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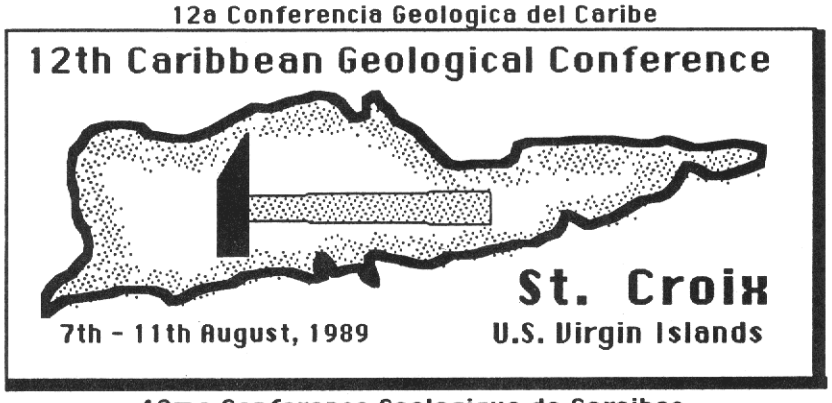

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REEFS OF ANTIGUA, WEST INDIES: CHANGES OVER 40 YEARS

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ABSTRACT

Changes in the reefs and shallow sediments off Antigua are tallied by comparison of aerial photographs from 1941 and 1954/58, and by summary of an earlier report (Weiss and Multer, 1988) on the period 1954/58 to 1981. Depletion of coralgal communities is the most serious change observed (241 hectares in the first period and 43 in the second), mostly on fringing reefs in developed areas. Patch reefs on the windward side lost coral from the reef tops during 1941-1954/58, apparently through a natural cycle of depression, for some subsequent recovery has occurred. Large areas of both grassy and mixed coral-and-grass bottom have been altered severely by dumping of dredge spoil and by drift of suspended sediment disturbed by dredging. On the leeward side of Antigua some areas of sand bottom have lost grass cover and others have gained grass cover, apparently as results of changes in the sediment load brought to the shallow shelf. Important areas of "scrolled sand" on that leeward shelf seem to alternate between arcuate ridges of bare sand on grassy bottom and bottoms in various stages of sediment removal, during which the loose sand is torn away, leaving linear blowouts in the grassy sea floor. Development since WW II has clearly altered Antigua's marine shallows, including loss of clarity of the waters of some bays. This study extends that of Weiss & Multer (1988), so that a 40-year record of the nearshore bottom is now available (1941-1981).

INTRODUCTION

Antigua (Fig. 1) is a large island (284 km^2; 108 mi^2) in the Limestone Caribbees, the outer chain of islands in the northern Lesser Antilles. It is one of the two islands belonging to the state of Antigua & Barbuda that lie on the Barbuda Bank, which is near the northern end of the Lesser Antilles chain. Like other islands in the Limestone Caribbees, it consists partly of Early Tertiary limestone laid on a foundation of volcanics of similar age. Antigua is favored by large areas of fringing, bank-barrier and patch reefs, and fine beaches, all important features for the tourist industry, which is perhaps the most important part of the Antiguan economy. The condition of these marine features should be of utmost concern to the government and commercial interests there.

A submarine geological map of the reefs and modern sediments of Antigua (Weiss and Multer, 1988) shows the areas and classifications of reefs and various types of sediments as of 1981, the latest date for which aerial photographs of the whole island were available. The planimetry of areas mapped was controlled on a stereoplotter with aerial photographs made in 1954 and 1958; changes between then (1954/58) and 1981 were fitted to the plotted sheet by direct comparison of the younger and older photographs. An abstract describing the map appears elsewhere in this volume (Weiss & Multer, 1990), and a summary of the changes in bottom conditions 1954/58 to 1981 is included in this report.

During the years of field checking and cartographic preparation of the reefs map it was learned that aerial photographs of Antigua had been taken much earlier than 1954--in 1941, in fact. They were taken by the US Army Air Force in August of 1941 (British Ordnance Survey files say March 8th, but the photographs all read Aug., 1941), in preparation for the establishment of a US Army air base on Antigua, as part of the "destroyers-for-bases" deal worked out by President Roosevelt and Prime Minister Churchill in September of 1941. The 1941 photographs were given to the Ordnance Survey of Great Britain by the US Defense Department (probably in 1947, when the 1942 photos were transferred), and all record of their existence was deleted from files in Washington. As several newer series of photographs were made, by the United States in 1942, 1954 and 1958, by the British government in 1968 and by the Royal Air Force in 1975, the availability of the 1941 photos was obscured. Having learned about them during a visit to the Ordnance Survey in 1985, it took until 1989 to obtain copies, for the US-British agreement provided that US permission be required before the photographs could be copied--and, as Washington denied their existence, they would not give permission!

This paper undertakes to compare the status of reefs and other bottom deposits as they were in 1941 with those of 1954/58, though the 1958 photographs were the principal control for the published map (Weiss & Multer, 1988). The 1954 series (1:10,000) covered no more than 10 percent of the island of Antigua, and none of the sea to east and west, although it does display well the large bank-barrier reefs off the north coast. Differences between conditions of the late 1950's and 1981 are expressed on the map (Weiss & Multer, 1988), and summarized herein for continuity (Figs. 2-8 and Table 3). This report, then, reaches back in time to compare the nearly virgin marine environment of Antigua (1941) with its status in the late 1950's, a time when much of the postwar development that has beset this tropical paradise was already in place. With the map (Weiss & Multer, 1988) and this paper, it is possible to reconstruct the many changes--mostly results of development--that have occurred between the island's pristine state and its current state (little change in the type and magnitude of development or of population pressure has occurred on the island since 1981). Descriptions of the major reef types in their present state, and examples of the principal biota, are given in Multer et al. (1986).

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PURPOSE

This paper has the obvious and implicit purpose of extending the record of changes in the reefs and associated sediments over a period nearly twice as long as that expressed in the reefs map (Weiss & Multer, 1988). As a contribution to science, it is a small step in the accumulation of dynamic data, which should be taken account of by commerce and government while planning further changes to the natural state of Antigua's marginal marine environment. Van Duyl (1985) expresses these and other sound purposes for areal studies of reefs most effectively and gracefully: reefs are protective ramparts and sources of food, income from tourists, building materials, and reef biota and products for trade. She also points out that baseline data such as these are required if we ever are to learn the degree of coastal urbanization, development and exploitation that reefs and other communities can withstand.

This paper and the earlier map (Weiss & Multer, 1988) with which it draws comparisons treat the reefs at a scale 10 times smaller than that of Van Duyl's map (Van Duyl, 1985). Her work, furthermore, makes much finer distinctions of ecologic and morphologic types than was possible for this study.

