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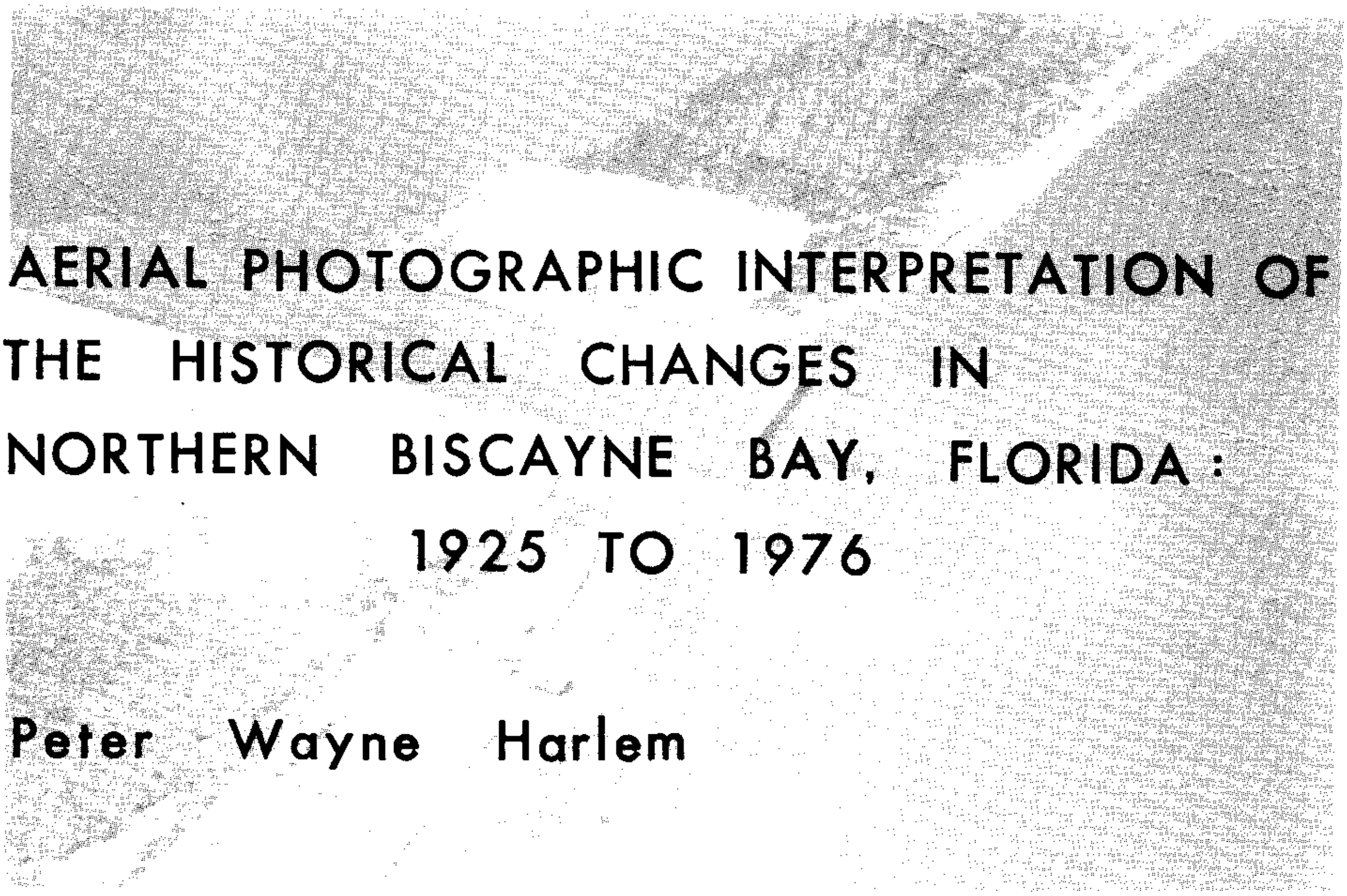

AERIAL PHOTOGRAPHIC INTERPRETATION OF THE HISTORICAL CHANGES IN NORTHERN BISCAYNE BAY, FLORIDA: 1925 TO 1976

Peter Wayne Harlem

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ABSTRACT

AERIAL PHOTOGRAPHIC INTERPRETATION OF THE HISTORICAL CHANGES IN NORTHERN BISCAYNE BAY, FLORIDA: 1925-1976

This study documents the recent environmental history of northern Biscayne Bay using vertical aerial photographs combined with field studies and supplimented with data on the preurban setting and the timing of urban developments and natural stresses. Aerial photographic surveys from 1925 and 1976 provided the basis for mapping important changes in terrestrial and submerged bay bottom environments. Where major changes were identified, aerial photography from numerous intermediate dates yielded additional information on the timing and specific character of change.

The maps delineate overall long-term increases in developed land and disturbed bottom areas (dredged and spoil bottoms), decreases in mangrove land and benthic vegetation areas, and changes in mangrove, bulkheaded, and sloping shorelines in the Bay. Man induced changes were found to be pervasive on land and along shorelines. Dredging and island construction within the Bay has disturbed 19 percent of the existing bay bottom. The major changes in the character of the Bay's terrestrial margins were caused by filling of swamps, expansion of original land areas, and the creation on new islands. Changes in the benthic environments result from: 1) circulation changes related to inlet and causeway construction, 2) direct dredging operations, and 3) increasing turbidity levels. Benthic vegetation has decreased over most of the study area except in the northernmost areas where substantial increases occurred following the opening of Bakers Haulover Inlet.

Aerial photographs record the effects of the major hurricanes of the 1920's and 1930's. These storms destroyed large acreages of coastal mangroves and they produced localized erosion of benthic plant communities. The amount and location of change produced by each storm was highly variable and some small storms had significant effects.

Analysis of sediment cores taken in substrates distrubed at known times yielded long-term sedimentation rates of 2.9 to 3.4 mm per year for northern Biscayne Bay.

INTRODUCTION

Biscayne Bay is a shallow subtropical lagoon located on the southeast coast of Florida (Figure 1). This north-south trending bay is divisable into a southern two-thirds and a northern one-third, called northern Biscayne Bay. Northern Biscayne Bay, with its urbanized coastline and extensively dredged bottoms, is the subject of this study.

The rapid urban growth of Miami and adjacent communities along the shore of northern Biscayne Bay has taken a mere 85 years. The purpose of this paper is to document the major events of those years and to determine the historical changes in the Bay's associated environments occurring as the combined result of rapid urban development and natural processes.

The principle tool used in this study is the historical aerial photograph. Excellent aerial photographs of the northern Biscayne Bay region date back to 1925, allowing a thorough analysis of the changing environmental patterns of the last 54 years. By comparing succeedingly younger age photographs of the same areas it is possible to map the distribution of subenvironments for any photographed year, and the changes between years can be monitored and documented. Once the changes are known the rates of change can be determined, long term trends recognized, and the cause of each change studied.

Much of the data offered as evidence for ideas expressed in this paper is presented in the form of vertical aerial photographs. Therefore, I have included a brief discussion in the Methods chapter on how to best utilize this data for readers unfamiliar with aerial photographs. Successful interpretation of historical aerial photographs requires knowledge of the present setting, the pre-development setting, and the important historical

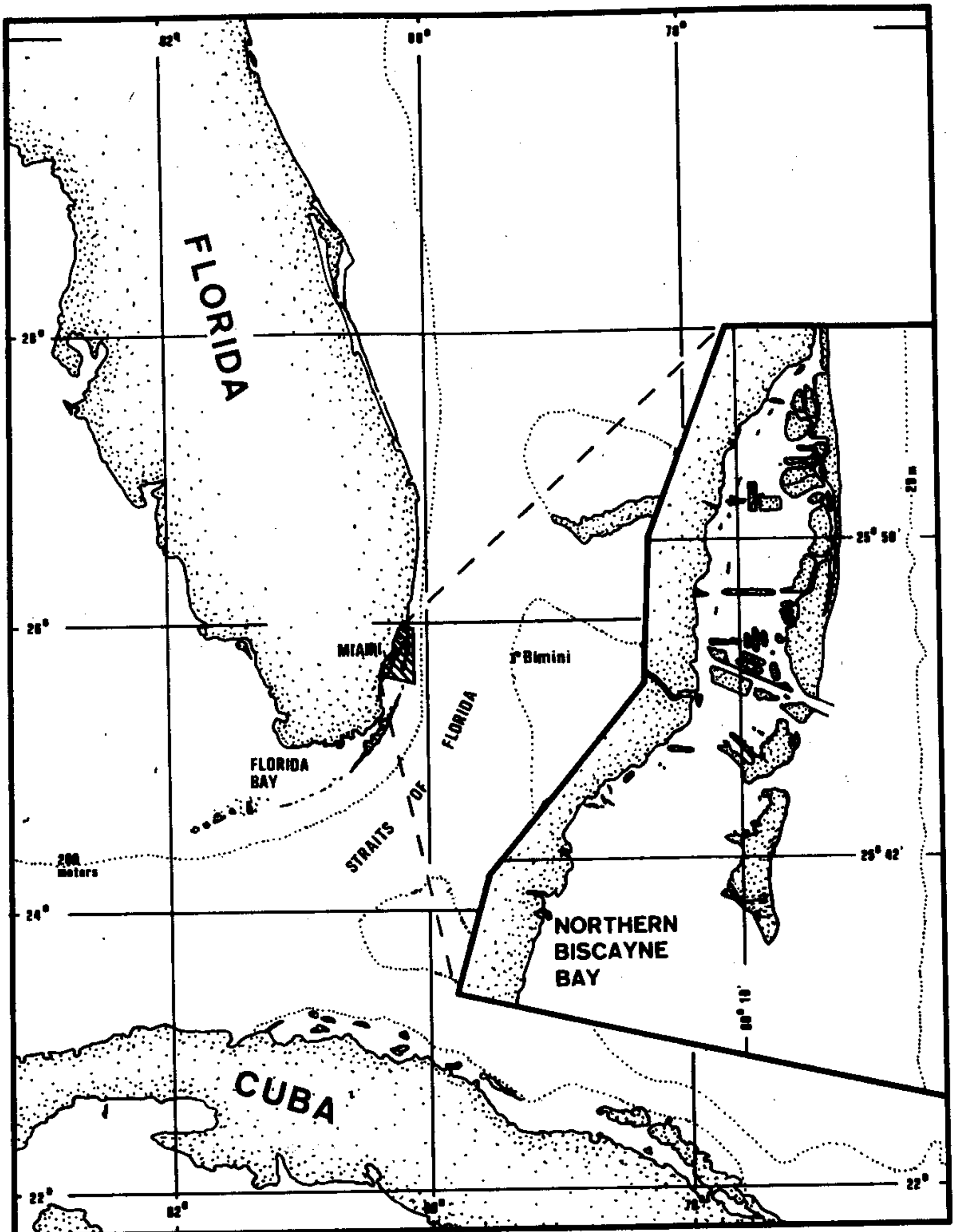


FIGURE 1. LOCATION OF STUDY AREA

events occurring since then.

