions that "rounded pieces of pumice....found on many of the cays appear to have been carried....from the volcanic Windward Islands to the offshore area of British Honduras and then thrown up on the cays by the wind driven surface waves and current." The distribution of pumice on the cays is erratic: one cay may have abundant pumice and a nearby island very little. Generally, it is more abundant on the exposed cays of Lighthouse Reef, Glover's Reef and the southern barrier reef, than on Turneffe and the northern barrier. The greatest amounts are found on the southern barrier reef cays. Most of the pumice is in small rounded pieces 0.5-2 inches in diameter, but there are numerous smaller fragments, and some larger ones up to 9 inches long. The pumice is silver-grey when fresh, often blackened on the outside, and has undergone some weathering. It does not form distinct zones on cays, as in some reef areas, and cannot be used for dating or as evidence of shoreline change. It seems to be accumulating at a fairly steady rate.

The second rock, a lava, is much less common, but a number of specimens can soon be found by searching shingle ridges, as at Half Moon Cay. It forms subrounded blocks up to 6 inches long. Dr. C.L. Forbes of the Sedgwick Museum, Cambridge, kindly comments that it is a very vesicular scoriaceous lava, red in fresh section, weathering to yellowish-brown with many black spots which may be original or a weathering product. The zone of weathering extends inwards for $\frac{1}{2}$ inch from the surface of specimens. The lava contains shell inclusions. It does not float in water, and has probably been brought in tree roots (Emery, 1955).

The third rock, white quartz, is known only from a single specimen 1 inch in diameter picked up by Murray on Middle Cay, Glover's Reef. It, too, has presumably been rafted in by floating trees: suggesting an origin for both lava and quartz on the relatively close Honduras and Nicaraguan coasts, rather than in the Lesser Antilles.

Finally, the brown limestone, known from Half Moon Cay is rounded large pebbles up to 1 foot in diameter. I am indebted to Dr. Forbes for examining this rock in thin section and making the following observations: "The rock is a calcarenite with subordinate quartz sand and is much recrystallized. This means that it originated as a sand of which the grains were formed from a pre-existing limestone, being cemented by the addition of more lime to form the present rock. The small amount of quartz sand was presumably blown in by the wind or washed in by water before the final cementing. The limestone of which most of the sand-grains are composed, is of an obscure nature, but was most likely a calcilutite, I think. It could have been formed from a fine-grained calcareous mud, such muds being common deposits of warm marine lagoons. Thus, the rock could represent an earlier episode in the history of the place where you found it. But it could equally well have been brought in from some other region, along with the scoriaceous lava and pumice samples you showed me. (The white material filling pipes in the rock is also carbonate of lime presumably precipitated from vadose ground water in the burrows of organisms, in holes left by decaying plant-roots, or simply by replacement of the limestone along passages of easier permeability)."

None of these "erratic" rocks are of any quantitative importance in cay formation, though pumice may form a very local ground cover.

(b) Consolidated sediments

Lithified rocks on reef islands are of such variety and in some cases so difficult to distinguish that they may be incorrectly mistaken for each other and false conclusions as to their origin drawn. The more common types of rocks on reef islands may be grouped as follows (there are probably others):

1. Oolites and aeolianites dating from an earlier period in the island's history. Aeolianites are well seen in Bermuda (Agassiz, 1895), and oolites in the Bahamas (Newell and others, 1951) and on Pedro Bank (Zans, 1958, 8-11); they have not been seen in British Honduras.

2. True elevated reef rock, characterised by the presence of corals in the position of growth in a matrix of other calcareous sediments, described for example by Gardiner (1903-6) and Seymour Sewell (1935, 1936) in the Maldives. At lower elevations this may appear as the "honeycomb rock" of Stephenson and others (1931, 53, 101). It has not been certainly identified in British Honduras, except for small areas along the windward reefs of Lighthouse Reef.

3. Shingle conglomerate and shingle limestone. Shingle conglomerate was the name given by Stephenson to "recently cemented platforms of coral debris... everywhere more or less compacted together by means of mud and silt to form a hard rock" (Stephenson and others, 1931, 25). In Queensland it is formed from lithified shingle ridges on low wooded islands. In the Houtman's Abrolhos, Teichert sharply distinguished "rocks that result from the cementation of intertidal deposits largely composed of coral fragments. As far as the Abrolhos are concerned a clear distinction between shingle beach ridges and shingle limestones has always been easy to make, for nowhere were consolidated beach ridges found, and shingle limestone deposits are normally of such a nature as to suggest formation in the zone of breakers slightly outside the zone in which beach ridges are built" (Teichert, 1947, 152). The two deposits can best be distinguished, it seems, by their physiography and field relations.

4. "Promenade Rock". The exact status of this is uncertain; it has been described from the Great Barrier Reefs and from the Morant Cays, Jamaica. On the low wooded islands of the Queensland coast, Steers speaks of "a platform or promenade of coral conglomerate" (1937, 119), which may be "a cemented, ancient, and presumably raised rampart" (1937, 27)(cf. 1929, 252-56, and Spender, 1930, 209-210). Steers later gave this description of promenades on the Morant Cays: "The Morant promenades are made essentially of beach rock, with larger fragments of coral and shells. They are always to windward of the cay; they are very rough in detail, but appear level from a short distance;... they often show clear dips, but these dips are not consistent in direction. At first sight, they can easily be taken as raised features, especially as they are often partly covered with Sesuvium and grass and are about a foot above mean sea-level, but there is nothing to prove it. ... What is difficult to explain is their flat upper surface" (1940b, 309); and again: "They are mainly composed of cemented sand and... are of the same nature as ordinary beachrock; they may contain shells and coral fragments. Their outer and upper surfaces are eroded into very jagged forms. Apart from the detailed erosion forms, the average surface is often remarkably level, and from about 12 to 18 inches above high water mark; it is this characteristic which makes the term 'promenade' applicable. ... The outer surface layer of the promenade, about a quarter to a half an inch in thickness, was usually hard and compact, and stalagmitic in appearance when broken. ... The promenade rock often shows clear dips, but they are not regular in direction. The promenades occasionally show long and fairly straight cracks or joints, not in any particular arrangement, but on a considerable scale" (1940a, 39-40).

These descriptions have been quoted at some length because of their similarity to some of the Half Moon Cay exposures described in Section VI. Steers did not think the Morant promenades should be too closely compared with those of the Great Barrier Reefs, and left the question of their origin open, in the hope that work elsewhere, especially in British Honduras, might provide a solution (1940a, 40; Steers and others, 1940, 310). Unfortunately promenades are not common in British Honduras, even on the most exposed cays, nor are they found on Pedro Bank, where the similarities with the Morant Cays might be expected to be greatest (Zans, 1958). I doubt whether they indicate uplift, at least in the sense of a eustatic fall in sea-level, since, as Spender pointed out (1930, 210) we should in that case find more extensive remnants in more sheltered positions.

In parenthesis the formation of "ironshore" on tropical limestone coasts may be mentioned, since it may conceivably be confused with promenade rock. Ironshore only seems to form on coasts of solid carbonate rock, and has been widely described in the Caribbean (Caymans: Matley, 1929, Doran, 1954; Cozumel and mainland Yucatan: Edwards, 1957, 23-28; Ruatan, Bay Islands: Richards, 1938; San Andres, Nicaraguan coast: Parsons, 1956); but it is not found in British Honduras even on those sections of the mainland coast where limestone forms low cliffs. Parsons (1956, 55) considers it the same as the Morant and Queensland promenades, but such a conclusion seems dubious.

5. Intertidal beachrock and intertidal beach conglomerate. These are undoubtedly the best known lithified materials on sand cays and other tropical beaches. They seem to be mainly intertidal in origin, and generally form ribbons following the shore, dipping seaward at the angle of the beaches. Beachrock is found either on windward or leeward sides of cays, but never wholly surrounds them. In British Honduras, most of the outcrops occur on the windward side of cays, where erosion is currently taking place, and only rarely on prograding lagoon shores. There are many recent reviews of the beachrock problem (Emery and Cox, 1955; Ginsburg, 1953; Kaye, 1959; Russell, 1959), but no agreement has been reached on its origin, the most difficult factor to explain being its patchy distribution. It occurs in British Honduras on cays too small to have appreciable fresh water seepage through cay sands, as Gardiner (1931, 40) and others supposed; and it is found on both very exposed and very protected shores. All the incipient (newly exposed, poorly indurated) beachrock (BR II at Northern Cay, Lighthouse Reef; Deadman I, Turneffe) is in a very sheltered location, with the exception of that at Middle Cay, Glover's Reef; this is also the case on the barrier reef cays. The suggestion that blue-green algae are active agents in cementation has been disproved (Krauss and Galloway, 1960).

6. Rocks formed by cementation of sands in cay interiors, including the "cay sandstone" of Kuenen (1933, 86-88) and Seymour Sewell (1935, 502ff.), and the phosphate rock widespread in the drier parts of the Pacific (Fosberg, 1957). This group has not been certainly identified on the atolls, though it may occur at Harry Jones, Turneffe, and in the interior of Half Moon Cay, Lighthouse Reef. Sewell was "by no means fully convinced" of the distinction between cay sandstone and beachrock (1935, 501-502).

This review illustrates the diversity of rocks recognised by reef workers; of them, only the beachrocks have been investigated with any thoroughness. The difficulties of differentiating between the groups of reefrock, shingle limestones and conglomerates, promenade rock and intertidal beach conglomerate have been illustrated in the account of

Half Moon Cay in Section VI. One cannot emphasise too strongly the need for caution in interpreting lithified materials at this stage. The facts of distribution alone suggest that these and similar rocks, which at first sight may seem to indicate relative uplift, may in fact be lithified storm or hurricane constructions. To take a recent example: some months after Typhoon Ophelia at Jaluit Atoll, Marshall Islands, the reef-flat was partly covered with "broad, low tracts of imbricated slabs and boulders" developed from storm ridges (Blumenstock, Fosberg and Johnston, 1961, 619). If these are lithified, into what clear category will they fall--shingle limestone or conglomerate, beach conglomerate, or promenade rock? "There are necessarily, at the present stage, many structures described in the existing accounts of coral reefs of which one can only say with Professor Sollas (Funafuti Report, p. 24): 'I do not understand it, and forbear from speculation'" (Stephenson and others, 1931, 91).