METHOD

The qualities and properties of the 1941 photographs are important to their comparison with later, and in some ways technically better photographs. The 1941 prints are 7 x 9 inches, with the short dimension in the direction of the flight path; those used are matte prints. The scale is larger than most series flown in the years since: 1:10,000, with a high degree of consistency; a spot check shows variations of only 1 percent smaller to 3 percent larger scale. The condition of the sea was rather rough, with a conspicuous chop over the whole area (August, 1941; no day given). The area of the sea floor visible in these prints is much less than on younger photos, but this is due only partly to the rough sea. The film used was Eastman Regular Safety, and its ability to display the bottom is much less than that of more modern films: to only 3-4 meters of depth in these prints, compared to 20 meters depth in many of the more modern series. Clouds were scattered in August of 1941, but they obscure very little area because the plane flew so slowly that successive frames show the cloud moved off, in many cases!

Defects in the film are numerous, in marked contrast to later series. Most are operational: finger- and tape-marks made on the negatives, and numerous blobs and smudges that seem to result from careless handling in the darkroom. Even so, these do not much impair the prints for study.

The main problem for this study is the degree of coverage of the 1941 photographs. The flights were planned to assist the development of the military base, and the waters around Antigua were of no concern. Thus the photographs do not show much offshore, except in the northeastern quadrant where all of North Sound was covered in order to include the many islands there. The 1941 photographs cover only about 20 percent of the marine area mapped by Weiss & Multer (1988). Although the 20 percent includes all the bays around the island, the limited penetration of the film then used renders the deeper and grass-held (less reflective) parts of those bays invisible. The 1941 photographs do show the shallow bottoms close to the shore, however, and thus the fringing reefs. The bank barriers are also shallow enough to be interpreted readily, but only those on the east side are included in the flight paths. Patch reefs shallow enough to refract waves (less than 2 m) are clearly shown; some deeper ones lurk as dark hulks, particularly in the northeastern quadrant, and some are so deep as to be invisible on the 1941 photographs. In summary, perhaps half of the patch reefs in the bays on the northeast and east coasts can be studied from those photographs. Even so, such old photographs are the only pre-development record of conditions on and around Antigua that we have, and are thus an important part of the series of aerial investigations from which an assessment of the shallow marine realm can be discerned. A detailed investigation of any area should include study of the 1942 photographs as well.

USE OF THE FIGURES AND TABLES

A full-blown map of Antigua, with numerous geographic points identified, is beyond the scope of this volume. But the sketch maps herewith (Figs. 2-8) and the graphic data summarized in their captions express the differences between the reefs of 1941 in their natural state and those of 1954/58 (Weiss & Multer, 1988). The accompanying maps may be used simply as a record of the most important 17 years of change, or they may be studied in comparison with any of several maps of Antigua: the map of modern reefs and sediments (Weiss & Multer, 1988, 1:40,000), the standard topographic map of the island, which shows the location of most of the reefy masses by conventional symbols (Ordnance Survey of Great Britain, 1980, 1:50,000), or the US Defense Mapping Agency Hydrographic Office chart No. 25BHA25570 (1:50,000) of recent date.

Where figures overlap, the data concerning areas that have undergone change appear on the map figure of lower number, and are included with that figure caption.

TYPES OF BOTTOM CHANGES AND SYMBOLS

Coastline

The perimeters of the island of Antigua and its satellite islands, shown in Figures 2-8, are the water's edge; coastal mangrove swamps, mapped by Weiss & Multer (1988), are not shown here. The nature of the coast in Figures 2-8 is expressed by different kinds of line: solid line = rocky or earthen coast, dashed line = mangrove fringe or edge of mangrove swamp, and dotted line = sand beach.

Water Clarity

Comparison of the photographs of the principal harbors, as shown in both the 1941 and younger photographs, shows that the water in them was much clearer in 1941 than it is now, after much development. These are St. Johns Harbour, on the northwest coast (Fig. 8), and Falmouth Bay and English Harbour on the south coast (Fig. 5). St. Johns is the capital city and is surrounded by the heaviest population concentration. It was the first harbor to be improved and deepened for large sea-going vessels, and still the only one into which large cruise ships can enter. Falmouth Bay and English Harbour are among the most important recreational sailing ports in the Caribbean, and are heavily used year-round. Given the serpentine shape and narrow entrance of English Harbour (Fig. 5)