The major environmental changes seen between the oldest (1925) and the most recent (1976) aerial photographs are presented in map form. The aerial changes in terrestrial, shoreline and submerged Bay environments are calculated from the maps and presented in tables and graphs. Aerial photographs are further used to examine in more detail the changes in these environments and to determine the role of various processes.

This paper has two appendices: the first contains descriptions of the sediment cores taken as an adjunct to the aerial photography; the second reviews other studies of the role of boats and ships in shallow bays.

This paper, then, should provide the reader with an adequate historical perspective of the present environmental problems of northern Biscayne Bay. The success of future environmental decisions and restoration projects will depend on a working knowledge of the environmental history discussed herein.

METHODS

Historical black and white vertical aerial photographs of northern Biscayne Bay, the primary tool of this study, date back to 1925. A modest field program that included skin-diving and sediment coring was used to check maps made from the aerial photographs.

Aerial Photography

Aerial photographic interpretation began during the First World War, when airplane developments allowed the mobility necessary to make useful photographic images (Mitchell, 1921; Talley, 1938). Besides military applications, early aerial photographs were used for a variety of mapping projects ranging from maps of coastal areas and coastlines for maritime purposes to regional real estate and geologic surveys. The application of aerial photography to coastal or nearshore scientific problems, particularly environmental impact problems, has increased significantly in the last decade.

Chapter 20 in Volume 1 of the Manual of Remote Sensing (1975) deals exclusively with the marine environment. However, this manual discusses aerial photographs less than the newer, more sophisticated, multi-spectral and microwave imaging systems. Verstappen (1977) summarizes both aerial photographic interpretation and remote sensing with a few examples of shore zone applications.

Shepard and Wanless (1971) attempt to identify coastal sedimentary environments and the changes recorded by sequential aerial photography, and include a brief discussion of some of the present study area. They decided that aerial "photographs show more detail than can be found on any map or chart and are thus excellent guides to changes that have taken place between dates of photography" (p. 3). Conrad et al. (1968) attempted to determine the suitability of satellite images of the Bahamas for marine ecological surveys. They recognized that visible submerged objects are usually biological in origin and that this benthic biota could be used to detect submerged geological features. They noted that imaged objects were either floating on the surface, in the water column (i.e. suspended sediments), or attached or resting on the bottom. They stated, "In contrast to floating, suspended, or dissolved materials, the bottom biota are relatively intransient. For this reason they are good indicators of long-term environmental conditions" (Conrad et al., 1968, p. 3). Kelley (1969) used satellite photography to study a portion of southern Bicayne Bay but noted that, although very useful, remote photography of marine environments must not be considered a complete substitute for a thorough field program. Purdy (1964) used aerial photography of the Joulters Cay area in the Bahamas to interpret sedimentary environments. His interpretive map (Figure 13, page 32-B) apparently proved to be significantly deficient (see Harris, 1977) because of a lack of adequate field observations.

Other recent works that make use of aerial photographs include Zieman's (1972) look at circular grass beds, the United States Department of the Interior's (1973) analysis of the Bay's resources using color infra-red imagery, Hoffmeister's analysis of the Miami Oolite in Land from the Sea (1974) and Hoffmeister et al. (1967). Teas (1974) and Teas et al. (1976) looked at longer term changes in shoreline mangroves, and Marszalek et al. (1977) used water penetration film to study Florida reefs. Some limited use of aerial photographs can be found in Moore et al. (1968), Jones (1968), O'Gower and Wacasy (1967), Reark (1974) and D'Amato's (1973) look at pollution from an ocean outfall. Readers interested in other, non-photographic remote sensing studies from the Biscayne Bay region are referred to Kolipinski and Higer (1970) and Rona (1977).

The two types of aerial photograph used in this study are oblique and vertical. The earliest oblique aerial photographs of the Miami area date from the 1910's; some are included here.

The majority of the photographs used in this study are vertical aerial photographs from the following years: 1925, 1928, 1932, 1940, 1973 and 1976. Photographs from years between these dates were used when available. The 1940 photographs are the oldest set of photographs that provide complete coverage of the study area.

The vertical aerial photographs used are available from the sources listed in Table 1. Old oblique aerial photographs can be found in the files of the Historical Association of South Florida and a few of these appear in Smiley's Yesterday's Miami (1973). For more information on the availability of other photographs, Barwis (1975) provides source and ordering information as well as selected photo I.D. numbers. A guide to selecting and ordering aerial photography can be found in Baker (1976).

After securing the desired prints of the aerial photographs, maps were prepared with information interpreted from the photo images. Photo interpretation is simple, in theory. There are. however, many variables that must be understood that affect the photo image. A thorough discussion of these variables is beyond the scope of this paper, but this information can be found in most aerial photograph interpretation texts, such as Talley

Table 1. Aerial Photographic Survey Source Data

Survey	Accession No.	Scale	Source	Notes
1925	-	1:10,000	Main Library, Miami-Dade Public Library System, Miami, Fl.	May be seen by permission of the Director of the Florida Room
1928	697, 687	1:20,000	NOAA, National Ocean Survey Coastal Mapping Division, C3415 Rockville, Md. 20852	Trimetragon with 2 or 3 oblique panels
1932	808, 806	1:10,000	NOAA, National Ocean Survey Coastal Mapping Division, C3415 Rockville, Md. 20852	Trimetragon with 2 oblique panels
1940	CJF-10 CJF-14 CJF-15	1:40,000	National Cartographic Information Center USGS National Center Stop 507 Reston, Va. 22092	First full survey of Biscayne Bay
1976	PD 1638	1:24,000	Topographic Office Department of Transportation 605 Suwannee Street Tallahassee, Fl. 32304	Special water penetration film

(1938), War Department (1942), or Bowden and Pruitt (1975). To aid those unfamiliar with vertical aerial photographs, the following suggestions and general information are offered.

1) The scale of vertical aerial photographs in this report vary. A one-half kilometer scale bar is provided with each print or series of prints. The original survey scale is listed in Table 1 and the area covered by the original images can be seen in Figures 2 through 6. The majority of the figures in this report have been enlarged from the original photographs and each contains a small map showing the photo location in black.

2) Several types of film, cameras and filters are available to the aerial photographer. Each different type used will produce differences in the final image. As a result, many features will appear quite different in sequential photographs because of tonal variation. For example, the land portions photographed with special Kodak water penetration film appear much darker when compared with normal panchromatic film images (Figure 23). Unless the specific attributes of the film are known, shape, size and relative location or setting of any feature are the most important criterion used for identification.

3) The different sets of photographs were taken on days with different weather patterns, at different times of the day, at different stages of the tide, and occasionally in different seasons. Because of this, one should not expect all of the photographs to look identical because the camera's ability to photograph submerged bottom features is strongly controlled by these factors. Most of the vertical photographs used were taken during the winter or early spring when brief periods of cloudless