Relict beachrock and present evolution of sand cays

Assuming that true beachrock is essentially intertidal, then it becomes a valuable tool in interpreting cay history. To some extent it forms an "armourplate" against cay erosion, but its success is not invariable, and once a beach shifts under wave action a line of relict beachrock may be left as evidence of its former position. Multiple shifts leave multiple lines of beachrock, recording position and orientation of former beaches. The record is not complete: beachrock is notoriously patchy in distribution, and may be either subsequently covered by fresh beach sands, eroded away, or itself broken and moved by wave action. Russell (1959) has shown how beachrock exposures may alter drastically with seasons, and there is no doubt that many inconspicuous exposures are not seen by investigators, even in careful surveys. Much attention was devoted during both expeditions to mapping relict beachrock in shoal water near cays, and several general conclusions emerge. In most cases, lines of relict rock record continuing migration of cays away from reef edges and reef openings, back across the reef flat towards the lagoon. Cays are eroding to windward, aggrading to leeward, and very little beachrock is thus exposed on lee shores (an exception is Southwest Cay II, Glover's Reef, discussed in Section VII). This is in striking agreement with evidence from other areas, including the Maldives (Gardiner, 1903-6; Seymour Sewell, 1935, 516-517, 1936, 85) and the Carolines (McKee, 1958, 248-249). There is also a tendency, noted particularly on the barrier reef cays, for the outer, presumably older lines of beachrock, to lie at a lower level than inner newer lines: some even form a base for branching corals, which would be impossible in their original intertidal location. This evidence is discussed elsewhere (Stoddart, 1962), and taken to indicate slight drowning of the cays in modern times, perhaps associated with the present climatic amelioration: but the difficulties of such an interpretation are stressed.

There is much other evidence of erosion on cays, chiefly in the form of undercut cay margins, toppled coconut trees, and unusual shape of cays. Undercutting has been almost universally noted in the detailed cay descriptions. Kuenen noted the same phenomenon in Indonesia (1933, 1950; also Sewell in the Indian Ocean, 1935, 512-518), and interpreted it as evidence of a fall in sea-level of the order of 2 metres; several workers have recently adopted this as an essential element in reef theory (Cloud, 1954; Wiens, 1959). Vermeer (1959) described evidence which in his opinion showed a similar 5-7 foot fall in sea level in recent times in British Honduras. There is no evidence of this on the atolls (Sections V, VI), and none on the barrier reef which can be regarded as substantiated beyond reasonable doubt. The question of such a 6 foot fall is discussed with reference to the reefs in Section IX, but it can be stated here, quite unequivocally, that if the sea level stood 6 feet higher than now, the cays as we know them would simply not exist. None of the cays are so high that they cannot be referred to a sea-level at or near the present; conversely, if such a stillstand did take place, cay development must have been weak in the extreme, for while present seas can build ridges 10 feet high, the 6 foot seas can only have constructed beaches 3-4 feet high. Further--and this is a significant point--rise of sea level by 6 feet would have the effect of increasing degree of exposure, considerably altering patterns of wave refraction, and moving the locus of cay accumulation lagoonward. The only way out of this dilemma is to assume that the reefs grew up entirely to the 6 foot level, and have subsequently been completely planed away: an improbable circumstance in the 2,000 years which Fairbridge (1961, 168-169) allows. If this stillstand can be demonstrated on the British Honduras cays, which after much detailed work I regard as very doubtful, then the cays must all postdate it, and be less than 2,000 years old; this, too, I find improbable.

There remains the possibility of minor fluctuations of sea-level. The evidence consists of the undercutting noted, which is generally in beaches 2-4 feet high, and has nothing to do with a 6 foot stillstand, and of raised beachrock. The undercutting is almost universal on atolls and barrier reefs, the raised beachrock limited to Lighthouse Reef and Turneffe. No raised beachrock or other lithified material is found on the barrier reef or Glover's reef, and for this reason cannot indicate a eustatic fluctuation. In the case of Turneffe and Lighthouse Reef it seems to indicate positive local uplift, and the case of Turneffe is briefly discussed below. This leaves little but the undercutting. One may follow Kuenen and believe that a fall in sea-level will lead to erosion of the cay by erosion of its foundation--in which case, why are raised beachrock and reefrock not more widespread? Or one may consider it to result from a slight rise in sea-level shown by drowned beachrock, in which case it should be a world-wide phenomenon. This drowning is estimated at about 4 inches in the last century, increasing in rate in the last 20 years (Fairbridge, 1961, 102-105). It may be significant that in those areas where the raised beachrock is found, undercutting of cay margins is very poorly developed. Speculation on such limited evidence is bound to be dangerous, and the question is best left open at this stage. However, we may note that a deepening of water to this extent is equivalent to increasing the degree of exposure, and hence in shifting the locus of cay accumulation lagoonward. The known rise is small, but still considerable when compared with the tidal range.

Fortunately we are able to estimate in one case (Sandbore Cay, Lighthouse Reef) the rate of cay erosion and migration, at approximately 1 yard per annum, becoming more rapid in the last 15 years. This figure is probably much too high for most cays, since Sandbore is in an exceptionally exposed position and is unprotected by shingle ridges. Detailed mapping over a period of years should lead to more reliable data. Whether the cays are decreasing or increasing in size is a moot point, which has been argued for other areas. It has been suggested that as the seaward shore retreats further from the reef edge, the waves reaching it will be less powerful and erosion will slow down, without any necessary retardation of lagoonward growth. On the other hand, in their migration lagoonward, many cays have now reached the inner limit of the flat on which they stand. Verwey (1931, 203) published a diagram showing a cay extending lagoonward on the flat on its own detritus, without perhaps realising the vast amount of material required. Once a cay begins to be pushed off its reef flat, it will rapidly decrease in area and may disappear altogether; evidence indicates that this stage is now being reached on the British Honduras reefs.

Turneffe: a special case

The sand cays of eastern Turneffe form a special case, distinct from cays elsewhere in British Honduras. The following facts are relevant: At Soldier Cay, where the atoll is widest, there is a short section of exposed, drying reef along the main eastern reef. At nearby Harry Jones there is a tilted beachrock rising to 2 feet above the sea. Extending north and south from this point, along the east side of the main mangrove belt, is a sand ridge, which is underlain by the Harry Jones beachrock, and hence must have shared in its uplift. North and south of the ends of this sand ridge, where the atoll begins to narrow, are a number of atypical sand cays, located back of unbroken reefs on unusually shallow reef flats--the Deadman Group in the south, the Cockroach Group in the north. These may represent a stage in the development of a continuous sand ridge. It is suggested, as a point for discussion, that this is in fact the case, and that these facts taken together show slight recent warping of the Turneffe bank, reaching a maximum in the Harry Jones-Soldier Cay area, and decreasing north and south. This would also help to explain the development of the Deadman and Cockroach Groups. For reasons already made clear, we cannot accept eustatic fluctuations of sea level as explanations of these several features.

Effect of hurricanes on sand cays

The incidence and effect of hurricanes have been briefly noted in Section III. Elsewhere their general effects are well known, witness the accounts of the 1934 cyclone at Low Isles, Great Barrier Reef (Moorhouse, 1936), and the devastations of Arno Atoll recorded by Wells (1951, 5-7). Recently hurricane effects have been studied in great detail following Typhoon Ophelia at Jaluit, Marshall Islands, in 1958 (Blumenstock, 1958a, 1958b, 1961; McKee, 1959). A recent resurvey at Jaluit indicates that some of the changes may be only temporary interruptions (Blumenstock, Fosberg and Johnson, 1961). Long term effects may be summarised from British Honduras data as follows:

1. Catastrophic erosion of cays, which in conditions of rising sea-level cannot easily be repaired; illustrated by Saddle Cay, Lighthouse Reef. This may lead to

2. Destruction of cays, where the whole island is washed away. This can be well illustrated from the barrier reef, not so easily from the atolls. The second of the Pelican Cays, Turneffe, and Bushy Cay, Glover's Reef, may have disappeared in this way. Once a vegetated cay is destroyed and replaced by a "second generation" sandbore, a long period must elapse before chance colonisation by vegetation takes place, if at all. About six cays have disappeared in recent years through hurricane activity; indeed, many areas now lacking cays, where islands might reasonably be expected (such as reef gaps), may be only temporarily without them, and search may well show traces of beachrock at these points.

3. Physiographic effects include the exposure of beachrock and other rocks as shores shift under hurricane wave action, as at Half Moon Cay; the stranding of large boulders as at this cay and Middle Cay, Glover's Reef; the breaking up of beachrock; and the accumulation of large rubble on reef-flats, as at Soldier Cay, Turneffe. "Rampart wash" and fresh sand carpets may be largely hurricane deposits.

4. Effects on vegetation: these are difficult to determine in the absence of previous surveys, and only aligned fallen coconuts (Glover's Reef cays) can be ascribed to hurricanes at present. Hurricanes may help to account for the haphazard distribution of some species of plants on cays, and for the destruction of mangrove areas, revealed by abnormally low regrowth compared with other areas.

These are all very general observations. However, it is hoped that the physiography of the atoll cays is described in sufficient detail in this paper to make possible accurate estimates of the effect of future hurricanes. In this respect, regular resurveys to establish long-term changes are required (perhaps every decade), to distinguish these from hurricane effects, which ideally should be assessed as soon as possible after the damage.