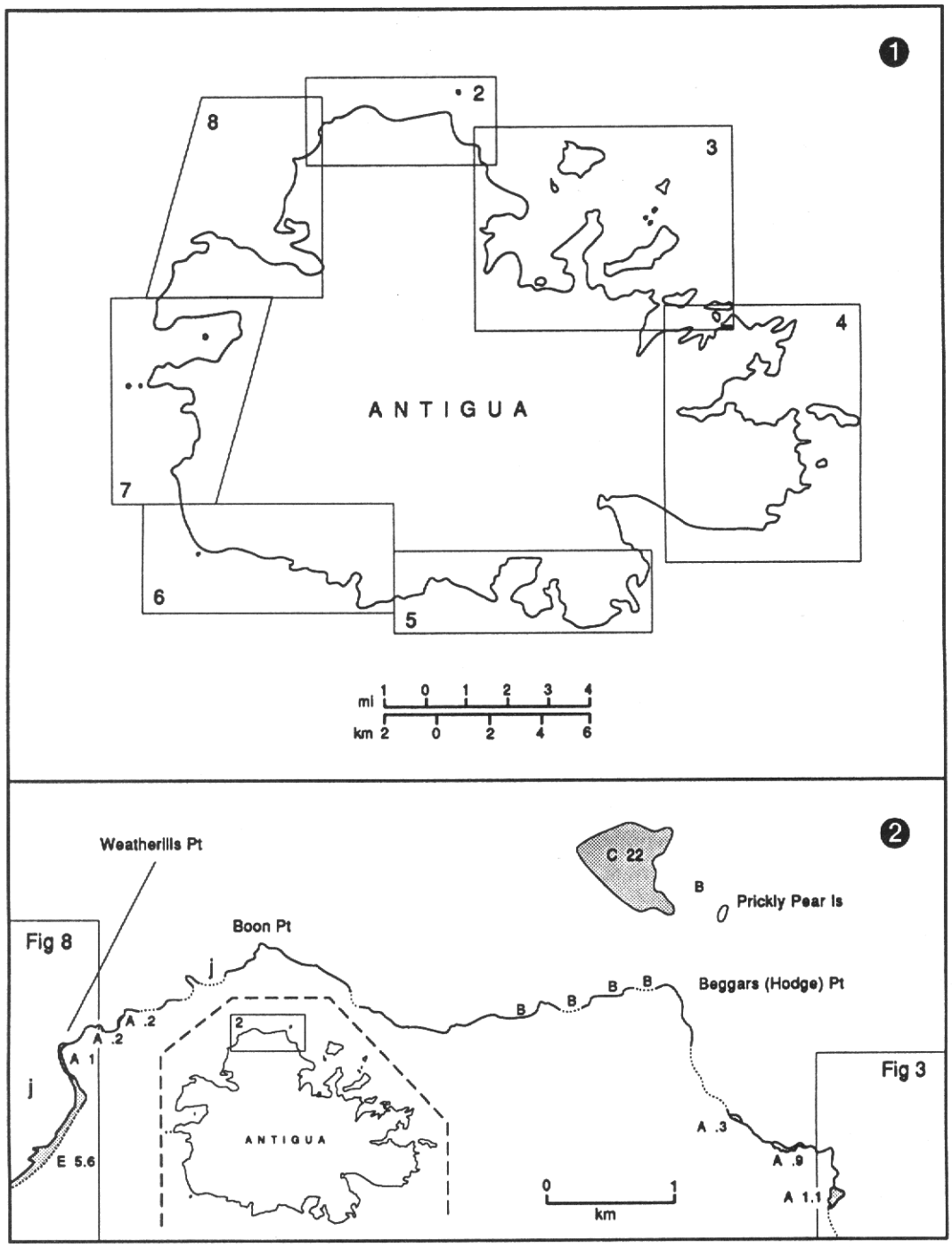

Figure 1 - Outline map of Antigua, showing outlines of areas covered by Figures 2-8, in each of which changes of bottom material are keyed to Tables 1, 2 and 3 by letters and symbols.

Figure 2 - The north coast of Antigua, with inset of the whole island. Rocky coast is shown by a solid line, mangrove fringe by dashed line and sand beach by dotted line. Here and on following figures changes from 1941 to 1954/58 are represented by capital letters and Roman numerals; the areas affected, in hectares, are given by the Arabic numbers. The lower-case letters and (+) symbols locate changes between 1954/58 and 1981, although no areas are cited.

Affected areas in hectares (numbers) sum to: (A) 3.7, (C) 22, (E) 5.6; several unmeasured (B) areas also occur.

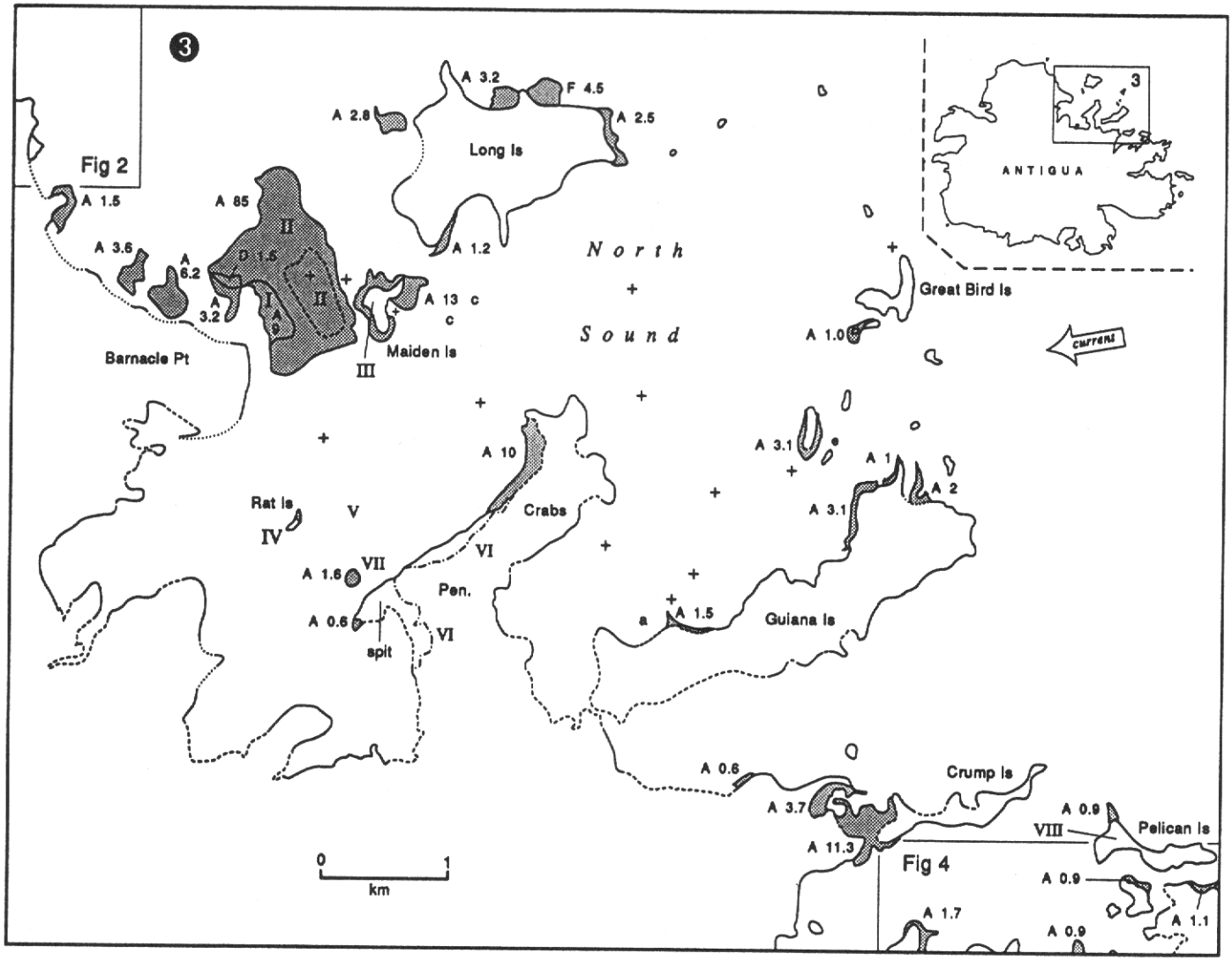

Figure 3 - The northeastern quadrant of Antigua, including all of North Sound.

I - This area was a "deeper reef" in the usage of Weiss & Multer (1988), a terrace below the fringing reef.

II - This large area was sand mottled with numerous coral clusters (5c of Weiss & Multer, 1988) in 1941.

The part enclosed within dashed line was a coral-dotted bank with deeper channels to east and west of it. Seawater piled into North Sound from the east by NE Tradewinds and the North Equatorial Current escaped to the northwest through these channels and the one between Maiden and Long Islands.

The area has since deteriorated to muddy sand by the dredging of ship channels close to Maiden Island and farther south in North Sound.