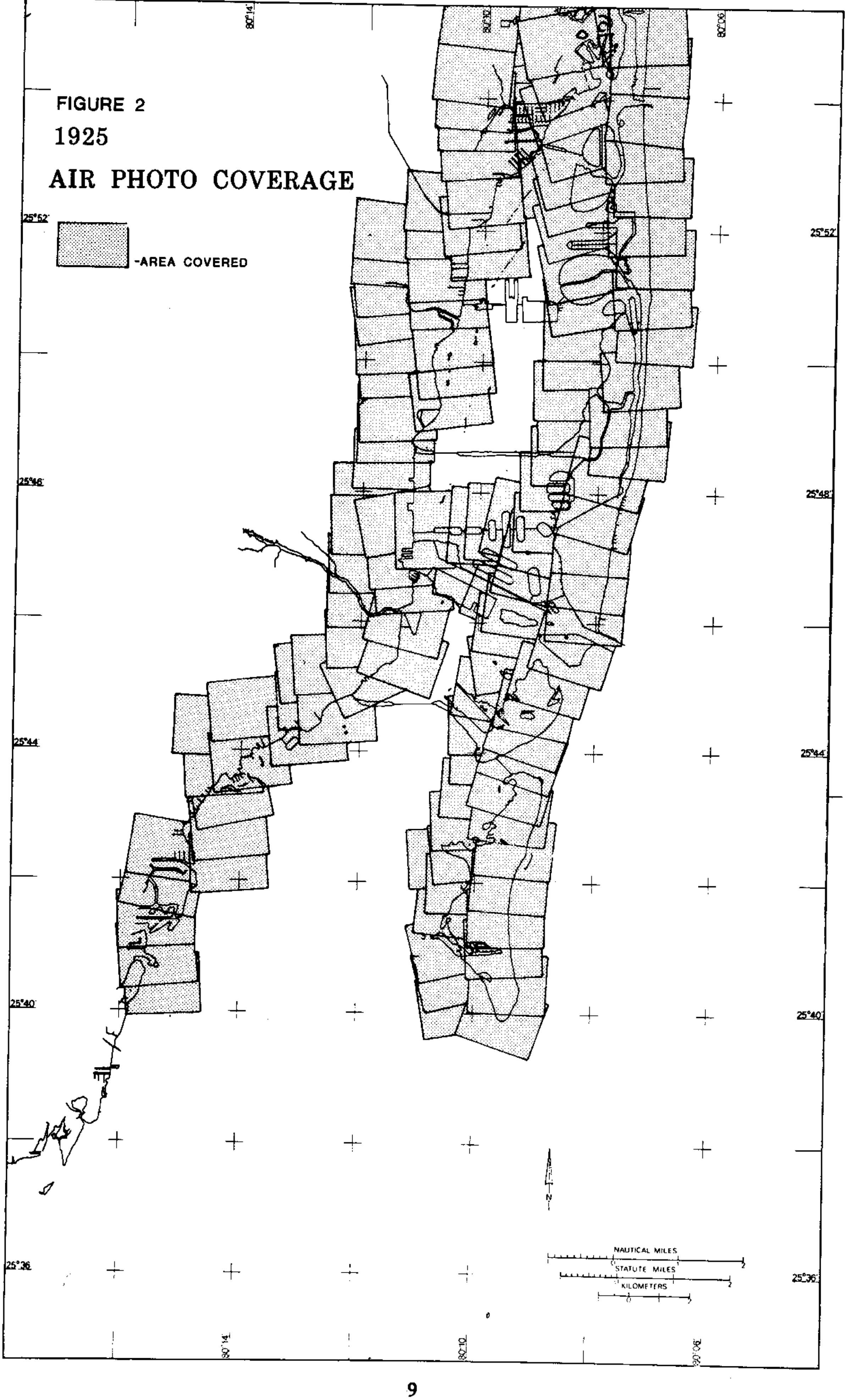


FIGURE 2
1925
AIR PHOTO COVERAGE
-AREA COVERED
25°52'
25°48'
25°44'
25°40'
25°36'
80°14'
80°10'
80°06'
N
NAUTICAL MILES
STATUTE MILES
KILOMETERS