Vegetation of sand cays

Little will be said here concerning cay vegetation, partly because I have no botanical knowledge, partly because present vegetation patterns on cays are so artificial and ephemeral. The startling change in appearance of many cays between the two expeditions, and the record of clearing at Half Moon Cay, is sufficient evidence on this point. A large number of cays are now virtually unvegetated apart from coconuts, while the ground vegetation of most of the remainder is subjected to repeated cutting back, particularly on inhabited cays. Vegetation, however, is of the greatest importance in stabilising sand cays, more so in my opinion than beachrock, yet very little is known of reef island ecology and flora in the Caribbean. Millspaugh has described the Florida Keys (1907) and Alacran (1916), Bowman the Dry Tortugas (1918), Howard Bimini, Bahamas (1950), and Børgesen the Virgin Islands (1909). The most relevant regional accounts have been those of Asprey in Jamaica (Asprey, 1959; and Robbins, 1953; and Loveless, 1958), Chapman on the Jamaican cays (1944; Steers and others, 1940), and J.H. Davis on the Florida Keys, Dry Tortugas and Marquesas (1942). Sauer (1959) has published a recent survey of coastal pioneer plants of the Caribbean and Gulf of Mexico, based on wide-ranging field studies.

The dominant vegetation of the cays is the coconut, Cocos nucifera, though it is probably not native to this region (Bruman, 1944; Beccari, 1917). According to Edwards, the only references to coconuts in the Relaciones de Yucatan refer to plants imported from other Spanish possessions (Edwards, 1957, 100). He comments (p. 89): "It may have been brought from the West Indies by the early Spaniards and planted in Yucatan, but we find no mention of its occurrence along the Caribbean coast of the peninsula until the latter part of the Nineteenth Century." However, coconuts were widespread on the sand cays of British Honduras by 1810 (Henderson, 1809; 1811, 21-22), and were established on the atolls at least as early as 1720 (Saddle Cay, Section VI). They have probably greatly increased in importance in the last 50 years.

In their natural state the cays may have supported broadleaf forests, of which traces remain only on Half Moon Cay, Lighthouse Reef, and Northeast Cay, Glover's Reef. The dominant constituents are Cordia sebestena, Bursera simaruba, Bumelia retusa, Pithecellobium keyense and Pouteria campechiana, with perhaps sapodilla and mahogany. Pinus caribaea, found on one of the uninhabited barrier reef cays, is not seen on the atolls.

With the exception of cocal and restricted broadleaf forest, the vegetation of the cays falls into six groups: (a) strand plants; (b) marginal thicket; (c) interior thicket; (d) other interior areas, chiefly grass; (e) marsh and swamp; (f) mangrove. The strand plants include those species, many pan-tropical, common to sand beaches--an outer zone of Sesuvium portulacastrum and Ipomoea, an inner zone with the hardy colonising grass Sporobolus virginicus and other plants such as Euphorbia and Canavalia. Sesuvium is found on both shingle and sand, Ipomoea generally on sand. The "marginal thicket", lying landward of the strand zone, differs according to substrate and exposure: in exposed shingle areas Tournefortia gnaphalodes and Cordia sebestena are most common; on less exposed sand shores they are replaced by Suriana maritima and Coccoloba uvifera. The "interior thicket" is less well known. Besides Suriana it includes Conocarpus erectus, Erithalis fruticosa, Rivina humilis and Ernodea litoralis. Areas not covered by thicket are generally under coconuts, with an undercarpet of low herbs (Stachytarpheta jamaicensis, Wedelia trilobata, Ambrosia hispida, Cakile lanceolata), the grasses Andropogon glomeratus and Cyperus planifolius, the lily Hymenocallis littoralis, and the legume Sophora tomentosa. The vegetation of interior marshes has been almost entirely removed, and they are now usually covered by a mat of Wedelia trilobata, which seems to prefer damp, shady locations, with a few relict mangroves. The mangrove zone is not, by definition, well developed on sand cays, and is represented only by scattered mature trees round cay margins, and innumerable Rhizophora seedlings in shoal water offshore.

The strand plants are evergreen, fleshy, and adapted to cay conditions (thus Sesuvium leaves are plump and fleshy in direct sunlight, thinner in shade; while Tournefortia and Sophora show xerophytic adaptations). No cacti are found on the atoll cays which distinguishes them from the Jamaican and Florida cays, nor are cultivated fruit trees, in distinction to the breadfruit and other fruit trees of the Pacific islands. One fact of interest is the irregularity of distribution of cay plants: *Ambrosia hispida* is widespread on Sandbore Cay, Lighthouse Reef, and Cay Bokel, Turneffe, but is of minor importance elsewhere; *Sesuvium* and especially *Ipomoea* may be entirely absent on some cays. Many of the cay plants have seeds viable after long immersion in salt water, notably *Tournefortia*, which can germinate after six months (Sauer, 1959, 9).

Attempts have been made to relate the present distribution of plant associations on cays to stages in the development of vegetation on new cays: that the bare sand is first colonised by a strand association (*Sesuvium*, *Ipomoea*), which ultimately develops into tall interior thicket (David, 1942, 126-131; Chapman, 1944). The succession in space is also a succession in time. If this is to have value it requires detailed work by trained botanists and in this connection it should be noted that the maps showing vegetation distribution on the cays are intended to show gross features of the vegetation only. Strand vegetation alone is recorded in any detail. No previous collections have been made from these cays, so that the list of plants collected (Appendix 2) will probably be much extended. I am very grateful to Dr. F.R. Fosberg for the identifications, and much advice on botanical matters.

Marine algae and other plants have been noted in some of the detailed cay accounts. Algae were collected and the identifications are awaited. For an account of some algae from the barrier reef, see William Randolph Taylor (1935).

B. The mangrove cays

In addition to sand cays, Vermeer described two other types from British Honduras: "mangrove cays", consisting of clumps of *Rhizophora mangle*, which he noted from the barrier reef lagoon and Turneffe, and "mangrove-sand cays", which he described only from the barrier reef lagoon (Vermeer, 1959, 32-40). Both these types are found on Turneffe, the mangrove-sand cay is also found on Lighthouse Reef, and they are absent only from Glover's Reef.

The mangrove cay

Little information is available on mangrove cays, partly because of the difficulties of studying and mapping them. They are frequently large and cover a much greater area than the sand cays; they have little or no dry land, consist wholly or predominantly of *Rhizophora mangle*, and have little wild life apart from birds and boa constrictors. As Vermeer notes, one of the closest approaches in the literature to the British Honduras type of mangrove cay is in the Bogue Islands of Jamaica, described by Steers (1940a), which I was able to see from the shore in 1960. On the atolls, simple mangrove cays are confined to Turneffe, where they often rise from fairly deep water, suggesting some kind of basement. The completeness of the canopy and stilt and drop roots give a unique and disconcerting atmosphere to this type of cay.

It has often been loosely stated that mangrove colonisation leads to growth of land areas, but it can be seen that mangroves can only take root in shallow water (Vann, 1959, 359-360). A drying shoal is not necessary, for Rhizophora seedlings can grow in 2-3 inches of water; they are found on varied substrates, from coarse shingle to sand, but are most numerous on sheltered shores of medium-fine sand. Where a mangrove cay rises from water deeper than 1-2 fathoms, then some kind of basement must underlie it: such as a sand bank or coral patch-reef. Once Rhizophora is established on such a shoal, however, there is little doubt that its intricate root system will serve to trap further sediment and raise the floor level, partly at least because of humus accumulation and the formation of peaty mangrove soil (David, 1940, 325-327; Newell and others, 1959, 224-225). Mangrove may even be a fine-sediment producer by aiding chemical erosion of reef rock on which it stands (Wharton, 1883; Fairbridge, 1950, 334).

As the floor level rises, ecologic conditions change, and there is a fairly well documented transition from pioneer Rhizophora, through Avicennia, to Conocarpus bush, and finally to dry land thicket and forest (Richards, 1953; Davis, 1940). This leads to an ideal succession in time at any one point, and to a succession in space at any particular time. In British Honduras, however, one has the impression that Rhizophora is overwhelmingly dominant in the true mangrove cays, and that the general succession is not here established. Rhizophora grows rapidly, and in the case of one barrier reef cay the entire island is known to have developed since 1819; on the other hand, map evidence (which is admittedly liable to error) does not show any great extension of mangrove area on Turneffe since about 1750. This may partly be due to the contemporary rise in sea level of 4 inches per century cancelling out the effect of mangrove sedimentation and retarding the succession. Alternatively, the fact that mangrove cays, especially in the Turneffe lagoons, do not seem to be expanding laterally, may result (a) from limited foundation area, and (b) tidal current scour. It has already been suggested (Section V) that many of these cays may stand on karst-eroded foundations of Glacial age.

Generally the mature Rhizophora of these cays reaches a height of 20-30 feet; the tallest seen, on the east side of Turneffe, reached 40 feet. While young they are liable to be uprooted in hurricanes; no examples were seen on the atolls, but unusually low mangrove cays in parts of the barrier reef lagoon suggest such action.

The mangrove-sand cay

This type of cay was described by Steers in the Bogue Islands, north coast of Jamaica (1940a, 36-37). These are a group of mangrove islands, the innermost with no dry land, the outermost with "low sand areas lying on or near the outside of the mangroves... The lee side shows no land at all." The sand areas here are up to 250 yards long and 20 yards wide, but do not rise more than 18 inches above the sea. Vermeer (1959, 35-40) describes the mangrove-sand cay type from the British Honduras barrier reef lagoon, where he found cays up to 5 miles in length, bounded on their seaward, exposed side by sand ridges 1-200 yards wide and 4-12 feet high; hence on a much larger scale than in the Bogue Islands. From the detailed cay descriptions in Sections V and VI it will be seen that mangrove-sand cays are well-developed on both

Turneffe and Lighthouse Reef. Indeed, one might say that Turneffe is really one large mangrove-sand cay, in view of the extensive sand ridge on the eastern side of the main lagoon mangrove mass. On Lighthouse Reef, Northern Cay and Long Cay are examples: both have extensive sand areas on their northern sides, and Long Cay has a long, low narrow sand ridge along its eastern, reef-facing shore.