III- For the record, Maiden Island is shown in its original shape, before being altered by heaps of dredge spoil. Further, the former fringing reef there is not so much deteriorated as it is buried by dredge spoil (see Weiss and Multer (1988)).

IV - Rat Island has been enlarged by 150 percent since 1941. The older, bedrock part is the small, northern oval; a large heap of skeletal sand and gravel has been built southwestward from the bedrock nucleus.

V - The former Mouse Island was barely awash in 1941, but now wholly submerged. It may have been a sand bank, as suggested by Weiss & Multer (1988), but its progressive diminution makes it more likely that it was originally a low-lying mass of weak Antigua Limestone.

VI - The dot-dash line shows the original bedrock margin of Crabs Peninsula. It has been straightened by development--both fill and dredging--on the northwest coast. A narrow sand spit at the southwest corner has not changed much in length since 1941, when it had a mangrove swamp behind it. But now the spit is 2-3 times wider and the swamp behind it has been loaded with sand to the degree that the mangroves have given way to terrestrial scrub vegetation, and the shore behind the spit has the modern configuration shown on maps (cf note VII).

VII- This was a coral-covered patch reef in 1941. The eminence on the sea floor shows in later photographs, but is indistinguishable from neighboring grass-held sand bottom. The coral community has been mantled by debris from the development of the northwest shore of Crabs Peninsula (cf note VI).

VIII-In 1941 Pelican Island had a narrow rim of coral fringing the west and south shores. By 1958 it had been mantled by skeletal sand, as it remains today.

Affected areas in hectares sum to: (A) 176.2, (D) 1.5, and (F) 4.5.

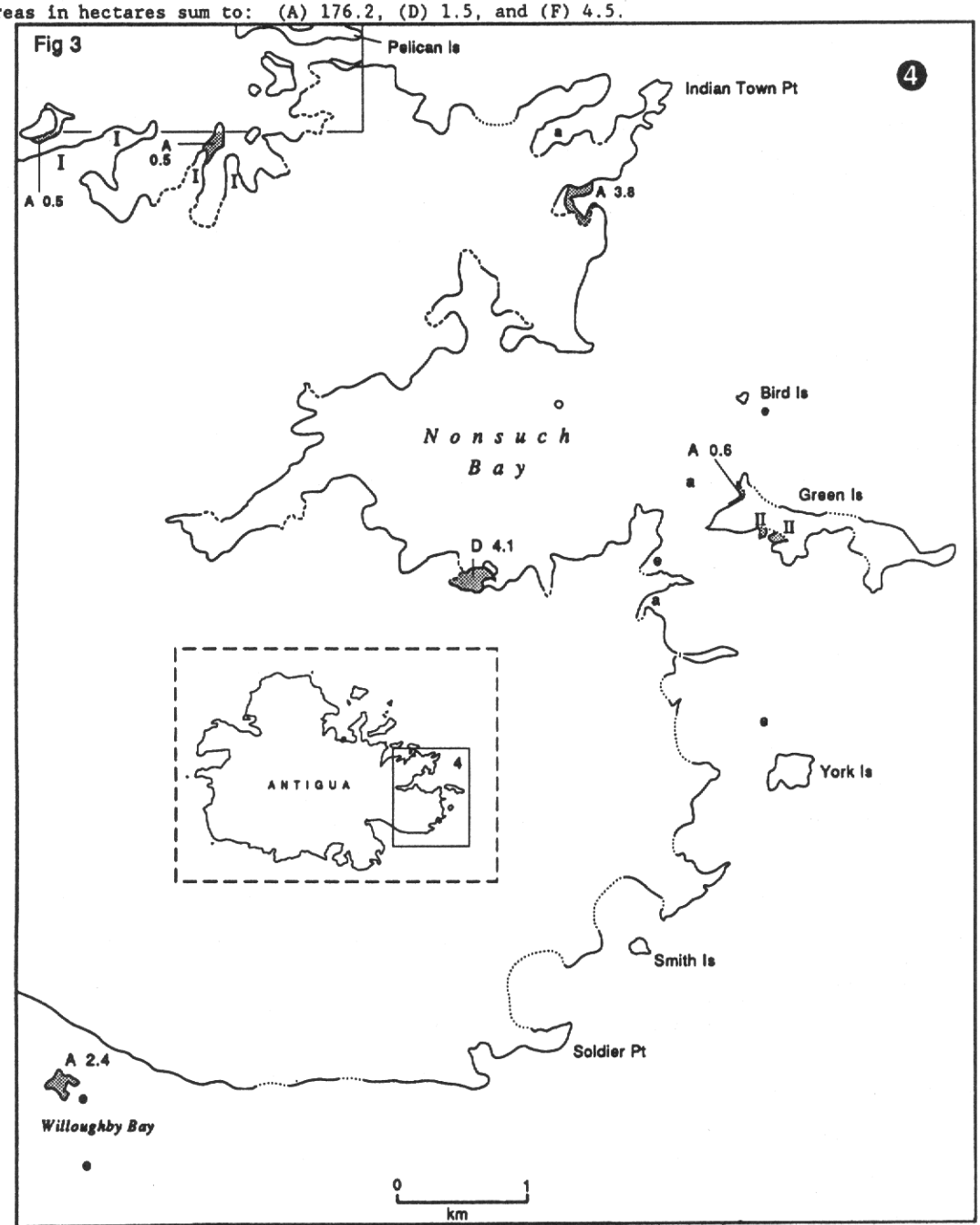

Figure 4 - the eastern sector of Antigua, from Pelican Island at the north to Willoughby Bay on the south. The largest bank barrier of the windward coast lies off Nonsuch Bay, between Green Island and Indian Town Point.

I - A very narrow mangrove rim occurred in 1941 at the toe of the steep rocky banks in this area, but was gone by the late 50's. Development has not occurred here: can a slight sea-level rise have destroyed the narrow, linear ecologic niche on these steep slopes?

II - Two small patches were grass-held sand in 1941 and are mapped, in error, as fringing reef by Weiss & Multer (1988). Grass-held sand remains on these two places, which were not affected by the post-1958 damage, mapped by Weiss & Multer (1988).

Affected areas in hectares sum to: (A) 9.2 and (D) 4.1.