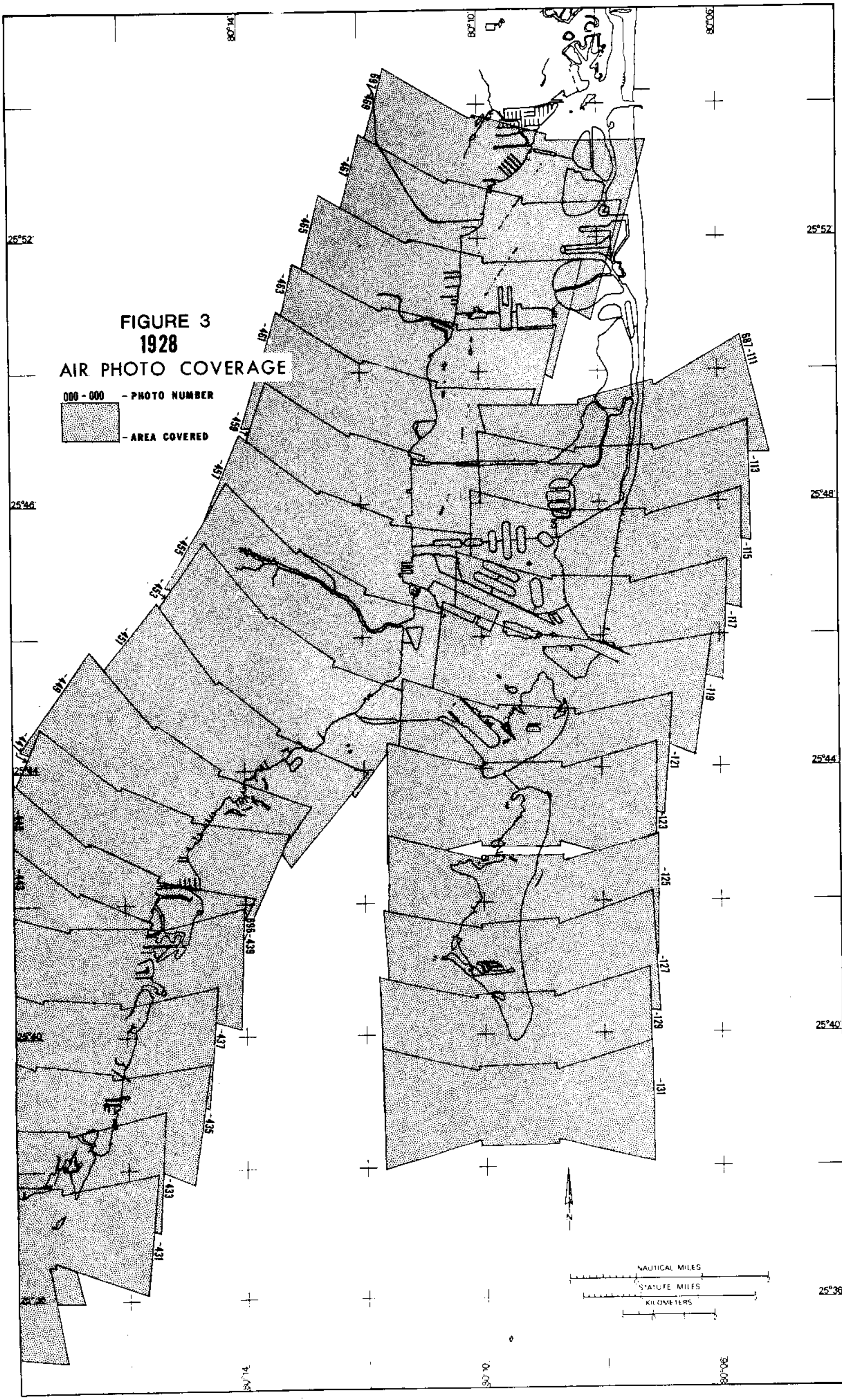


FIGURE 3
1928
AIR PHOTO COVERAGE

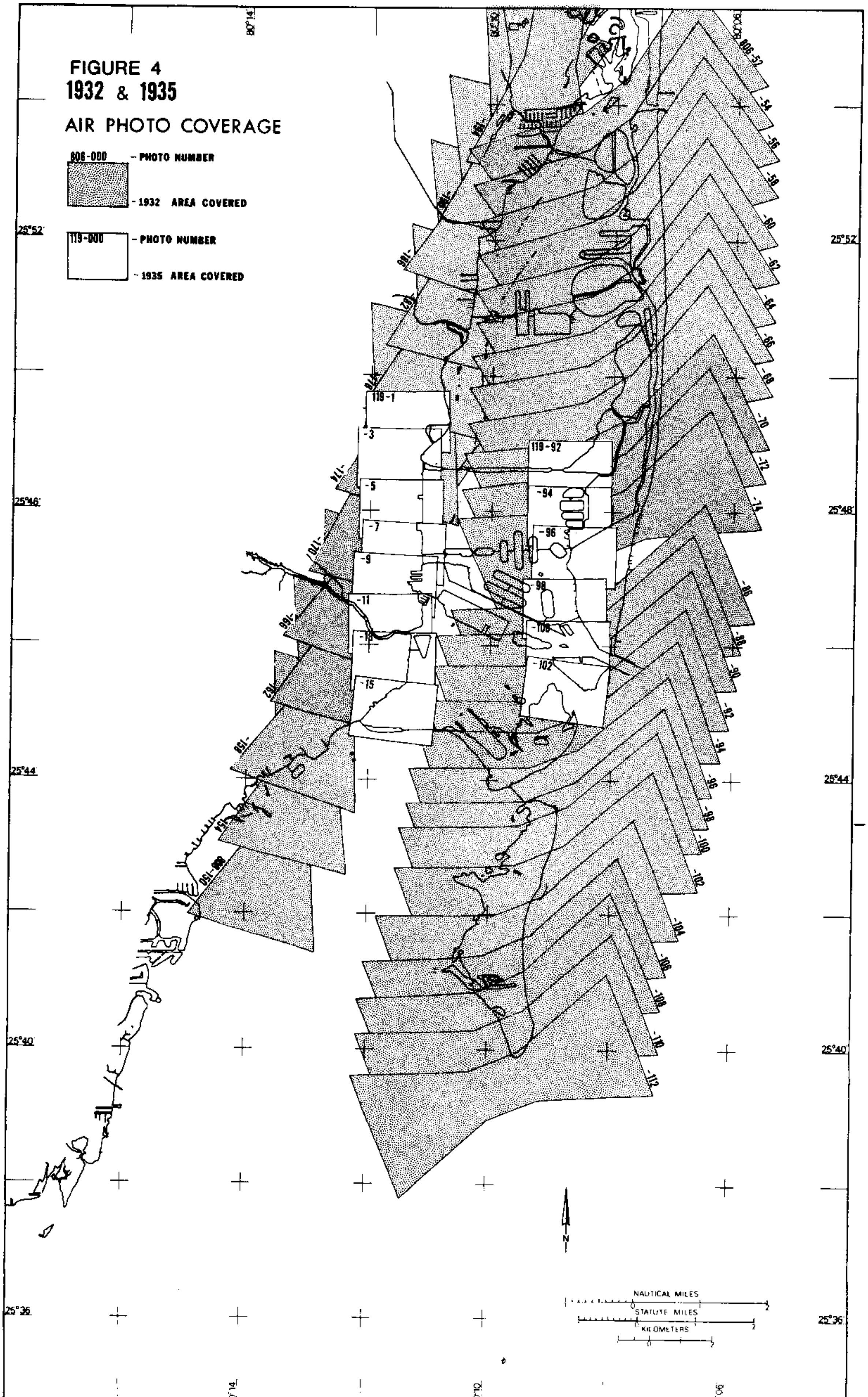
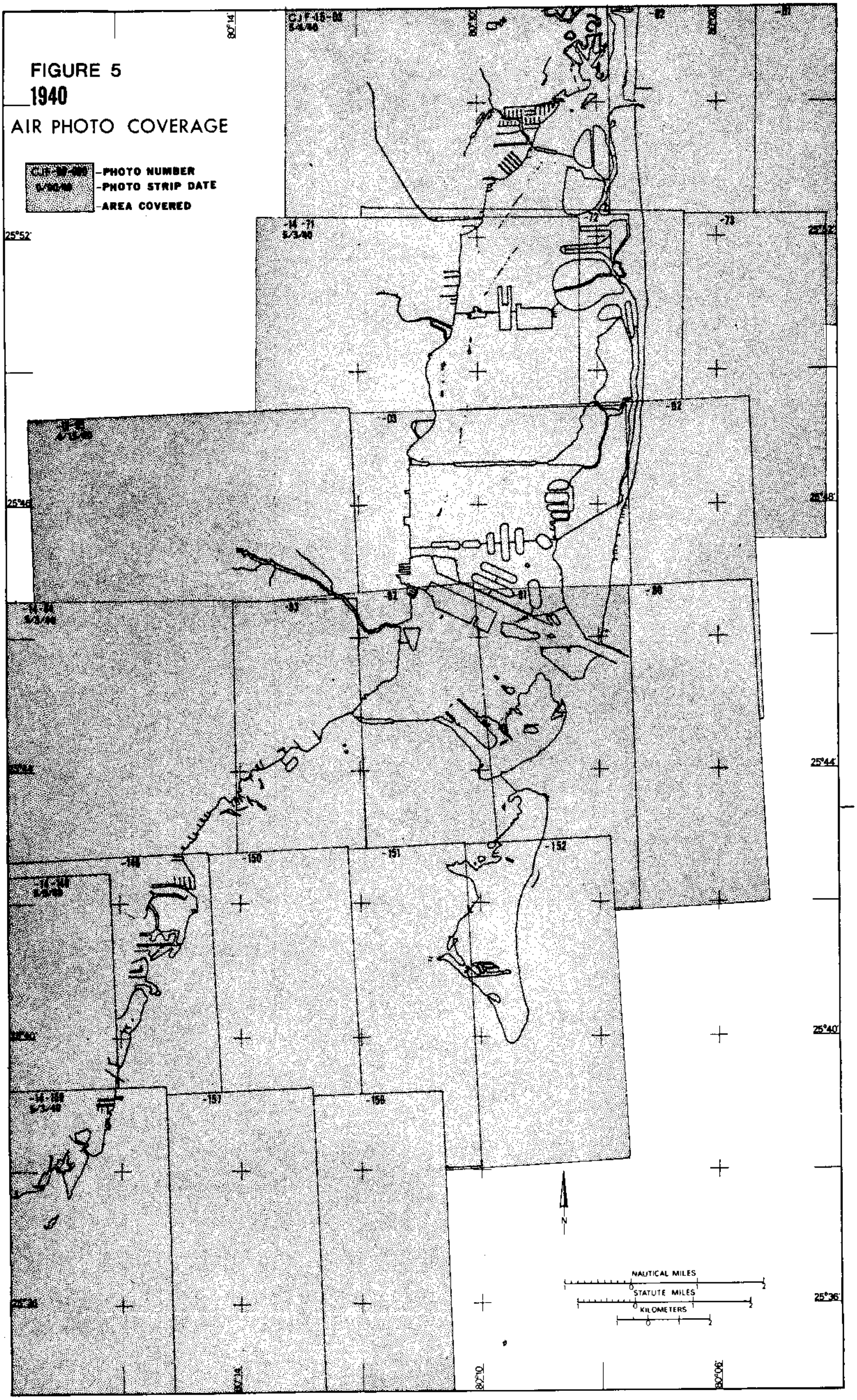


FIGURE 4
1932 & 1935
AIR PHOTO COVERAGE
806-000 - PHOTO NUMBER
- 1932 AREA COVERED
119-000 - PHOTO NUMBER
- 1935 AREA COVERED
25°52'
25°48'
25°44'
25°40'
25°36'
80°14'
80°10'
80°06'
NAUTICAL MILES
STATUTE MILES
KILOMETERS
N

FIGURE 5
1940
AIR PHOTO COVERAGE



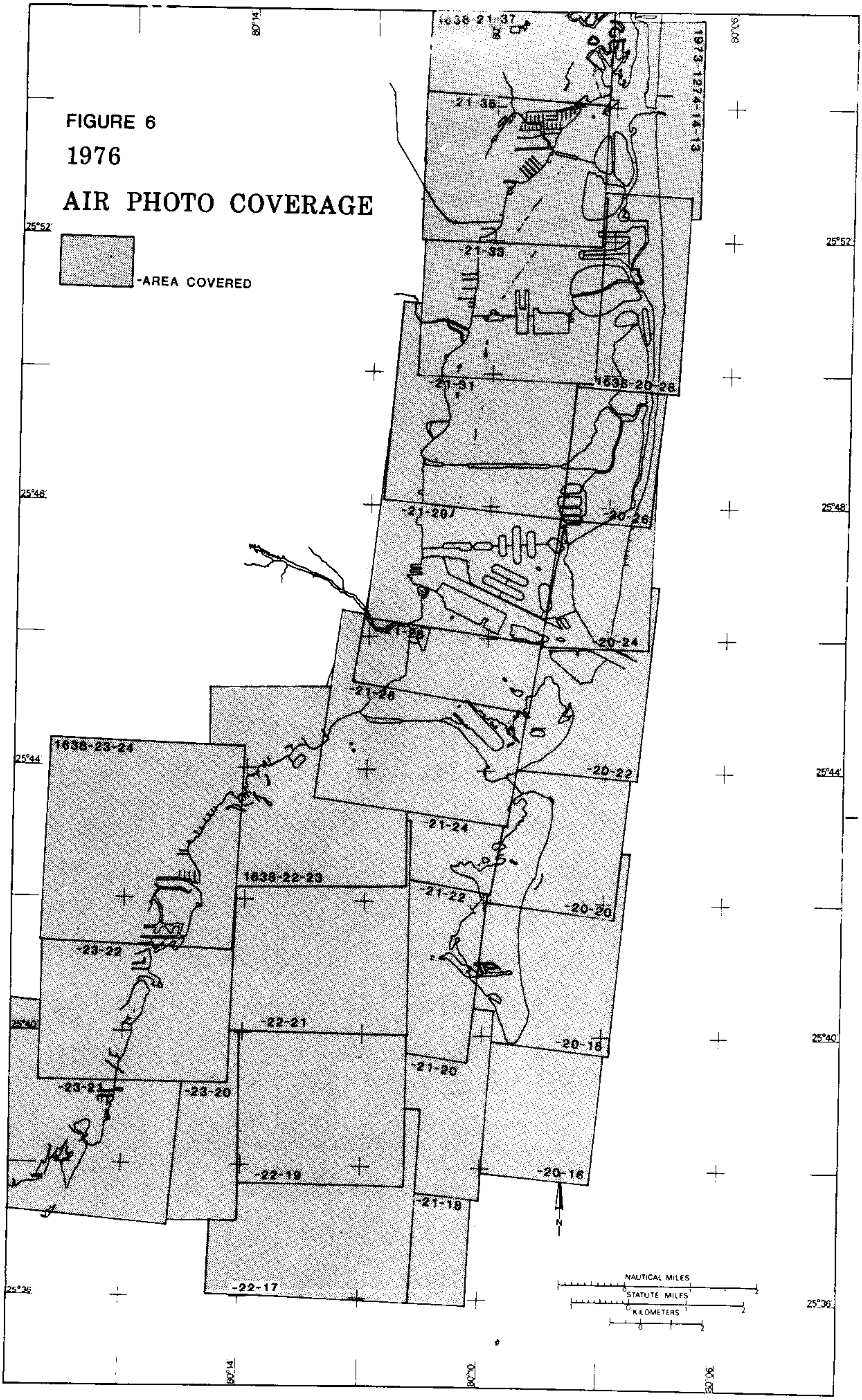


FIGURE 6
1976
AIR PHOTO COVERAGE
-AREA COVERED
1638-21-37
-21-35
-21-33
-21-31
-21-28?
-21-28
-21-26
-21-24
-21-22
-21-20
-21-18
1973-1274-14-13
1638-20-28
-20-26
-20-24
-20-22
-20-20
-20-18
-20-16
1638-23-24
-23-22
-23-21
-23-20
1638-22-23
-22-21
-22-19
-22-17
25°52'
25°48'
25°44'
25°40'
25°36'
80°14'
80°10'
80°06'
N
NAUTICAL MILES
STATUTE MILES
KILOMETERS

weather are available. Comparing photographs taken in different seasons increases the interpretive problems resulting from seasonal fluctuations in terrestrial and marine biological communities.