Mangrove-sand cays include four main vegetation zones: (a) the strand vegetation of the seaward sandy shore; which is comparable to similar strand areas on sand cays, except that shingle-loving plants such as Tournefortia are unimportant; (b) the sand-area thicket of palms, Conocarpus, Suriana, Coccoloba, and other trees and bushes, with an undercarpet of Hymenocallis, Wedelia, Stachytarpheta, Andropogon, Cyperus, Eragrostis; (c) the mangrove-transition zone, with Conocarpus, Avicennia, Laguncularia, and some tall ancient Rhizophora; and (d) the Rhizophora zone, often "hollow", with much standing water and dead and dying trees, fringed with vigorous, bushy mangrove. On both the atolls today the vegetation of the sand areas of the mangrove-sand cays has been largely cleared for cocal, and the vegetation boundary between sand and mangrove areas is now unnaturally abrupt. Beachrock forms along the sandy shores, exactly as on true sand cays, and the main difference between the two is that shingle is generally absent from mangrove-sand cay shores on account of their distance from the reefs.

Origin of the mangrove-sand cays

Vermeer explained the three cay types (sand, mangrove-sand, and mangrove) of the barrier reef lagoon as resulting from differing degrees of exposure to wind and waves. "Thus, in going from the main barrier reef to the (mainland) shore one might expect to encounter, in succession, sand, mangrove-sand and mangrove cays" (1959, 39-40). This is attractively simple, and undoubtedly contains much of the truth; but in the case of the barrier reef it depends largely on the shallowness of the lagoon floor back of the barrier, and where deeper water is found quite a different zonation results. Further, mangrove cays may occur in very exposed locations (Pelican Cay, Turneffe; Columbus and other cays, barrier reef), suggesting that degree of exposure, or proximity to the reef, is in itself not a sufficient explanation.

The only other area in which detailed botanical work on mangrove-sand cays has been carried out is in the Marquesas Group, off southern Florida, studied by J.H. Davis. Here cays are found with inner mangrove zones, and outer sea-facing sand ridges. In the adjacent Dry Tortugas, few or no mangroves are found, and only sand cays occur (Davis, 1942, 131-133), in spite of the fact that "seeds and seedlings of all three (mangrove) species float there by the thousand" (134). This Davis explains primarily by the fact that "at the Marquesas there are no coral reefs, but at the Tortugas living coral reefs abound" (122); hence sediments at the Marquesas are finer than at the Tortugas. In an earlier paper, he pointed out that mangroves grow better on marl muds than on coarse calcareous sands and shingles (Davis, 1940, 358). These conclusions can be applied to the mangrove and mangrove-sand cays of British Honduras (Stoddart, 1962): the presence of mangrove is related largely to the grain size of the debris supply, which depends both on exposure and on the source of the debris. Mangroves are least common on exposed coral reefs, where there is a constant supply of coarse debris; they take hold either on sheltered coral reefs, or on lagoon sand shoals, where the debris is fine sand or even mud, and coarse material is uncommon. Whenever coral reefs are found close to mangrove islands in fairly exposed locations, then sand and even shingle ridges will be formed (exposure in this sense includes not only distance from the reefs and absence of intervening islands, but depth of water offshore). This explains the formation of the low wooded islands of the Great Barrier Reefs, with their distinctive association of shingle ridges, mangrove and sand cays on one reef patch (Spender, 1930); the very similar cays described from the Java coast by Umbgrove (1928, 1930); and the precisely analagous islands, unnoticed by Vermeer, from the British Honduras barrier reef lagoon, which I hope to describe shortly. The size of the debris determines the effect, on cays, of exposure, in the broadest sense. This suggests a general principle, of world-wide application to all types of cays--mangrove, mangrove-sand, sand, shingle, and low wooded islands.

The mode of development of the mangrove-sand cays off British Honduras, in the Marquesas and Bogue Islands, is largely unknown. Vermeer (1959, 116) considers that this type of cay "appears first to have been formed as a sand cay and subsequently colonised by mangrove seedlings on the leeward side". I doubt whether this is the case, for if so we might reasonably expect to find embryonic mangrove-sand cays not yet colonised by mangrove: in other words, sand cays lacking all the characteristics of form and location of true sand cays. Such islands are not found, and one doubts whether the sand ridge itself could accumulate without the obstructive effect of the mangrove. This is in fact suggested by the Bogue Islands. The two sections probably originate and develop as a single unit, rather than form sequentially.

Finally, the largest problem of all: why are the mangrove cays so extensive on Turneffe and Lighthouse Reef, and absent on Glover's Reef? This appears fundamentally a question of levels. Turneffe owes its mangrove to its highstanding, shallow upper surface, perhaps developed by karst erosion in Glacial times to give the lagoon-rim form (Section IX). There is evidence of recent local warping which would locally expand the shoal area and lead to further mangrove colonisation. On Lighthouse Reef there is evidence of local uplift of the entire bank of not more than 2 feet: again, this would cause shoaling of the lagoons and increase the possibility of mangrove growth. On the barrier reef and on Glover's Reef there is little or no suggestion of any similar movement, and here, respectively, mangrove-cays differ significantly in their distribution, or are absent.

C. Conclusion

In this review the probable origin of the atoll cays has been outlined, and the problems connected with them stressed. Many comparisons have had to be made with the barrier reef cays, on which work is progressing, and when this is complete, it is hoped to combine both accounts, compare them with cays described from the Caribbean, Indonesia and

Australia, and outline a general theory of cay formation. Most previous descriptions of cays have been from barrier reef or patch reef areas, rather than from atolls: many Indian and Pacific Ocean atolls have islands which include much elevated solid rock, and are thus rather dissimilar to the cays discussed here. These reef-islands form a study in themselves, quite distinct from that of uncemented cays. Some of the suggestions made in this section (for example, the influence on cays of rising sea-level) are at present rather speculative, and more experimental and field studies are needed to qualify them. To take one problem: are we justified in assuming (as the evidence suggests) that cay retreat is everywhere at present in operation, and in looking for a general cause; or have we misread the evidence, and are cays in fact cyclic structures, forming, eroding, reforming continually, under essentially static long-term conditions, rather like the evolution of multiple shingle ramparts as shown by Fairbridge and Teichert (1947)? This is one question--there are many others--of the utmost importance; and no simple answers are in sight.

Spender defined a sand cay, in an oft-quoted phrase, as "a perfect equilibrium structure due to the drift over the reef flat, the wave system of the lee of the reef, and the height of the flat. For that reason, cays tell nothing of the past history of the reef but only of the actual momentary level of the reef" (1937, 141). This may apply to simple sandbores, but not to large vegetated islands of the type found on these Caribbean reefs and atolls, which are both more complex and more interesting than Spender's summary might suggest. An extension of cay studies throughout the Caribbean area, especially along the west coast of Central America, would add immeasurably to our knowledge in a completely unknown area.

IX. ORIGIN AND DEVELOPMENT OF THE BRITISH HONDURAS ATOLLS

Though this paper chiefly described the results of a reconnaissance of the British Honduras atolls, and is mainly concerned with their present condition, some brief remarks may be made in conclusion on their development towards their present form. As stated in Section II, the reefs appear to be built on fault-controlled ridges and platforms, bounded eastwards by steep slopes carrying the sea floor down to depths of over 10,000 feet. The faulting is associated with the evolution of the Bartlett Trough, the main movements of which were of Pliocene date, and thus the reef foundations probably came into being in late Tertiary times. No solid rock outcrops on the atolls, and no drilling has been carried out, so it can only be suggested that the fault-bounded platforms may consist of Cretaceous and Tertiary limestones overlying Palaeozoic rocks, as they do on the adjacent coastlands. The three atolls rise 900-1,000 feet from the platforms on which they stand. Making maximum allowance for Pleistocene fluctuations of sea-level, this is several hundred feet deeper than reef-building corals can grow (Stearns, 1946, 261). If the foundation of the atolls below about 450 feet can be shown, by boring or seismic work, to consist of reef-building corals and their debris, then subsidence of the fault-blocks and upgrowth of reefs from them is indicated (Darwin, 1842). The alternative, implied by Ower (1928), is that the foundations of the atolls, below the maximum depth of reef-building corals, consist of isolated fault-blocks of limestones or Palaeozoics, delimited by faults transverse to the main lineations. The only evidence for such faults lies in the existence of the reefs themselves; and thus this fundamental question remains unsettle.

Pleistocene events

The subsequent course of events is by no means clear, but it is possible that reef-building corals became established on the Platforms before the onset of Pleistocene glaciation; indeed, it is possible that they had built a reef several hundred feet in thickness in late Tertiary times. Certainly when glaciation began the banks stood at or near their present level: Turneffe with its upper surface 2-3 fathoms below present sea-level, Lighthouse Reef 2-4 fathoms, and Glover's Reef 15-24 fathoms; or rather lower, allowing for subsequent reef-growth and sedimentation. The onset of glaciation brought, as Tylor first recognised in a long-neglected statement (1868, 1869, 18, 72), and as Daly subsequently stressed (1910 and later), multiple falling of sea-level coinciding with each separate advance of the continental glaciers. This would have the two-fold effect of killing all near-surface reefs by the mere fact of exposure, irrespective of temperature change, and of exposing the summits of the banks, a mass of reef and lagoonal limestones, to subaerial erosion. The question as to whether corals could survive during the glacial periods--whether the atolls are located in Davis's coral seas or marginal belts (Davis, 1923, 1928)--is thus, on such steep-sided blocks, somewhat academic. Palaeotemperature curves published by Emiliani (1955), based on isotope ratios of near-surface Foraminifera in two Caribbean deep-sea cores, suggest that over the last 280,000 years, near-surface sea temperatures in the Caribbean have undergone fluctuations of not more than 6°C. Even a fall of this amount in the winter surface temperatures recorded at Rendezvous Cay would not extinguish the reefs, though the species-composition might be radically changed and the reefs attenuated.