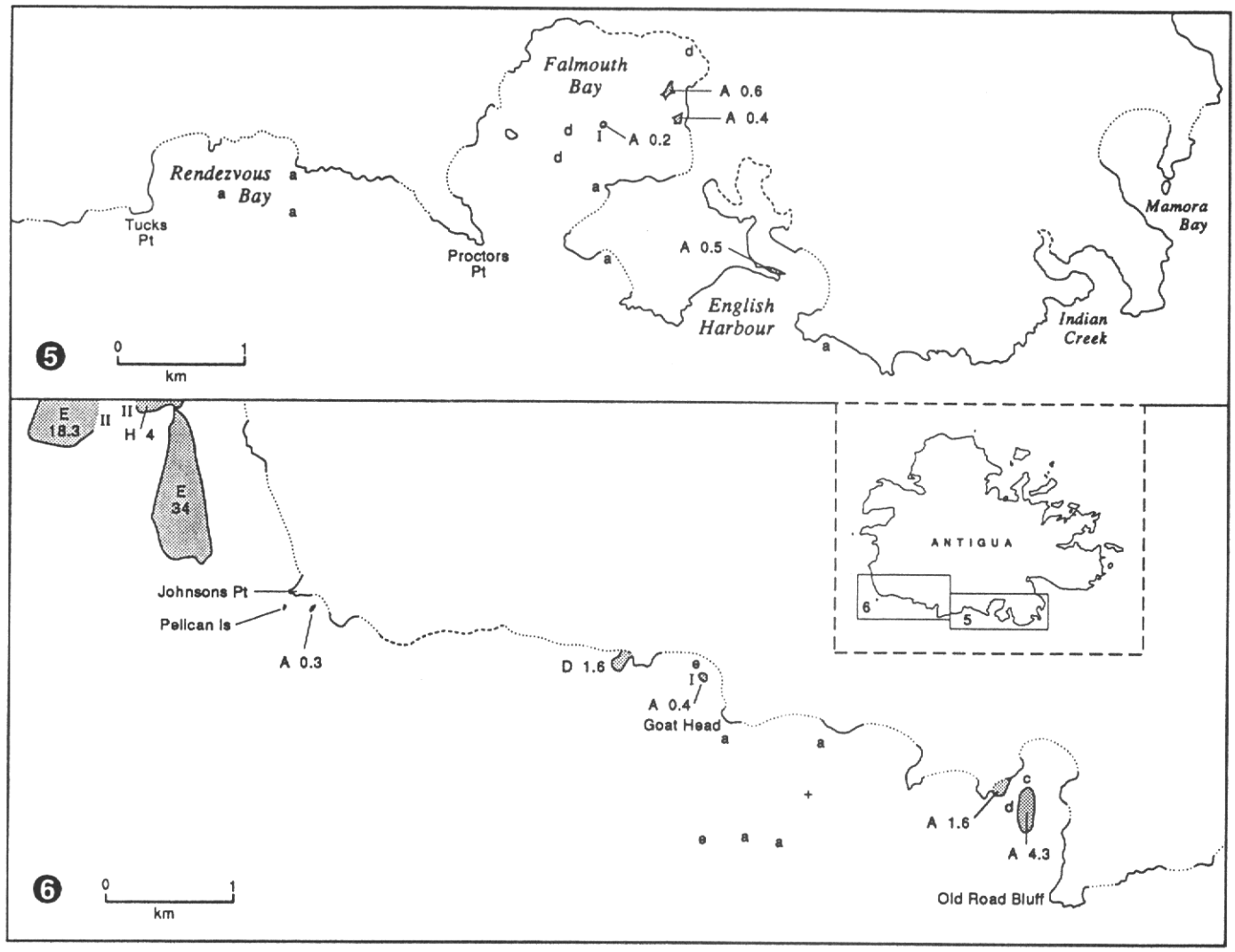

Figure 5 - The south-central coast of Antigua includes the two busiest sites of yachting activities: Falmouth Bay and English Harbour.

I - This small area was a pinnacle or patch reef, rising from the Millepora-Porites bank, now degraded to a bump of the latter community.

Affected areas in hectares sum to: (A) 1.7.

Figure 6 - The southwestern quadrant of Antigua. The very large bank-barrier reefs that lie west of Old Road Bluff and extend beyond Johnsons Point are not included in the 1941 photographs. Fringing reefs are narrow along the south coast. The largely sand-covered shelf on the west side of the island begins in the current shadow of Antigua, northwest of Johnsons Point.

I - A small patch reef has been covered by sediment.

II - Cloud cover obscures the sea floor. Values of areas in hectares apply only to those visible.

Affected areas in hectares sum to: (A) 6.6, (D) 1.6, (E) 52.3), and (H) 3.95.

it does not flush as readily with tidal change as either of the other two. Now these waters, particularly St. Johns and English Harbours, are heavily loaded with suspended sediment, both mineral and organic particles. The bottom muds are foul, sulfurous and black (Kamm, 1981). The 1941 photographs show about 2 m of clear water over nearshore shallows in English Harbour and the outer half of St. Johns Harbour; little can be seen there now, for transparency is a fraction of a meter.

A general decrease of clarity of water and increase of suspended sediment in the shallow waters of Antigua may be indicated by the large plumes of suspended sediment seen in the more recent aerial photographs in the lee of the headlands and of the whole island. Even though the conditions of the sea were rougher during the 1941 photography than during 1954, 1958, or 1981, few such plumes are to be seen in the older photographs, and they are small and closely related spatially to beaches on the west coast. Such plumes and sheets of turbid water now sometimes cover

many square kilometers in the northwest and southwest quadrants of the island, and over wide areas off the west coast, all in the lee of the North Equatorial Current that bathes the Lesser Antilles. Of course it is possible that such large plumes are episodic and storm-generated, and that only certain ones are caught by the camera.

It is certain that the development of Antigua's bays and shores has contributed to the fouling of some of the former and the loss of sediment to the narrow shelf and open sea to the west of the island. Some of the disturbance and loss of sediment may of course be due to sea-level rise, but I believe that dredging of ship channels (e.g., Fig. 3, II) and local alterations of the beaches have played an important part. Regrettably, no way presents itself to quantify the changes. Kamm's study (1981) will, however, serve as a benchmark for future studies of the shallow marine and coastal sediments.