4) Small portions of each set of photographs are obscured by cloud cover or smoke. The amount of information obtainable from marine areas is additionally limited when turbidity is present, when the surface of the water is disturbed by waves, by water depth and by the reflection of sunlight. In spite of these limitations most of the bottom of northern Biscayne Bay is shallow enough to provide quality images of benthic communities and sediment patterns.

Field Work

Two categories of "ground truthing" or field observations were used to proof preliminary maps: air observation and diving observations. Aerial reconnaissance was conducted in a helicopter and in a blimp owned by the Goodyear Tire and Rubber Company. The helicopter overflight was of necessity brief, but provided information from areas along the western side of the Bay viewed from very low altitude. The airship Mayflower was utilized on May 4, 1978, the day after passage of a cold front with high winds. Water visibility was nearly zero due to the wind conditions but valuable information about the sources and transport processes of turbidity was obtained. Oblique photos (see Figures 27 and 33) were taken during these flights.

Surface and diving observation was accomplished in small boats and on one occasion on the University of Miami's R/V ORCA. The object was to visit as many areas as possible and to check areas of confusing or missing aerial photographic coverage. All sites visited were observed by skin diving and notes on community, sediment, and observed important physical processes were compiled. No attempt was made to catalog every different species of plant and animal or to identify every visible sediment grain. The dominant species of plant (if present) was noted (in order to give the community a name) and an attempt was made to identify important sediment producing organisms. On calm days, most of the northern Biscayne Bay has visibility ranging between about 10 cm to as much as 15 m. On a windy day visibility can be reduced to zero. In addition to snorkeling stops, many spoil islands and mangrove or developed shorelines were visited and examined.

Coring sediments has been proven a valuable tool to sedimentologists trying to unravel the local history of deposition. Wanless (1969) made extensive use of a variation on this technique, hand coring of unconsolidated sediments, in his work on the sediments of Biscayne Bay. For a complete description of the technique see Wanless (1969, p. 18).

Sediment cores are used in this study to better understand the historical changes in communities and sediments seen in the aerial photography. During field work, core sites were selected to clarify confusing photographic images, to calibrate the sequence of bottom changes, and to estimate rates of sediment deposition. Photographs of the cores taken for this study are in Appendix A. Schematic core descriptions accompany photographs and a discussion of the core data is found in a later chapter.

SETTING AND HISTORICAL BACKGROUND

(Note: Place names mentioned below can be located in Figures 12 and 16 through 21).

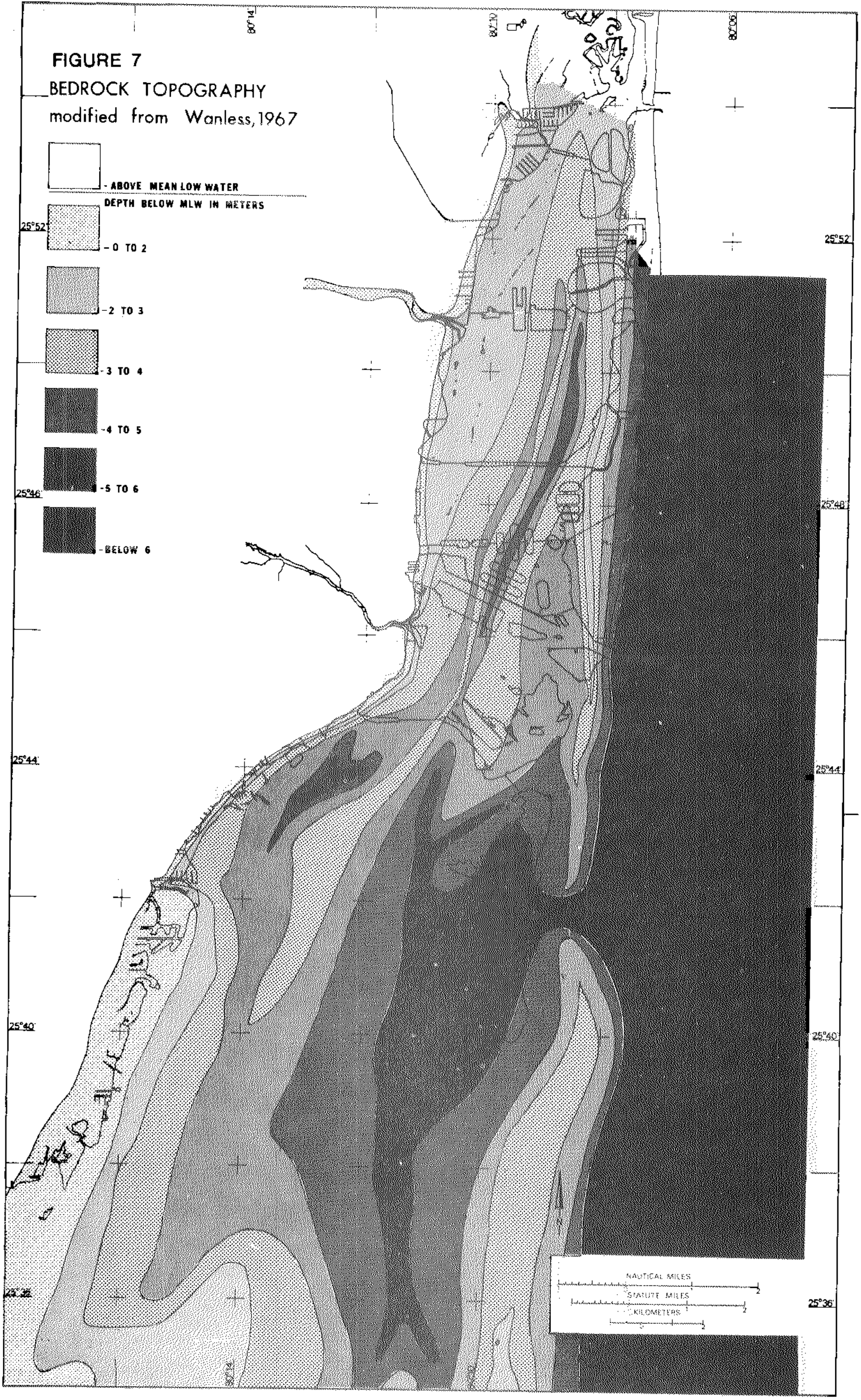
Present Setting

Northern Biscayne Bay is 3 to 15 km in width and about 38 km in length. The Bay is underlain by a shallow bedrock basin (Figure 7) of Pleistocene limestone (Wanless, 1969). Key Largo limestone forms the eastern ridge and the oolitic Miami limestone forms the Atlantic Coastal Ridge defining the western bayshore and separating Biscayne Bay from the Everglades (Figure 3). Zero to 6 m of Holocene-age sediment has accumulated over the Pleistocene surface, and sediment is generally thickest beneath the eastern barrier island system and the Safety Valve (Figure 8). Bay sediments are various mixtures of quartz sand, carbonate sand and shell, carbonate mud, and organic particles (Figure 9). Cross sectional profiles of the sediment cover are shown in Figure 10. The carbonate sediments are largely produced within the Bay, but the quartz sand has been carried down from the north by coastal processes or weathered out of local rock units (Wanless, 1967, 1969, 1976b).

The eastern border of northern Biscyane Bay is a discontinuous string of low (3 m or less) sand barrier islands. The oolitic rock Atlantic Coastal Ridge to the west is a series of low hills with lower intervening swales that trend perpendicular to the ridge axis (see Hoffmeister et al., 1967). The major streams of the region flow in the swales when crossing the ridge. The Miami River, located in the approximate center of the study area, is the principal source for drainage from the Everglades to the west.