The major effect of glaciation would, however, be the sea-level fall. Daly estimated this at a maximum of 33-38 fathoms (1915, 174), Stearns at 45 fathoms (1946, 261) (200-230 and 270 feet respectively). Charlesworth in a recent review gives figures of 93 metres (300 feet) for the last glaciation and 120-130 metres (400-430 feet) for maximum glaciation (Charlesworth, 1957, II, 1354-1355). Such a fall would expose the whole of the British Honduras coastal shelf, lead to deep incision of river valleys now filled with alluvium (e.g. North Stann Creek: Dixon, 1956, 29), and to the extension of drainage lines across the emerged area. It is thought that the Belize Deep-Water Channel, meandering across the coastal shelf and cutting through the barrier reef, with depths of up to 190 feet, is such a drainage line, though why it should pursue this course, and why it should cut so great a trench, is unknown. At the same time the coastal shelf reefs and the summits of the outer banks, would be exposed to karst erosion. Hoffmeister and Ladd (1945) showed experimentally that under erosion a limestone block tended to develop an irregular concave surface, and MacNeil (1954) used this as the basis for a theory of atoll development on subaerially preformed foundations. Such a process may well have resulted in the present form of Turneffe, where a mangrove covered rim surrounds a deeper, extensive lagoon area (fig. 49). In this case the present reefs are superficial additions to the edges of the atoll-like bank, rather than its essential cause.

Glover's Reef (fig. 49) is somewhat different, for here the lagoon floor descends to depths of over 140 feet, and averages 90-120 feet. This is still well above the presumed low limit of the glacial seas, and must have been subjected to karst erosion. On Lighthouse Reef (fig. 49) the general lagoon floor level is only 20-25 feet below present sea-level, and would be similarly affected: the Blue Hole provides evidence of karst erosion down to 480 feet. Workers on the Gulf Coast of the United States envisage a glacial low limit of about 450 feet (Le Blanc and Bernard, 1954). Why such features as the Blue Hole are not much more numerous is not clear. Dimpling of the Lighthouse lagoon floor on a much smaller scale than the Blue Hole, and some of the deep passages and holes on the Barrier Reef, may be ascribed to subaerial erosion, but evidence is lacking from Turneffe and Glover's Reef at present.

Karst erosion certainly continued therefore during glacial low sea-levels, and may have resulted in the basining of the tops of the banks and the creation of a rudimentary atoll form, though this was probably already in existence. Daly (1910 and later) stressed low-level benching of islands and banks by the glacial seas, but the absence of such benches in British Honduras lends support to Newell's view (1960) that such benching was of small effect. There is no evidence from the atolls of deep abrasion platforms, while on the coastal shelf the barrier reef edges a tilted antecedent platform of probably pre-glacial age, in whose formation it played no part, much as Vaughan supposed (1916, 1919a).

Daly recognised (1919) that reefs might become re-established during inter-glacial high sea-levels, and there is some evidence of major reef upgrowth of either pre- or inter-glacial age on both the barrier reef and Glover's Reef. The evidence is entirely physiographic. On the barrier reef, the present reef-flat rises from a broad platform 3-4 miles wide in the north and 2-4 fathoms deep. Farther south, where the surface reef becomes fragmented, the "lower flat", as it may be termed, becomes narrower (averaging 1 mile in width), but maintains its depth for over 100 miles. Its surface is irregular and in places deeply pitted, suggestive of erosion; it rises steeply on the lagoonward side from the lagoon floor, and is edged on the seaward side by the present "upper" reef-flat and reef. Serial sections across the coastal shelf and barrier reef show the remarkable persistence and regularity of this feature. It was shown in Section VII that a similar "low platform" is found at a depth of 4 fathoms surrounding the Glover's Reef lagoon; this too is rimmed on its seaward side by the present reef-flat and living reef. It might also be noted that the Lighthouse Reef lagoon floor lies at or a little above the level of this "lower platform".

This feature is clearly not related in origin to the present, post-Würm living reefs, which date entirely from the last rise of the sea. Dr. E.G. Purdy informs me that a peat from the Belize Deep-Water Channel at 70 feet in depth has been dated at 8,000 years BP, which narrowly circumscribes the age of present living reefs. It is unlikely that the lower platform results from the subaerial erosion described by MacNeil, on account of its width, horizontality and extent, and one is led to the conclusion that it can only be an old reef surface, developed during a much longer period of time than present living reefs. Much of the evidence for this rests on data from the barrier reef which cannot be discussed here, but the conclusions must also be valid for the atolls. Whether the surface is one of upgrowth or degradation is another matter: its surface on the coastal shelf is irregular and pitted, and was probably much eroded during exposure. It is intersected by the Belize Deep-Water Channel and a few other gaps. Work carried out by Dr. B.W. Logan on Campeche Bank (personal communication, 1961) suggests that a similar level cannot be traced north of the Yucatan Peninsula. He finds marked eustatic benches at 50-55 fathoms (correlated with the Wisconsin glaciation), 30-35 fathoms, and 16-20 fathoms; and suggests that a level at 2-4 fathoms might be related to the lower depth limit of Acropora palmata reefs. He describes such a constructional bench on the Campeche Bank at depths varying from 30 feet in windward locations to 10-15 feet to leeward. It seems unlikely, however, that this can be applied as a general explanation for a feature of such size as the British Honduras "lower reef-flat". The absence of such a level on Campeche Bank throws some doubt on its eustatic origin; yet its horizontality over a large area suggests that foundering cannot account for its present low level. Whatever its origin, this bench is of the greatest importance in the physiography of the British Honduras reefs, for on it all the present surface reefs are built, and its presence at Glover's Reef shows that the atoll-form was already established when it was built. Benches underlying modern reefs have been described from Bikini (15-50 feet deep: Tracey, Ladd and Hoffmeister, 1948; Emery, Tracey and Ladd, 1954, 26ff.), from Raroia (edges at 25 and 65 feet: Newell, 1956, 334, 341), and Andros Islands, Bahamas (an inner platform at 2 fathoms separated by a line of oolite cays from an outer platform at 2-16 fathoms: Newell and others, 1951, 10, 24); but there seems little point in attempting to correlate these with benches in British Honduras.

The lower levels described as eustatic by Logan cannot be identified in British Honduras; they probably exist as unconformities within the reef-mass, and have been buried by later growth and sedimentation. They have also been described from the Gulf Coast by Shepard and others (1960), and the 16-20 fathom level in particular seems widespread in the Caribbean basin. Zans (1958, 7) describes it from the Pedro Bank, and examination of charts shows widespread occurrence of levels of from 11 to 23 fathoms on at least 13 banks in this area (Admiralty charts 450, 486 and 762). Stillstands of the sea at such levels, connected with glacial eustatism, have undoubtedly been important incidents in the growth of present reefs.

The emphasis in reef-growth is thus placed on glacial control of fluctuating sea-levels, though this does not preclude earlier subsidence on the Darwinian model. Whether or not subsidence has taken place is, in view of these fluctuations, irrelevant insofar as present surface form and features of the reefs is concerned (MacNeil, 1954). Darwin himself thought subsidence an unlikely explanation for these atolls, basing his opinion on Captain Allen's reports of Owen's survey. He doubted that both the barrier reef and its lagoon floor were built by reef-corals, thinking rather of an accumulation of sand similar to that which he thought was taking place on the Nicaraguan and Yucatan banks. On the atolls he wrote:

> "....immediately on the outside of this barrier-like reef, Turneffe, Lighthouse and Glover Reefs are situated, and these reefs have so completely the form of atolls, that if they had occurred in the Pacific, I should not have hesitated about colouring them blue. Turneffe Reef seems almost entirely filled up with low mud islets; and the depth within the other two reefs is only from one to three fathoms. From this circumstance, and from their similarity in from, structure, and relative position, both to the bank called Northern Triangles, on which there is an islet between seventy and eighty feet, and to Cozumel Island, the level surface of which is likewise between 70 and 80 feet in height, I consider it more probable that the three foregoing banks are the worn-down bases of upheaved shoals, fringed with corals, than that they are true atolls, wholly produced by the growth of coral during subsidence...." (Darwin, 1842, 202).

Thus Darwin's view is comparable with that adopted here, though for rather different reasons; his undogmatic approach is still instructive.

Post-glacial history

With the rise of sea-level in the last few thousand years, reefs grew to the surface and expanded seawards, leaving a shallow sandy reef-flat averaging 1 mile in width. Cays were formed on this flat from reef-debris, and vegetated, and beachrock formed around their margins (Section VIII). The evidence taken from British Honduras as a whole seems to indicate that sea-level has not at any time since the last glaciation stood considerably higher than at present--a view taken by many workers on the Gulf Coast (Le Blanc and Bernard, 1954; Shepard and others, 1960). On the other hand, work in the Pacific seems to indicate a recent higher stillstand of the sea, as summarised by Tayama (1952, 271):

> "The so-called sea level Coral Reefs are not of Recent origin. The Sea Level Coral Reefs have been generally accepted as recent, but most of the present reef-flats are abrasion surfaces, like pavements, displaying cross-sections of truncated reef-building corals, benches and mushroom rocks. The so-called Recent Coral Reefs are relicts of coral reefs of corals of the age of the Younger Raised Coral Reef Limestone. As Dr. H. Yabe has stated, the coral reefs, in the recent seas, are in process of destruction rather than of construction. The scope of the destruction, however, is limited to an area approximately 2 metres above low tide."

Stearns so interpreted the reef-flats of Eniwetok Atoll, Marshall Islands and other Pacific areas (1945a, 1945b, 1946) (cf. Ladd and Tracey, 1949, 300, and Emery, Tracey and Ladd, 1954, 92), and Cloud, following work on Onotoa, saw in this supposed fall from a 6 foot stillstand a general explanation for the appearnce of existing reefs (1952, 1954). On the characteristics of a reef-flat developed by downwearing of an earlier, higher surface, he wrote: "If it is sparse in living coral and veneered with green algae and clastic debris, and particularly if it is also a relatively smooth surface, it was probably truncated" (1952, 54). These characteristics, taken by themselves, hardly seem an adequate foundation for a conclusion of such importance. More positive evidence of emergence is needed, such as areas of dry reef-rock and mushroom rocks, shallow rock-floored reef-flats, raised beachrock, raised beaches and abnormally high cays, all found consistently over wide areas and developed on diverse structural units.