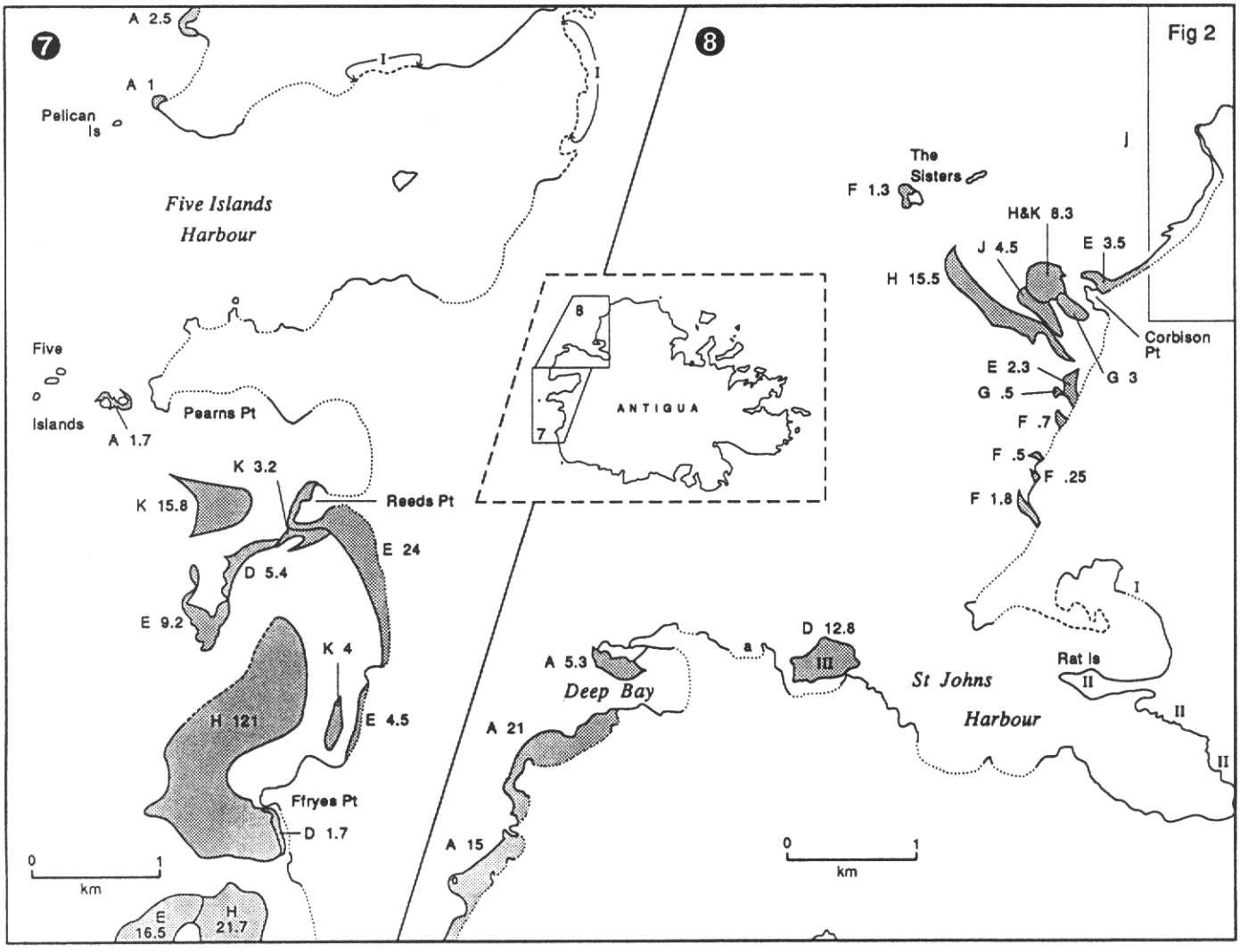

Figure 7 - The west-central coast of Antigua includes the large Five Islands Harbour with a shallow bottom mostly of mud. The bottom on the shallow shelf off the west side of Antigua has little coral and large areas of sand and grass-held sand.

I - Mangrove fringe has taken over sand beach in the two zones, totalling 1700 meters.

Affected areas in hectares sum to: (A) 5.2, (D) 7.1, (E) 54.2, (H) 142.7, and (K) 23.

Figure 8 - The northwestern quadrant of the island of Antigua, centered on St. Johns Harbour. The city of St. Johns, the capital and largest population center, surrounds the southeast end of the harbor.

I - A sandy beach has developed since 1941, perhaps by sea-level rise, or accumulation of dredge spoil?

II - Changes of the shore and commercial structures along the rim of St. Johns Harbour are not tallied, although the causeway to and docks on Rat Island are much wider now than before development set in.

The shallow waters at the margin of the outer harbor were clear in 1941; by 1958 the harbor bottom was everywhere obscured by suspended sediment, even in the shallowest parts.

III- A large area of sand with little vegetation was probably formed by dumping of dredge spoil there from the ship channel.

Affected areas in hectares sum to: (A) 41.3, (D) 12.8, (E) 5.8, (F) 4.55, (G) 3.5, (H) 15.5, (J) 4.5 and (H & K) 8.3.

Changes to Reefs and Bottom Sediments

1941 to 1954/58

The changes are described in terms expressing the difference from 1941 conditions to those of 1954/58. It is important to remember that much of the non-reef bottom, all of the deeper reefs (Weiss and Multer, 1988), perhaps half of the patch reefs, and the bank barriers off the north and south coasts are invisible, or not covered, by the 1941 photographs. The sorts of changes described in Table 1, and recorded in Figures 2-8 are minima of what may actually have occurred as Antigua was transformed from an agricultural, undeveloped island to a busy, modern, tourist mecca with large populations of visitors, ships and yachts, plus all the modern infrastructure and transport necessary to the new economy and way of life. The several types of changes (Table 1) are identified by letters, which appear on the maps and in their captions. The numbers associated with the letters (except B), on the maps (Figs. 2-8) and in Table 2 refer to the area(s) affected in hectares (1 ha = 10,000 m^2, 2.47 acre, or 107,099 ft^2.)

Table 1 - TYPES OF CHANGES OF BOTTOM SEDIMENT

Changes 1941 to 1954/58 are marked with capital letters in the table and on Figures 2-8.

A/a - Deterioration of vigorous coralgal community by loss of coral and increase of or burial by bare skeletal sand or grass-held sand

B - Seagrass flats on tops of reefs, behind the reef front, are less heavily vegetated

C/c - Mixed coral and sand, or sand mottled with small clumps and boilers, has lost much of the stabilizing vegetation and the boilers are reduced in size; also includes some burial by sand

D/d - Grass-held sand meadows have been buried by bare sand

E/e - Bare sand has grassed over; or the density of the grass has increased conspicuously

F - Former submarine outcrop now sand covered

G - Submarine outcrop now exposed by removal of former sand cover

H - Grass-held sand has become "scrolled" (see subsequent discussion)

J/j - "Scrolled-sand" bank overspread by bare sand

K - "Scrolled-sand" bank smoothed or buried and covered by sea grasses

Changes 1954/58 to 1981 (described by Weiss and Multer, 1988) are located on Figures 2-8 by lower-case letters corresponding to certain of the capitals above: a, c, d, e, j. Sites of increase of coral and grass from 1954/58 to 1981 are marked on Figures 2-8 by (+).