The present Bay is shallow (generally less than 3 m) except in the

FIGURE 7
BEDROCK TOPOGRAPHY
modified from Wanless, 1967



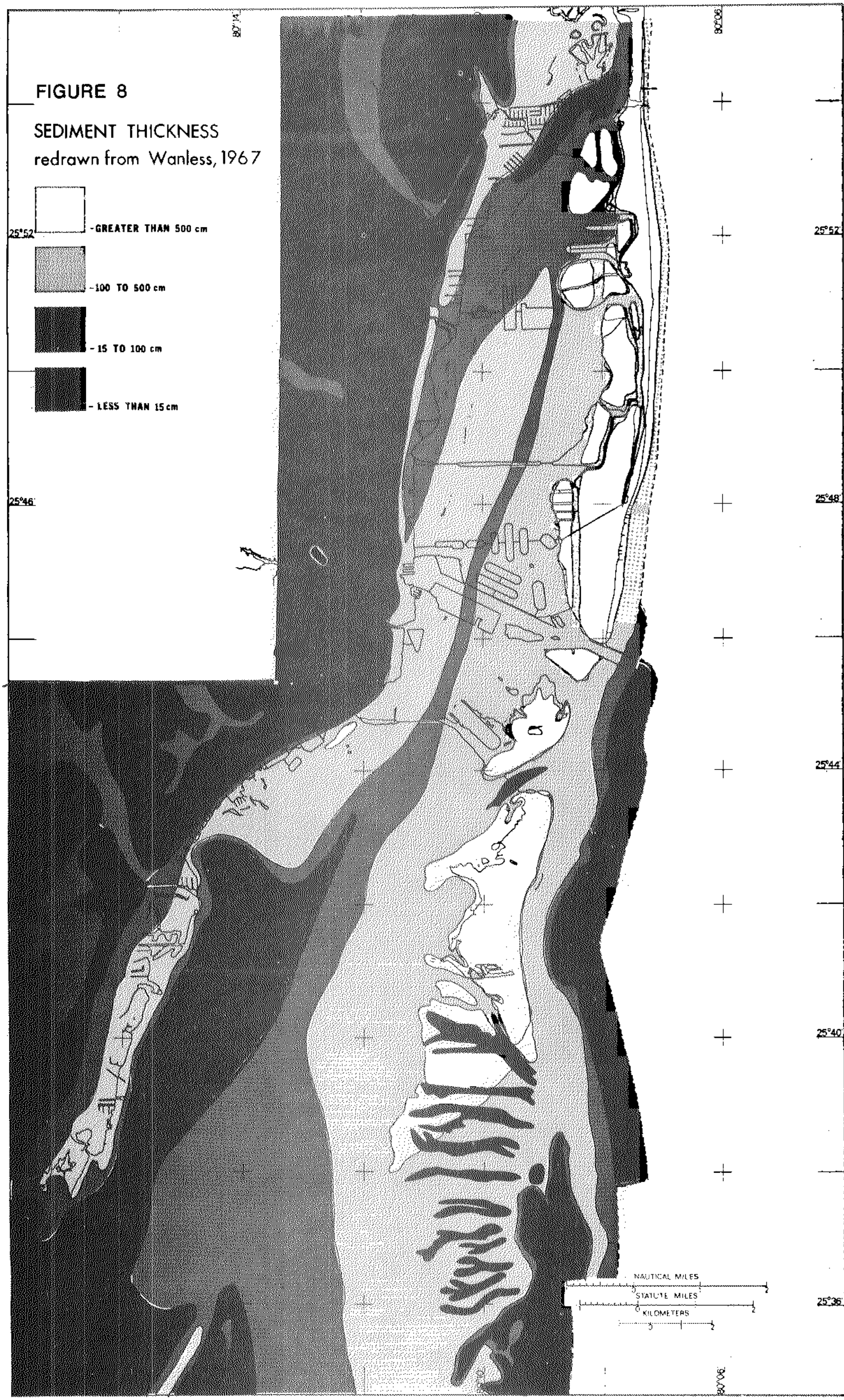


FIGURE 8

SEDIMENT THICKNESS
redrawn from Wanless, 1967

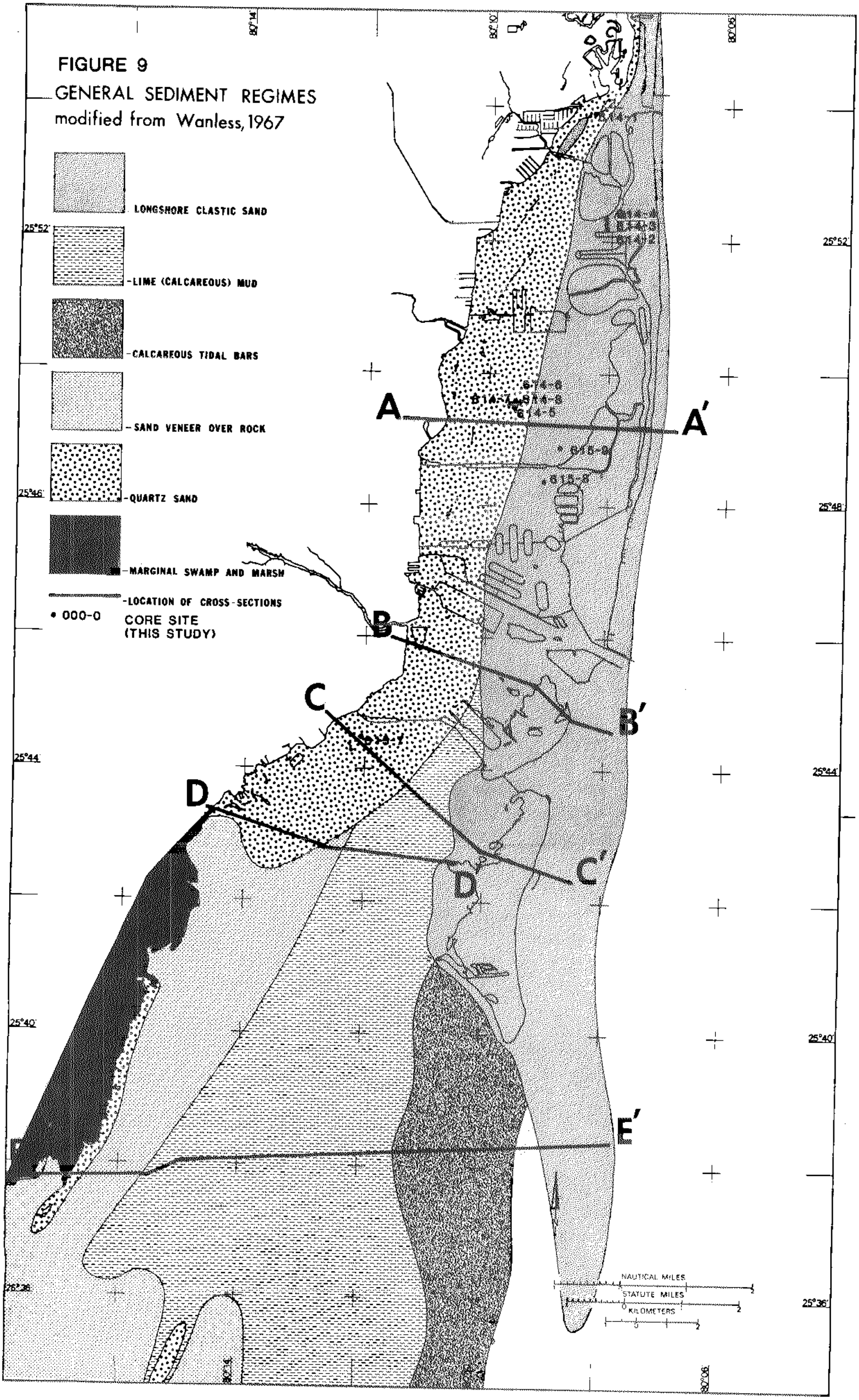


FIGURE 9
GENERAL SEDIMENT REGIMES
modified from Wanless, 1967

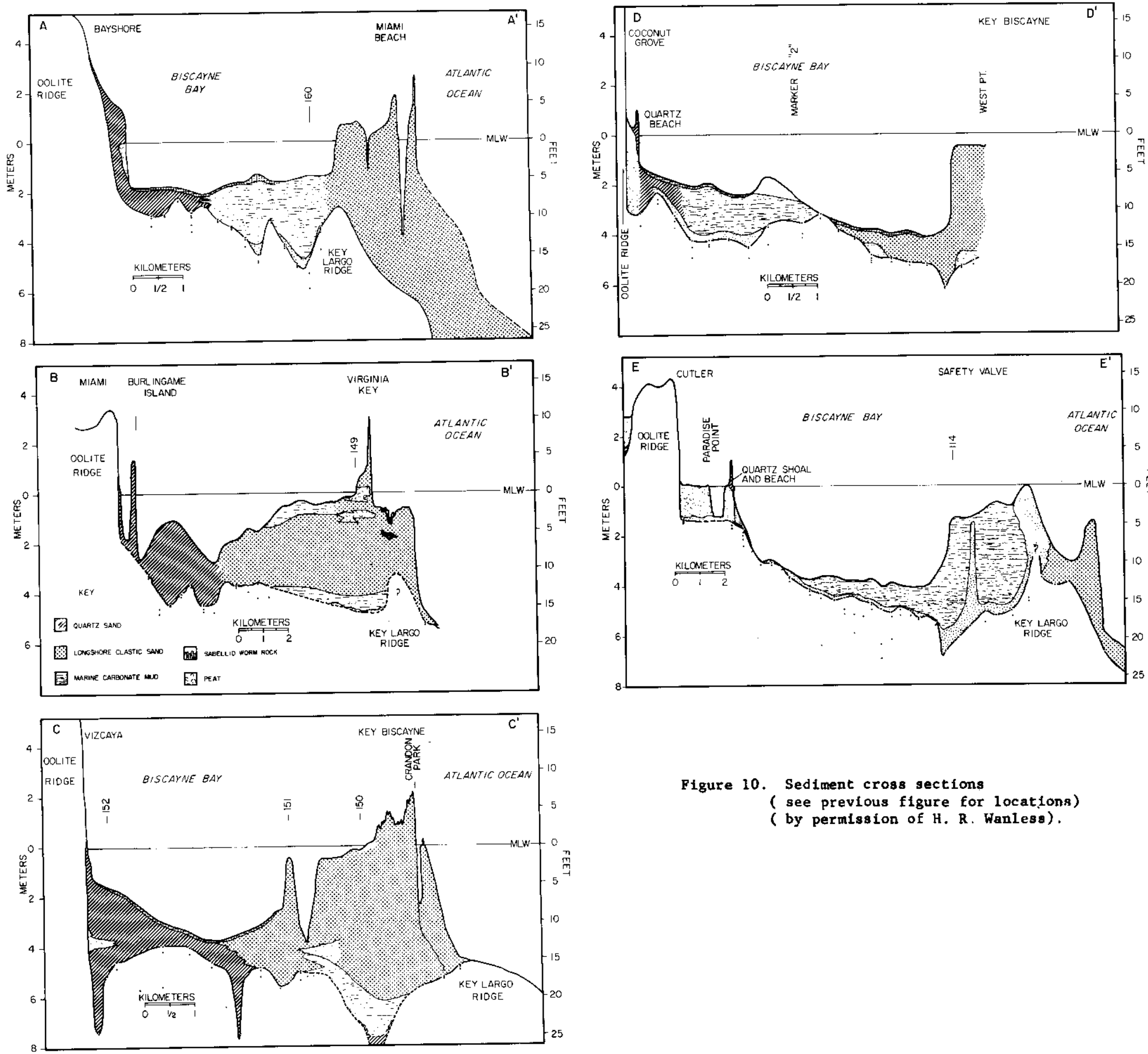


Figure 10. Sediment cross sections
(see previous figure for locations)
(by permission of H. R. Wanless).

extensive dredged bottom areas. Dredged bottoms are generally 2 to 4 m in depth, but a few are in excess of 10 to 12 m (NOAA chart 11467).