Vermeer (1959), however, considered that there is sufficient evidence of a 6 foot high stillstand on the British Honduras reefs to justify correlation with the Pacific 6 foot bench. His evidence for this is threefold: (a) Vermeer described raised beaches from two cays, Ambergris Cay, barrier reef, and Long Cay, Lighthouse Reef. Both were visited in 1961, and no evidence was found to establish this view. These he correlated with the Harry Jones raised beachrock, Turneffe, figured in Dixon's (1956) report as 7 feet above sea-level--a misprint, since the beachrock does not rise more than 2 feet above the sea at any point. (b) He considers that the reef-flat of the central barrier reef is abnormally wide and shallow, and that it must therefore be an erosional surface. (c) He correlates these instances with nearby areas, especially in Quintana Roo, where similar instances are said to have been found.

Vermeer's conclusion is thought to be erroneous, for the following reasons. The raised beaches which form the basis of the theory are not established, and no trace of similar beaches has been found on any of the 70 cays mapped in detail on the British Honduras reefs since 1959. Regarding the reef-flats, nowhere on the British Honduras reefs do we find a single erosional mushroom rock or exposed eroded reef above present sea-level: with the exceptions only of the patches on the windward reef of Lighthouse Reef, and the dry reef at Soldier Cay, Turneffe. Beachrock remnants at Half Moon Cay, Lighthouse Reef, stand 12-18 inches above mean sea-level, and extensive remnants at Northern Cay on the same atoll at similar elevations, taken together with the patches of drying reef-rock, suggest that the atoll as a whole has undergone a recent positive uplift in recent times, but that this has not been greater than about 2 feet. On Turneffe, the restriction of drying reef to a single area at Soldier Cay, and the fact that it lies only a few hundred yards from the Harry Jones raised beachrock, thought, on account of its lateral dip, to be tectonic in origin, suggests that here too is evidence of local uplift, rather than of eustatic shifts of sea-level. Height-equivalence alone is an insufficient ground for correlation of evidence in support of the eustatic theory, for many other factors relating to each item of evidence must be considered. Local differential movement, resulting from crustal instability, is only to be expected on the margins of a tectonically active area such as the Bartlett Trough--witness upraised reef limestones of recent age in Cuba, Haiti and Jamaica. To accept the eustatic theory of a 6 foot fall in sea-level, we must first explain the total absence of erosional mushroom rocks and similar evidences on the reefs; Vermeer's reference to a so-called "Negro Head" marked on charts of the barrier reef lagoon is misleading, for the name simply applies to a small mangrove island south of Middle Long Cay, and does not have any wider implication. Furthermore, all the cays at present found are referable to present sea-levels (Section VIII), none being so abnormally high that they must have developed in such a high stillstand. Detailed surveys are of assistance here, for without instrumental levelling on a number of cays as standard, one consistently overestimates their heights by as much as 30-40%. Most of the more protected cays are less than 4 feet above the sea, and very few indeed rise more than 8 feet. Thus, after a fall of sea-level of 6 feet to the present level, only very restricted small areas could possibly be referred to the earlier stillstand. Kuenen (1933, 1950) and many others (Gardiner, 1903-6, 1931; Sewell, 1935, 464-479) have considered reef islands to be relicts exposed by such a fall of sea-level, and some have gone so far as to argue that without such a fall very little or even no land at all would exist on the reefs. Since so very little of the land of the British Honduras cays can possibly have existed above a 6 foot sea-level, this is not thought to apply to these reefs to more than a very limited extent, which has been discussed in Section VIII.

Finally, we may briefly examine the instances which Vermeer correlates with his supposed 6 foot stillstand in nearby areas. First he mentions elevated reefs in northern British Honduras (Romney and others, 1959). Flores (1952) briefly mentions these and considers them "Mio-Pleistocene" in age, which would make them very considerably older than the sea-level stand to which Vermeer thinks they have developed

(Fairbridge terms the 6 foot stillstand the "Abrolhos Submergence" and dates it at only 2600-2100 years BP (Fairbridge, 1958, 479; 1961, 147)). Dixon, too, doubts whether these exposures have any relation to exposures on the offshore cays at the present time (personal communication, 1961). Vermeer also refers to elevated coral found by Edwards (1957) on the Quintana Roo coast. Very little information is available on these exposures, and they may be equivalent to those of northern British Honduras. There seems little basis for Edwards's statement (1957, 22) that on Chinchorro Bank "coral reefs....occur above their level of formation" (See Appendix 3).

While dismissing therefore the idea of a 6 foot eustatic stillstand (and a fortiori the numerous other high stillstands of post-glacial time listed by Fairbridge (1961)) because of lack of evidence, there remains the possibility of minor fluctuations of sea level affecting the area as a whole. These have been discussed in another paper (Stoddart, 1962), and the evidence consists largely of physiographic features of the cays and drowned beachrock. The difficulties of such an interpretation are there stressed, and the tentative conclusion reached that undercutting of cay margins and the migration of cays away from reef edges may indicate a slight negative shift of sea level, as envisaged by Kuenen (1933); and that drowning of relict beachrock and intensification of cay erosion has resulted from a subsequent small rise of sea-level (Fairbridge, 1947), perhaps associated with the recent shrinkage of glaciers (Ahlmann, 1949). These changes are on a very much smaller scale than anything required by the 6 foot and higher stillstands. Kaye (1959) has stressed the difficulties of precision in determining levels and changes of levels, especially in short visits to cays; he considers it doubtful whether measurements can be accurate to more than ± 1 foot, and doubtful whether sea-level shifts of less amplitude than ± 2 feet can be detected in rapid surveys (though Newell has claimed to identify relative movement of only 15-20 cms (much less than a foot) at Raroia (1956, 334)). The writer would agree with Kaye's opinion, even at the risk of excessive caution. It is possible that all these effects may result from a slowly rising sea-level, and that erosion has been initiated without any fall of sea-level at all.

These conclusions may well be upset by future detailed work, particularly on the British Honduras coast and the infill of the deeper valleys, but even if fluctuations are found there and can be dated, the problem of correlation with the reefs and cays is immense, as Australian experience shows (Steers, 1929, 1931, 1937). Conversely, if these conclusions are shown to be correct, then Cloud's views on the origin of surface reef features (1953, 1954) do not have universal application, and some reefs at least have not been affected by a recent fall in sea-level, but results from "an essentially static position of sea level during a considerable period" (McKee, 1959, 243).

Classification of the reefs: some considerations

In a previous paper (Stoddart, 1960), the three reefs considered here were termed the "outer bank reefs", while in the present paper they are termed atolls. It is fitting in conclusion to consider briefly the validity of this term as applied to these reefs, and to suggest its limitations.

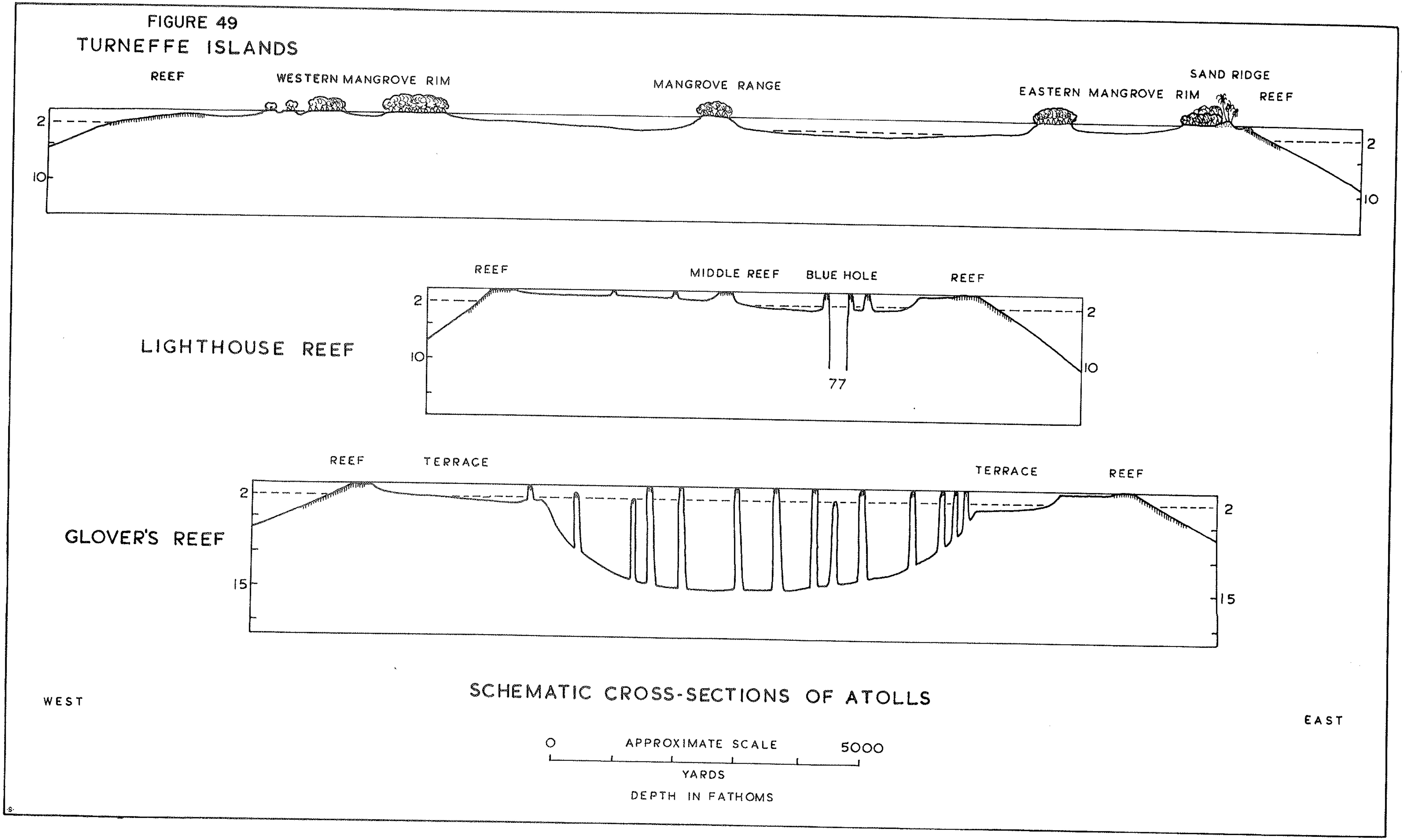
Since the time of Chamisso, the atoll has been recognised as "a mass of rock, which rises with perpendicular walls from the unfathomable depth of the ocean, and forms on the surface an overflowed plateau. A broad dam, constructed by nature round the edge of this plateau, changes it into a basin" (Chamisso, in Kotzebue, 1821, III, 140; see 140-159, 331-336). Darwin (1839, 1842) subsequently elaborated on this picture, but went further and tended to exclude from the atoll-class atoll-like reefs not clearly formed by subsidence (exemplified by his treatment of the British Honduran reefs quoted above). Yet even so thoroughgoing a Darwinian as Davis was compelled to admit that atolls are "inscrutable structures" (1928, 14), and that the definition of an atoll must depend upon its surface features rather than inferred or even demonstrated origin. Thus the fundamental question of what constitutes an atoll revolves round certain observable phenomena. Thus Cloud (1957, 1009) states that "atolls consist of ringlike organic reefs that surround lagoons in which there is no pre-existing land. The ring-reef, the lagoon, and the absence of pre-existing land are all essential features." This definition differs in one important respect from Chamisso's, for Chamisso adds (with a certain poetic license) that atolls rise "with perpendicular walls from the unfathomable depth of the ocean." This criterion is of some importance, for by accepting it we exclude reefs rising from shallow shelves with poorly developed reef-rims, having only a superficial surface resemblance to true deep-sea atolls. Thus, in the Caribbean, Glover's and Lighthouse Reefs would qualify as atolls, Alacran Reef would not. In my view there are not sufficient similarities between these reefs to classify them all as atolls, if the term is to retain its usefulness. Any definition must, therefore, include (1) the fact that reefs rise from depths greater than the depth at which reef-building corals can grow, which, taking glacial low sea-levels into account, may be placed at 75 fathoms; (2) that they possess a well-developed reef-rim and reef-flat, which for example, Glover's does and Alacran does not; and (3) that the reefs contain a lagoon.