Table 2 - SUMMARY OF CHANGES, 1941-1954/58, IN HECTARES

CHANGES SYMBOL \ FIG.	2	3	4	5	6	7	8	SUM
A	3.7	176.2	9.2	1.7	6.6	5.2	41.3	244
B	(not measured)							
C	22							22
D		1.5	4.1		1.6	7.1	12.8	27.1
E	5.6				52.3	54.2	5.8	118
F		4.5					4.6	9.1
G							3.5	3.5
H					4	142.7	19.6	166.3
J							4.5	4.5
K						23	4.2	27.2

1954/58 to 1981

The map prepared by Weiss and Multer (1988), described elsewhere in this volume, covers an area much larger than the scope of the 1941 aerial photographs. Thus some of the changes of bottom sediments occurring from 1954/58 to 1981 cannot be represented on the figures accompanying this report.

Even so, in order to give a 40-year view of sedimentary environment dynamics, the locations of most of the 1954/58-1981 changes, as well as their natures, are illustrated in Figures 2-8 of this paper; they are symbolized together with the older changes already described by using lower-case letters corresponding to the capital letters in Table 1. Some changes seen in the later period are not recognized from the earlier, particularly the increase of coral on some windward patch reefs and the colonization of old dredge spoil by small coral clumps. These are represented by (+) symbols on the maps, especially in North Sound (Fig. 3).

Repetition here of the areas affected during the 1954/58-1981 interval from the published map (Weiss and Multer, 1988) would clutter Figures 2-8 and make them ineffective. However, the sites of those changes and their natures are indicated in the figures, and a summary of their magnitudes is given in Table 3.

Table 3 - SUMMARY OF CHANGES, 1954/58 - 1981, IN HECTARES

a - Loss or depletion of coral and gain of sand	31
c - Mixed, patchy coral and grass-held sand has lost vegetation and coral	11.5
d - Grassy "meadows" buried by or gone to sand	7.8
e - Bare sand grassed over or grass density increased	60.9
j - "Scrolled" sand spread smooth or covered by sand	3.9
+ - Increased area of coral (17.9 ha) or increase of coral density (11.9 ha)	29.8

Of these, the first three may be regarded as destructive, erosive, etc.; the fourth and sixth may be considered healing or constructive. The changes summarized here are described fully by Weiss and Multer (1988), as well as a few other instances not illustrated in Figures 2-8.

SPECIAL FEATURES

Upon comparison of the areas of the marine bottom shown in both the 1941 and 1954 and 1958 photographs, two aspects were distinguished that cannot be presented effectively in the maps. They require discussion, partly because their causes and stages of development are unknown, and partly because the magnitudes of the areas affected are uncertain and therefore not measurable.

Sand on Patch Reefs

Several score of patch reefs occur around Antigua (Weiss and Multer, 1988), particularly in the areas shown in Figures 3 and 4. As was explained earlier, fewer than half of these show well on the 1941 photographs, partly because of the insensitivity of the film used to the dim light reflected from depths of more than about three meters and partly because the patch reefs had less sand cover then and were less reflective.

Those patch reefs clearly visible in the 1941 photographs, including many in North Sound (Fig. 3) and in the large bays south of it (Figs. 3, 4), all have dark upper surfaces. They appear to have a rough, furry texture that shows clearly that they were capped by dense, vigorous colonies of living coral. No brightly reflecting light spots suggest the presence of skeletal sand. The patch reefs having this dark appearance are those that cause refraction of the waves, and probably were then less than 2 meters below sea level.

These same patch reefs had conspicuous patches of sand on their tops by 1958, and these persist today. On the smaller patch reefs the sand occurs in small patches among the clumps and heads of living coral; on the larger ones the living coral tends to be concentrated around the margin of the patch reef and the top can be mostly sand--microatolls, in effect. Direct inspection of such microatolls does not give one the impression of deterioration; the coral is healthy, and patch reefs with sandy patches on top are in no way abnormal. But there was a significant change in the ratio of coral to sand on many patch reefs in the areas of Figures 3 and 4, and to a lesser extent elsewhere around Antigua, between 1941 and 1958.

It would be easy to speak of abuse or pollution, but difficult to prove. Further, these changes have occurred at sites which are washed by normal seawater, and are up-current from the sites of dredging and other major disturbances of the bottom that development has brought. Nearby sources of pollution are very scarce in the area affected: one hotel exists on Long Island (Fig. 3), but was not there in 1958 and, although the north shore of Crabs peninsula (Fig. 3) was altered before 1958, the industrial development, marina, and motel are all post-'58.

A more likely explanation for the decrease in the ratio of coral cover to skeletal sand on the tops of the patch reefs is some natural trend of coral depletion, of the sort that has now been observed on St. Croix, and elsewhere (Bythell et al., 1989; Hubbard, 1989). It is also possible that a hurricane tore up the patch reefs of the northeast quadrant of Antigua between 1941 and 1958, but the bank-barrier reefs off the east coast show no significant differences across the time period, and this explanation is not considered likely. Two "serious" hurricanes passed rapidly over Antigua in August of 1950 (D.V. Nicholson, personal communication, November, 1989).

"Scrolled sand"

Many areas of the sandy bottom in the lee of Antigua have a pattern and texture (Fig. 9) different from the bare sand and grass-held sand bottoms to the north, east and south of Antigua. The pattern is of wavy streaks of light-colored bottom (bare sand) that join and separate along their length, and crudely resemble festoons of drapery or bunting (Fig. 9). The light-colored streaks are conspicuous because the background is dark, grass-held sand. Small, linear patches of this "scrolled sand" occur close to shore at the northwest and southwest corners of the island, where the persistent currents refract onto the open shelf west of Antigua. Larger patches of the same sort of texture occur on the shelf, off the west coast, caused perhaps by the beat of refracted wave sets. Very small areas with similar patterns occur just within the openings of Falmouth and Mamora Bays (Fig. 5), where entering currents slow and drop sediment.

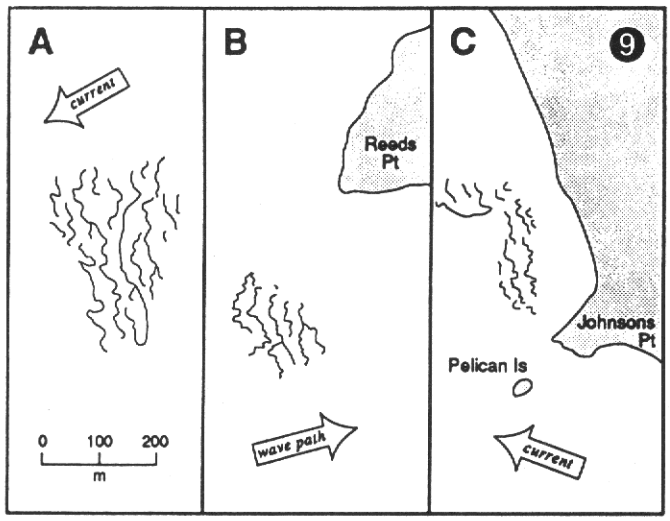

Figure 9 - "Scrolled sand" patterns. The lines show the bands of bare sand as they appear against the background of grass-held sand. Sketches are oriented with North at the top and all have the same scale; the coastline shows in B and C.