Tides enter northern Biscayne Bay via two artificial and two natural cuts through the barrier island system (Michel, 1976). To the south of Key Biscayne, tidal exchange is through the network of channels cutting the Safety Valve mud bar belt. Tides in the Bay are semi-diurnal and the mean tidal range is about 60 cm (Lee and Rooth, 1976). Tidal current velocities within the Bay are usually less than 50 cm per second, although higher velocities occur in the cuts (Smith _et al_., 1955; Van de Kreeke, 1976).

Fresh water enters the Bay through various natural, modified, or artificial waterways. It also seeps through the porous limestones and unconsolidated sediments, and enters the Bay through karst features (Kohout, 1967; Kohout and Kolipinski, 1967).

The climate of the region is generally mild and seasonally wet. Average yearly temperature for Miami is 74°F, and the average rainfall in adjacent wetlands can be as high as 150 cm per year (Thomas, 1974). Summer winds are generally mild and usually out of the south and east. Cold fronts during winter months can produce winds in excess of 20 m per second and of two to three days duration (Warzeski, 1976; Lee and Rooth, 1976).

Besides summer thunderstorms, the southeast coast of Florida is affected by occasional hurricanes and tropical storms (Table 2). Gentry (1974, p. 74) places the chance of a hurricane hitting the study area at between 1 in 4 and 1 in 5 for any given year. Hurricanes play an important role because they are the major modifiers of sediment bodies in the region (Warszeski, 1976, p, 33).

Studies that describe hurricane related damage include Gentry (1974)

Table 2. Hurricanes and Tropical Storms Passing Near Miami, 1895-1979

Date	Status	Name	Comments
8/ /99	H		Passed south to north offshore.
8/10/01	H		Passed over south Biscayne Bay; "slight intensity" (Tannehill, 1945).
9/11/03	H		Passed onshore north of Miami region.
10/14/04	TS		Winds less than 68 mph.
6/17/06	H		Passed southwest to northwest over Everglades. Winds 70 mph at Sand Key; heavy rain (Tannehill, 1945).
10/18/06	H		Passed along axis of Florida Keys, winds 75 mph (northwest) at Sand Key.
11/15/16	H		Passed over southern tip of Florida to east-northeast. Winds 71 mph north at Sand Key.
9/19/19	H		Passed east to west along lower Keys. Winds 84 mph Sand Key; 60 mph Miami.
10/21/24	H		Passed roughly west to east over north Everglades.
7/27/26	H		Passed roughly parallel to coast north of Palm Beach.
9/ /26	H		Passed to southwest offshore of Keys one or two days before . next storm.
1/18/26	H	Great Miami Hurricane	Passed over Miami to northwest, heavy damage, severe beach erosion, very high tides, maximum winds 138 mph (Tannehill, 1945).
10/20/26	H		Passed to northwest offshore of Keys.
8/ /28	TS		Moderate gales along coast crossed north of Miami heading northwest.
9/16/28	H	Great Palm Beach Hurricane	Passed north of Bay region near Palm Beach, heading to northwest.
9/27/29	H	Great Nassau Hurricane	Passed over Key Largo west-northwest. Winds 150 mph at Key Largo; grass beds eroded on Safety Valve south of Key Biscayne.
11/25/31	TS		Dissipated over Andros, Bahamas.
8/29/32	TS		Passed over Biscayne Bay to northwest.
7/30/33	H		Pased east to west north of Bay region. Winds 60 mph, Ft. Pierce.
9/ 3/33	H		Passed to north over Jupiter, winds 125 mph.
10/ /33	H		Passed to south over Florida Straits heading northeast
9/ 2/35	H	Labor Day Hurricane	Passed over Long Key, extensive damage in Keys; destroyed Overseas Railroad. Winds 40 mph (southeast) at Miami with high tide in Bay.
9/28/35	H		Passed over Florida Straits heading northeast. Winds 75 mph (northeast) Fowey. Passed with tide high.
11/ 4/35	H	Yankee Hurricane	Passed over south Bay heading southwest; winds 80 mph (southeast) at low tide; abundant coastal damage along Bay shores; tides 2.2 feet above normal at Miami.
6/ /36	TS		Passed west to east over Ft. Lauderdale.
8/28/36			Passed over Upper Keys; winds 65 mph Miami Airport.
9/ /37	TS		Passed to north over Andros, Bahamas.
8/11/39	TS		Passed north of Bay region.
10/ 6/41	H		Passed to northwest over South Bay. Winds from north 90-123 mph at Dinner Key.
9/ 4/45	TS		Crossed west coast of Florida near Ft. Myers. Winds 40-50 mph at Miami; some damage to boats in Biscayne Bay (summer 1941).
9/15/45	H		Passed over Key Largo to northwest. Maximum winds 138 mph (southwest) at Carysfort Reef light. Winds 86-107 mph (southeast) at Miami; damage extensive at Richmond Air Station in south Dade.

1946	TS		
9/17/47	H		Passed over Ft. Lauderdale to west; winds 90 mph (southwest) at Miami. 75 mph at Carysfort Light.
10/ 6/47	TS		Formed over Florida Straits, moved north, passed northwest of Bay region heading northeast. Winds 62 mph at Miami.
9/22/48	H	"Oxcart Panopes"	Passed over Key West heading north; winds 70-75 mph (south-southeast) at Miami.
10/ 5/48	H		Passed over Miami Airport heading northeast; winds 90 mph (northwest) at Miami.
10/17/50	H		Winds south at 96 mph, gusts to 120. Passed over Miami to north.
9/10/60	H	Donna	Passed over Tavernier heading northwest; maximum winds 140-180 mph; tides 5-6' above sea level in south Bay.
8/26/62	TS	Alma	Passed over Bay; winds 45 mph.
8/26/64	H	Cleo	Passed over North Miami; winds 100-135 mph. Damage from downtown Miami to Melbourne; tides in north Bay greater than 4 feet.
9/ 8/65	H	Betsy	Passed over Key Largo area heading west; winds 120-140 mph, 100 at Miami from north; tides plus 6.1 feet at Miami Beach; extensive flooding of lands east of Atlantic Coastal Ridge; beach erosion Miami to Palm Beach.
10/ 4/66	TS	Inez	Passed to south, winds 45-60 mph at Coral Gables.
7/17/68	TS	Brenda	Became Hurricane after passing
8/ 9/68	TS	Polly	Became Hurricane after passing.
9/ 6/69	TS	Gerda	Rain, no wind at Miami.
7/27/70	TS	Celia	
9/13/70	TS	Felice	
9/ 5/72	TS	Dawn	
8/19/76	TS	Dottie	
9/13/79	H	David	Passed essentially parallel to coast offshore heading north; tides at Miami less than 1 m above normal.

(Tanner, 1945; Monthly Weather Review, various) for the 1926, 1928, 1935, 1945, 1947, 1949, 1950 and 1960 storms; Craighead's (1964) mangrove paper; Perkins and Enos (1968), Pray (1966), Thomas et al. (1961) and Warszeski (1976). Chardon (1976, 1977, 1978) looked at coastal morphological changes produced by storms. The majority of the data in Table 2 comes from the yearly summaries of the Monthly Weather Review and Tannehill (1945).

The present distribution and abundance of benthic organisms in northern Biscayne Bay is not well known. A series of population studies intiaited with Moore et al. (1955) contained initial biological assessments and crude maps of the bottom communities south of 79th Street Causeway (see also Hela et al., 1957; McNulty, 1961, 1970; McNulty et al., 1962a, 1962b). A more recent benthic community map that partially includes northern Biscayne Bay was presented by Roessler and Beardsley (1975), shown in part here as Figure 11. A variation of this map can be found in Thorhaug (1976). Of particular interest is the large "bare" mud and silt areas south of Dodge Island and in mid-bay just south of Rickenbacker Causeway (Figure 11). Humm (1976) lists the benthic algae found in Biscayne Bay.

The importance of benthic plants, and their ecology in Biscayne Bay have been discussed by Weiss (1948), Smith et al. (1950), O'Gower and Wacasy (1967), McNulty (1961, 1970), Kohout and Kolipinski (1967), Moore et al. (1968), Roessler and Beardsley (1974) and Thorhaug (1976). The geologic significance and sedimentation patterns produced by benthic plants are discussed by Ginsburg and Lowenstam (1958), Wanless (1967, 1969, 1976a, 1976b) and Scoffin (1970).