Further refinement is needed in the matter of lagoon depths, whose variability has been recognised since Darwin's time. Daly (1915), Yabe and Tayama (1937) and Tayama (1952) have subsequently traced relationships between lagoon depths and the size of the atoll. Cloud (1957, 1013) recognises that "atolls may thus grade to table reefs with emergence or filling of the lagoon", citing Washington Island as an example of an atoll with "a very shallow brackish pond instead of a lagoon." Since table reefs (Tayama, 1935) will normally have more vigorous coral growth on their edges than in their centres, the question arises as to what depths a lagoon must have before a table reef becomes an atoll. Tayama attempts to deal with this difficulty by erecting the intermediate class of "Almost Table Reef" (1952, 221, 258-9), with small lagoons "generally less than 5 metres deep, but a depth of 20 metres is recorded" (258). Table reefs in his view are small and have no lagoon. For true atolls, Tayama found that in the South Seas the "shallowest record of all the lagoons is 9 metres" (1952, 247), or $4\frac{1}{2}$ fathoms. Clearly no general depth can be proposed at which an atoll ceases to be an atoll and becomes a table reef. One simple criterion may be proposed: if a definite lagoon exists, i.e. if there is a marked and recognisable break of slope between the peripheral reef-flats and the interior part of the bank, and other conditions are satisfied, then the name atoll is justified; and if not, not. If there is no well-marked reef-flat, then the bank is a table reef rather than an atoll.

What of the application of these criteria to the British Honduras reefs? Glover's Reef emerges as a splendid example of a true atoll, comparable to anything in the Pacific or Indian Oceans: it has Chamisso's "unfathomable ocean" surrounding it, and a beautifully defined reef-rim, with in addition a deep, basin-shaped lagoon. Lighthouse Reef has Chamisso's basic attributes, but the lagoon is shallow--with depths mostly less than Tayama's shallowest South Seas atoll. Nevertheless, because there is a well-marked break of slope between the peripheral reef-flats and the interior of the bank, which lies deeper than the reef-flats, it must be a true atoll, though rapidly becoming marginal to this class through reef-upgrowth and sedimentation.

Turneffe has only one of Chamisso's characteristics: it rises from a deep sea floor below the limit of growing coral. Growing reef corals are found in a well-defined belt round the edges of the banks, but do not form a discrete wave-breaking zone round its entire margin, and--more important--only locally fringe a reef-flat. There is thus no evidence that the present living reefs contribute significantly to the form of the Turneffe bank, and further, since there is no reef-flat the lagoon cannot be said to lie below it, and hence the term atoll is inapplicable. In fact the central lagoons are very shallow, and even without the mangrove rim the bank could hardly be termed an atoll except for convenience of discussion. The presence and distribution of the mangroves appear to be almost unique, as nothing quite comparable has been described in the literature; the nearest approach seems to be the Marquesas, off southern Florida, described by J. H. Davis (1942). Of the terms already in existence, only two seem to apply to Turneffe: "hummock reef", proposed by Teichert (1947) for the Houtman's Abrolhos, and "bank reef", Davis's term for reefs "which rise back from the outer margin of rimless shoals" (1928, 19, 29). Teichert's term seems to be restricted to reefs rising from shallow sea floors, and is thus inapplicable to Turneffe, with which Houtman's Abrolhos have little in common. Davis's term seems best suited, if stripped of its marginal-belt connotations and used descriptively. Given an appreciable rise in sea-level, it is quite probable that Turneffe would be rapidly transformed into a true atoll, and it is equally possible that it has passed through a true atoll stage sometime in its history.

The title of this paper is thus seen, in conclusion, to be partially a misnomer. Glover's Reef is a full-fledged atoll, Lighthouse Reef marginally so, while the Turneffe Islands may be termed a "bank reef" or "reef-fringed bank", and is not an atoll at all in the sense here defined. It should in my view be deleted from Bryan's "Checklist of Atolls", while the others remain. If the criteria here used are rigorously applied to atoll-like reefs, then more would probably be deleted, and those that remain possess more unity and common characteristics than before.



SCHEMATIC CROSS-SECTIONS OF ATOLLS

X. APPENDICES

1. Surveying

Problems of surveying sand and mangrove cays have been fully discussed elsewhere--by Lofthouse (1940a, 1940b), Kemp (Steers, 1938, 51-52), Spender (Stephenson and others, 1931), and in the revised edition of Handbook of Atoll Research, edited by Dr. Fosberg and Miss Sachet (1953). Outlines of the cays were mapped by compass traverse and pacing, with surprisingly accurate results. Greatest closure errors were found where beaches consisted of diverse material such as rough coral blocks, or on cays with lighthouses. Maps were as far as possible drawn up immediately. Where topography was considerable, lines of levels were surveyed across the island with a tripod quickset level, and again distances were paced. Details of cay composition and vegetation were booked round the cay margins during the initial traverse, and interior detail later filled in by transects normal to the shore. Speed and accuracy here depends on the recognition of "ecologic field units" of the type listed by Cloud (1952), and increases greatly with experience. Interior detail is least reliable where vegetation is most dense. Mangrove areas present special problems and cannot be surveyed to the same standards as dry land areas. Where mangrove zones on sand cays are less than 100 yards long the traverse was normally carried to seaward of them, but this was liable to disruption by deepening water, softening bottoms, and inquisitive sharks and barracuda. Elsewhere, the traverse was carried to landward, and the exterior sketched in very roughly. Recognition of vegetation units also improves with practice, and is helped by the fact that many plants (Sesuvium, Wedelia, Tournefortia and so on) occur in pure stands, often sharply delimited. Distribution of plants was normally sketched in (with pacing of distances) on completed maps. The cay was located with respect to its reef by intersection of conspicuous points--stranded trees, boulders, etc.

Beachrock mapping has problems of its own. Normally one member swam out (or if sufficiently shallow, paced out) to submerged beachrock exposures, and intersections were taken on him at salient points, by the other member from fixed shore stations. The geologic hammer proved a useful measuring rod for depth, thickness and width of beachrock, data being communicated to the person on shore for booking. Where the beachrock is complicated, it is useful to have a third person in a boat to take verbatim notes from the swimmer, and also to collect specimens.

The Turneffe cays were among the first to be mapped in this investigation, before techniques were worked out and the problems appreciated, so that the detail for certain cays on this atoll is less than one might wish.

It should be noted that the cay maps accompanying this paper are oriented according to compass north, not true north.

2. List of plants collected

The following list of determinations of plant specimens collected on the three atolls was furnished by F. R. Fosberg. Several of the specimens were in rather poor condition, or missing from the collection sent to Fosberg, and the names of these are from a set submitted to the British Museum. These are indicated as determined by W. T. Stearn, of that institution, who also sent suggestions on the nomenclature of several other species. The numbers cited are those of the collector, D. R. Stoddart, in all cases. Several specific names were changed after the stencils of the Bulletin were finished, hence the names used in the report differ from those in this list. In such cases, the synonym used in the report is added in parentheses in this list. The unidentified plant mentioned on p. 47 from Mauger Cay is _Batis maritima_.