A) Patch 0.8 km northwest of Corbison Point (see Fig. 8). The bare-sand festoons seem to have been elevated above the grass in 1941, but are known to have been blowouts in 1983.

B) Off Reeds Point (see Fig. 7). Wave refraction in lee of Antigua brings waves directly to shore. Relative elevation of the bare and grassed sand in 1941 cannot be determined definitely.

C) Off Johnsons Point (see Fig. 6). Here the festoons of bare sand definitely were elevated above the grassed sand in 1941, and also stepped downward away from the shore. Spread of current threads and wave refraction turn energy toward shore.

During aerial reconnaissance for the submarine geologic map (Weiss & Multer, 1988), these "scrolled sands" seemed to be areas in which abundant sand moving across the sea floor had piled up into irregular "windrows," rather like broad parabolic dunes. Diving on those off the northwest coast, in the early 1980's, showed that the sand streaks were not elevated above the grass-held parts of the sea floor, but were depressed. These were examples of the linear blowouts of sand and, presumably, grass that were first described by Wanless (1981). These areas were mapped by Weiss & Multer (1988) as "sandy mud and sand with parallel blowouts," having maximum "wavelengths" of 10 to 30 meters.

The 1941 photographs (scale 1:10,000) show that some of the "scrolled sand" bottoms have the light bands standing above the grass-held surfaces (Fig. 9). This is seen off Corbison Point (Fig. 9A) and near Johnsons Point (Fig. 9C). At other areas (Fig. 9B) the relative elevation of the bare sand cannot be demonstrated from the old photographs.

That the areas of the bottom having this "scrolled" texture change over time is demonstrated by the fact that instances of former sand elevation have since been observed to be sand blowouts, in the area of Figure 8. Thus the texture of the bottom is not constant, although the pattern on the bottom may be nearly so. Further, large areas off the west coast of Antigua have changed pattern as well, from "scrolled" to mottled (i.e., grass in patches, rather than streaks) or from mottled to "scrolled." The changes, insofar as they can be observed, are expressed by the symbols H, J, and K in Table 1 and Figures 6, 7 and 8.

Although these sand banks are dynamic, the areas affected remain about the same; the smaller patches near the northwest and southwest corners of Antigua, and in the mouths of Falmouth and Mamora Bays, have not changed their size or shape from 1941 to 1981, the date of our last photographs. The distribution of grass on the sandy bottom can change, and the bare sand may stand now above or now below the grass-held sand surface. Each of these sites is in a current shadow--some broad, some narrow--where suspended sediment is dropped from the rapid currents streaming by the north and south coasts of Antigua (e.g., Figs. 9A, C). Others seem to be controlled by wave paths (Fig. 9B). Some sand is spread in sheets that become vegetated randomly (mottled), and some is dropped so abundantly that the mass accumulates as low dunes over a grass-held surface.

Changes from such dunelets to blowouts result from episodic storms or storm surges, which entrain the bare sand, held only by mucilaginous algal mat, and leave the grass-held sand relatively undisturbed. Changes from "scrolled" sand bottom (J or K of Fig. 7 or 8) must result from major changes in the amount of sand swept into the shelf west of Antigua; such might be episodic and natural or the result of changes of the nearshore environments under development. As such development has affected the north shore much more than the south, and there is no corresponding skewness of the sediment changes, the cause is probably natural. If the process is natural, it is easier to explain the changes of bottom texture and pattern occurring within the same perimeters over 40 years. Probably the work is done by major storms or swells, and not just the routine currents and refracted waves.

Although no attempts have been made to study the sedimentary structures within any of these sandy bottoms, one wonders what they might be.

CONCLUSIONS

The map of reefs and modern sediments prepared by Weiss & Multer (1988) provides a benchmark of bottom materials around Antigua in 1981, one which can be useful in planning for further development and utilization of its marine resources. It also records changes of small areas over time (1954/58 to 1981). This paper extends the series of changes of bottom materials, and the areas affected, from 1954/58 back

to 1941, the date of the earliest aerial photographs taken of Antigua and its marginal shallows, and a time, also, when those shallows were virtually in their native state. Colonialism had changed the island significantly, but without affecting the sea, beyond the fouling of St. Johns and English Harbours. This paper, together with the map of Weiss & Multer (1988) records the changes of shallow marine materials from pre-development times to the current condition, a state of development that has reached very nearly its peak. The specific conclusions listed below refer only to changes from 1941 to 1954/58.

1. Fringing reefs, particularly on the north and northeast coasts, have been diminished in numbers, area, and the abundance of coral (particularly on the reef flats behind the crest). The geographical skewness points to marine and coastal development: dredging, construction of shore facilities--ramps and docks, pollution from sewage released directly into the sea, and minor filling on the shore associated with residential and commercial construction on the beaches and sea cliffs.

2. Associated with the loss of coral on some fringing reefs is a loss of sea grasses on the reef flats, particularly along the north coast (Fig. 2, B), which is rimmed with private homes and hotels.

3. The two bank-barrier reefs photographed in 1941, that passing southeast through Great Bird Island along the whole east side of Figure 3 and that extending from Indian Town Point to Green Island (Fig. 4), show no appreciable change over the interval.

4. The patch reefs recorded in 1941, perhaps half of the more than 100 extant (mostly in the area of Figures 3 and 4), show a marked loss of coral from the tops of the patches, without apparently, any loss of vigor of the marginal coral community, and certainly no loss of area or height. It is suggested that this is a consequence of the natural cycle of reef communities wherein the ratio of living to dead coral changes.

5. Large areas of bare skeletal sand have been grassed over, or the grass has become more dense. This is regarded as a progressive, stabilizing trend, but occurred almost entirely on the shelf west of Antigua.

6. Some areas in current shadows appear to accumulate large amounts of loose sand, which is heaped, or scoured, or grassed over, repeatedly, within about the same areas of the sea floor. These areas are most important on the shelf west of Antigua, and are thought to change in response to storm attack or storm surge, from time to time.

7. The persistence of shape and scope of mangrove fringes and swamps over time is remarkable, although not mapped on the figures. The narrow fringes persist, except where destroyed by man, apparently because their narrow niche is controlled by steep coasts. Within the broader swamps that fill lowlands at the heads of some bays the shapes and widths of the sinuous inlets in the dense mangrove also have not changed.

8. That the loose sediment on the shallow sea floor is unstable we certainly would expect. Convincing evidence is given by those few areas in which submarine outcrops of bedrock have either been covered or uncovered over time.

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