Gramineae

Andropogon glomeratus (Walt.) B.S.P.
Lighthouse Reef, Sandbore Cay, no. 553

Eragrostis ciliaris (L.) R. Br.
Lighthouse Reef, Half Moon Cay, no. 547

Eragrostis domingensis (Pers.) Steud.
Glover's Reef, Northeast Cay, no. 62

Paspalum pleostachyum Doell.
Glover's Reef, Northeast Cay, no. 63

Sporobolus virginicus L.
Lighthouse Reef, Half Moon Cay, no. 40

Sporobolus sp.
Lighthouse Reef, Northern Cay, no. 52 (Det. W. T. Stearn)

Cyperaceae

Cyperus ligularis L. (_Cyperus planifolius_ L. C. Rich.)
Lighthouse Reef, Half Moon Cay, no. 41
Glover's Reef, Northeast Cay, no. 64

Fimbristylis cymosa R. Br.
Glover's Reef, Middle Cay, no. 80

Palmae

Thrinax parviflora Sw.
Glover's Reef, Northeast Cay, no. 77

Amaryllidaceae

<u>Hymenocallis</u> <u>littoralis</u> (Jacq.) Salisb.
Turneffe, Harry Jones Point, no. 512
Lighthouse Reef, Half Moon Cay, no. 39

Orchidaceae

<u>Brassavola</u> <u>nodosa</u> (L.) Lindl. ?
Glover's Reef, Northeast Cay, no. 65

Batidaceae

<u>Batis</u> <u>maritima</u> L.
Turneffe, Mauger Cay, no. 542

Moraceae

<u>Ficus</u> <u>ovalis</u> (Liebm.) Miq.?
Glover's Reef, Northeast Cay, no. 71

Amaranthaceae

<u>Alternanthera</u> <u>ramosissima</u> (Mart.) Chod.
Lighthouse Reef, Half Moon Cay, nos. 551, 42

<u>Iresine</u> <u>diffusa</u> H. B. K. (<u>Iresine</u> <u>celosia</u> L.)
Turneffe, Harry Jones Point, no. 28
Glover's Reef, Southwest Cay, no. 82

Nyctaginaceae

<u>Neea</u> <u>choriophylla</u> Standl.
Glover's Reef, Northeast Cay, no. 68

Phytolaccaceae

<u>Rivina</u> <u>humilis</u> L.
Half Moon Cay, Lighthouse Reef, nos. 545, 44

Aizoaceae

<u>Sesuvium</u> <u>portulacastrum</u> (L.) L.
Lighthouse Reef, Half Moon Cay, no. 46
" " Hat Cay, no. 57
Glover's Reef, Northeast Cay, no. 75

Portulacaceae

Portulaca oleracea L.
Lighthouse Reef, Hat Cay, no. 56

Lauraceae

Cassytha filiformis L.
Lighthouse Reef, Half Moon Cay, no. 32

Leguminosae

Canavalia rosea (Sw.) D.C.
Lighthouse Reef, Half Moon Cay, no. 59

Sophora tomentosa L.
Glover's Reef, Long Cay, no. 79

Surianaceae

Suriana maritima L.
Lighthouse Reef, Sandbore Cay, no. 541
" " Half Moon Cay, no. 47

Euphorbiaceae

Drypetes brownei Standl.
Lighthouse Reef, Half Moon Cay, no. 60

Euphorbia blodgettii Engelm.
Glover's Reef, Northeast Cay, no. 70
" " Southwest Cay II, no. 84

Euphorbia mesembrianthemifolia Jacq. (Euphorbia buxifolia Lam.)
Lighthouse Reef, Half Moon Cay, nos. 33, 58
Glover's Reef, Northeast Cay, no. 74

Euphorbia trichotoma Kunth
Glover's Reef, Southwest Cay, no. 81

Passifloraceae

Passiflora suberosa L. ?
Glover's Reef, Northeast Cay, no. 66

Combretaceae

Conocarpus erectus L.
Turneffe, Mauger Cay, no. 549
Lighthouse Reef, Sandbore Cay, no. 538
Glover's Reef, Northeast Cay, no. 67

Apocynaceae

Stemodia maritima L.
Lighthouse Reef, Half Moon Cay, no. 49

Convolvulaceae

Ipomoea pes-caprae subsp. *brasiliensis* (L.) v. Ooststrom
Lighthouse Reef, Half Moon Cay, no. 31 (det. W. T. Stearn)

Ipomoea tuba (Schlecht.) Don
Lighthouse Reef, Half Moon Cay, no. 34 (det. W. T. Stearn)

Ipomoea sp.
Lighthouse Reef, Half Moon Cay, no. 37

Boraginaceae

Cordia sebastena L.
Lighthouse Reef, Half Moon Cay, no. 38
Glover's Reef, Northeast Cay, no. 76

Tournefortia gnaphalodes (L.) R. Br.
Lighthouse Reef, Half Moon Cay, no. 45

Verbenaceae

Avicennia germinans (L.) L.
Lighthouse Reef, Northern Cay, no. 55

Lantana involucrata L.
Lighthouse Reef, Northern Cay, no. 53

Stachytarpheta jamaicensis (L.) Vahl
Lighthouse Reef, Half Moon Cay, no. 35
Glover's Reef, Southwest Cay II, no. 83

Rubiaceae

Erithalis fruticosa L.
Lighthouse Reef, Half Moon Cay, nos. 546, 30
Glover's Reef, Northeast Cay, no. 73

Ernodea littoralis Sw.
Lighthouse Reef, Half Moon Cay, no. 552
" " Northern Cay, no. 51

Hamelia patens Jacq.
Lighthouse Reef, Half Moon Cay, no. 36

Compositae

Ageratum littorale Gray?
Lighthouse Reef, Half Moon Cay, no. 48
Glover's Reef, Long Cay, no. 78

Ageratum maritimum H. B. K.?
Turneffe Is., Mauger Cay, no. 543
Lighthouse Reef, Half Moon Cay, no. 43

Ambrosia hispida Pursh
Lighthouse Reef, Sandbore Cay, nos. 554, 50
Glover's Reef, Northeast Cay, no. 72

Borrichia arborescens (L.) DC.
Lighthouse Reef, Half Moon Cay, no. 548
" " Hat Cay, no. 54

Wedelia trilobata (L.) Hitchc.
Lighthouse Reef, Half Moon Cay, no. 61
Glover's Reef, Northeast Cay, no. 69

3. A Note on Chinchorro Bank Atoll, Mexico

It was planned to visit this atoll also in 1961, but this proved impossible owing to the great expense involved. It appears similar in many respects to the British Honduras atolls farther south; but like them it has never been properly described. This note briefly summarises what is known of it. The atoll is kidney-shaped, 26 miles long and 6½-9½ miles wide, surrounded on all sides by a steep-to reef, which is best developed on the windward side (West Indies Pilot, I, 1956, 484-486). Chinchorro is the only atoll in this area to have been surveyed in detail, by Commander Barnett in 1839, the chart being published in 1850 and not since revised. The lagoon, like that of Lighthouse Reef, is shallowest on the west side (1-2 fathoms) and deepens eastwards to 2½-4 fathoms. The deeper portion is bisected by a tongue of shoal water (1-1½ fathoms) extending NNE-SSW, and forming the foundation for Great Cay, rising in the centre of the atoll. The greatest depth found in the lagoon is 4½ fathoms.

There are four cays on the atoll: Cayo Lobos in the south, Great Cay (Cayo Centro or Grande) in the centre; and Cayos Nortes in the north. The cays are described as follows in the West Indies Pilot, I, 1956: "Cayo Lobos (Lat. 18°23'N, Long. 87°22'W) is about 5 feet (1^m5) high and composed of indurated sand and bleached coral. Cayo Centro (Grande) lies in the middle of the lagoon about 1½ miles from the eastern edge of the reef. It is a low ridge of sand covered with vegetation and palms, the tops of which are from 40 to 50 feet (12^m2 to 15^m2) high. The centre of the cay is occupied by a salt-water lagoon. Cayo Norte consists of two low narrow cays situated close together about 1 3/4 miles within the northern edge of the bank. They are covered with dense vegetation and the tops of trees on them are from 40 to 50 feet (12^m2 to 15^m2) high." (p. 485). These observations presumably derive from Barnett's in 1839. The ornithologist Griscom spent three days on Chinchorro in 1926, visiting Cayos Nortes and Cayo Centro. One of the Cayos Nortes is uninhabited, and he described it as a "miniature atoll about 200 yards long, with a somewhat higher beach (than Cayo Centro), and no trees" (1926, 1). Cayo Centro he described at greater length, calling it a "perfect atoll", which somewhat strains the usage of the term. He found it

> "consisting of a narrow ring of sand beach, enclosing a central lagoon with one small outlet. The central lagoon is a mangrove swamp with very little open water, full of herons and crocodiles. The leatherwood is the only plant on the island which could be called a fair-sized tree, the flora of the beach otherwise consisting of scrub palms, sea-grape, and a few other shrubs with fleshy leaves of halophytic West Indian types. The destructive hurricane which visited the coast some ten years ago caused the sea to break over the whole island, killing all the taller trees and probably greatly reducing the resident land-bird population. The island has never been inhabited, and is visited occasionally only by turtle fishermen. The forest of dead trees, their gaunt and twisted arms gleaming white and naked in the tropical sunshine, rises above the scrub, and adds a touch of sadness and desolation to a scene, which is, to say the least, lonely and remote"(1926, 1).

Cayo Centro thus seems comparable to Northern Cay, Lighthouse Reef.

Edwards (1957, 22) considers that, from chart evidence, "coral heads and reefs here occur above their level of formation." He presumably refers to Blandford Ledge and Skylark Ledges at the southern entrance, which have been charted in detail; there is no evidence that they are raised. Allen (1841) described the Chinchorro Reefs as "even with the sea"--a description which he also gave to unraised reefs on Lighthouse and Glover's Reefs. Griscom says that "The outer reefs are nearly half a mile wide in places, and the biggest coral heads are four to six feet below the surface. Inside the reef is a lagoon with a white sand bottom, the water gorgeously coloured and clear" (1926, 1). He does not mention raised reefs. The lagoon itself has many patch reefs.

There are two lights on the atoll: one, 44 feet high, on Cayo Lobos; the other, 52 feet high, on the northern cay of Cayos Nortes. The Cayo Lobos light is said by British Honduran fishermen to have been out of action since Hurricane Janet passed over this area in 1955.

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