Original Setting

In 1887, northern Biscayne Bay had many of the same general features

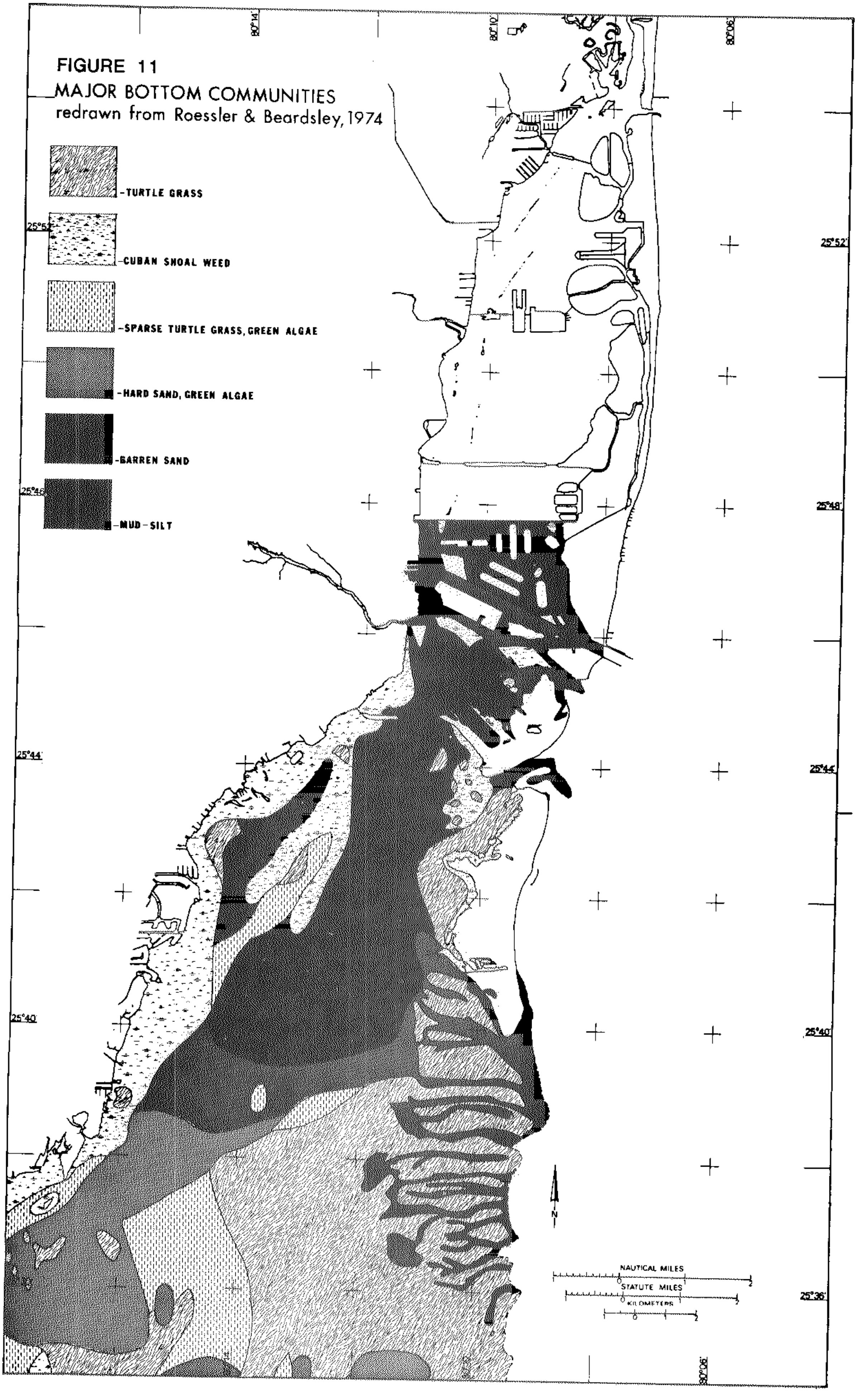


FIGURE 11
MAJOR BOTTOM COMMUNITIES
redrawn from Roessler & Beardsley, 1974

as it has today. The western shore was dominated by the low coastal ridge of oolitic limestone upon which grew pines and hardwoods (Agassiz and Griswold, 1896; U.S. Coast and Geodetic Survey, chart #165, 1887). This shore was lined by narrow mangrove swamps except to the extreme north and south where the swamps were wider and backed by freshwater marshes. The oolite rock outcropped in a few spots directly at the bayshore just north of Coconut Grove (see photos in Parks, 1977). The eastern border of the Bay was bounded by the low beach ridge and swamp barrier island complex comprised of Miami Beach (then connected to the northern mainland above Bakers Haulover), Virginia Key and Key Biscayne (Figure 12). These islands were bordered on the bay side by wide mangrove swamps and a few large mangrove islands.

Seasonally, large quantities of fresh water entered the Bay both through the porous rocks and sediments as springs and through streams along the western bayshore (Dole, 1914). The Miami River, Little River, Arch Creek and Snake Creek originated in the Everglades and provided outlets for floodwaters. Exchange of tidal water between Biscayne Bay and the ocean was through Norris Cut, Bear Cut, Cape Florida channel and through the Safety Valve. The balance between fresh and salt water in northern Biscayne Bay probably fluctuated drastically after some climatic events and between seasons. The possible effects of salinity or temperature stress on the natural Bay environments prior to the opening of Bakers Haulover cut and Everglades land reclamation is unknown.

Northern Biscayne Bay had average depths less than 2 m (see Handbury, 1896). A cross-Bay shoal roughly split the Bay north of the Miami River in two (Figure 18). North of this shoal the Bay had depths slightly deeper

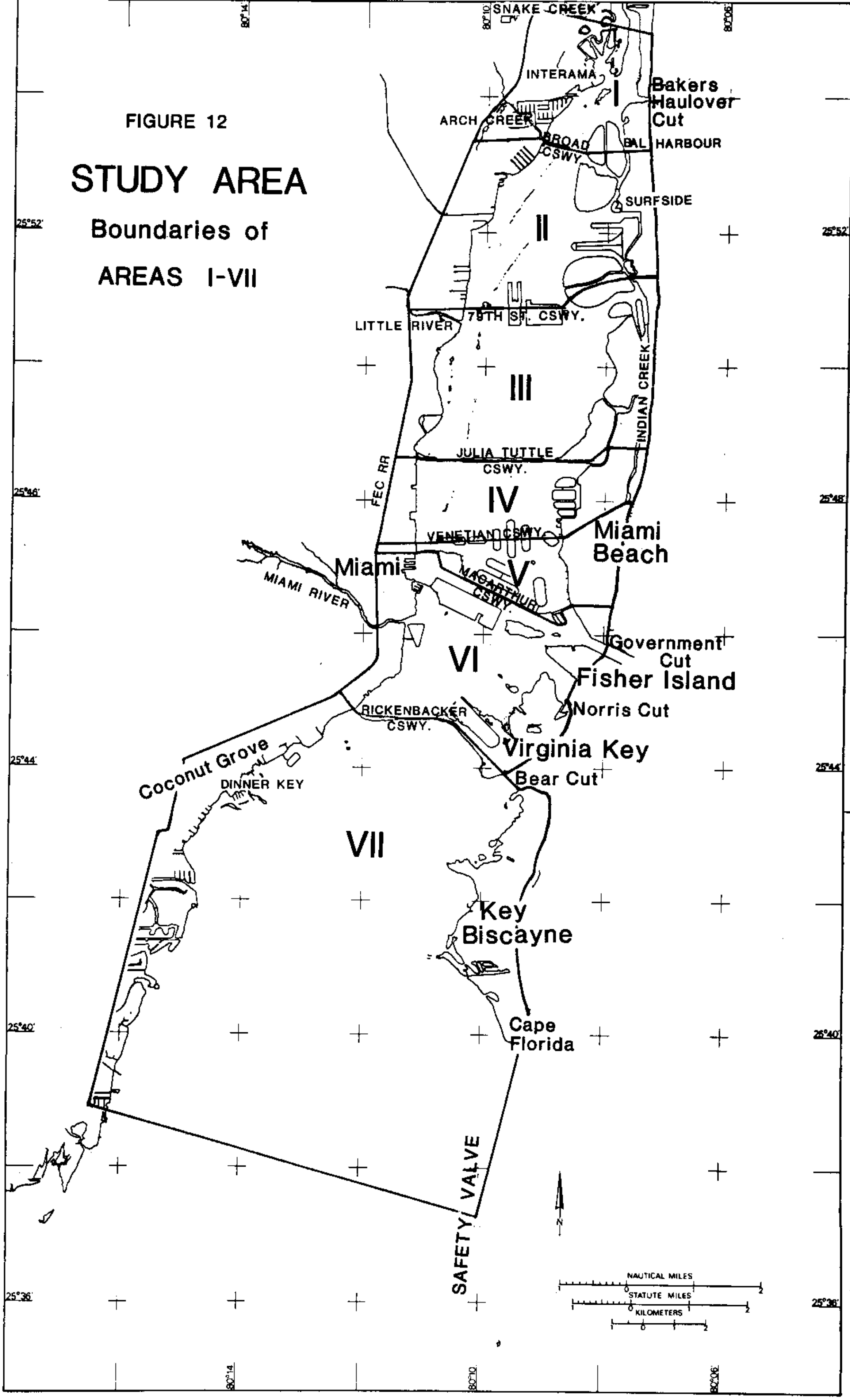


FIGURE 12
STUDY AREA
Boundaries of
AREAS I-VII
SNAKE CREEK
INTERAMA
I
Bakers
Haulover
Cut
ARCH CREEK
BROAD
CSWY.
BAL HARBOUR
SURFSIDE
II
LITTLE RIVER
79TH ST. CSWY.
III
INDIAN CREEK
JULIA TUTTLE
CSWY.
FEC RR
IV
VENETIAN CSWY.
Miami
Beach
Miami
MIAMI RIVER
V
MACARTHUR
CSWY.
VI
Government
Cut
Fisher Island
Norris Cut
RICKENBACKER
CSWY.
Virginia Key
Bear Cut
Coconut Grove
DINNER KEY
VII
Key
Biscayne
Cape
Florida
SAFETY VALVE
NAUTICAL MILES
STATUTE MILES
KILOMETERS
25°52'
25°48'
25°44'
25°40'
25°36'
80°14'
80°10'
80°06'

than to the south of it. A maximum of 2.7 m was found in the area north of the present west end of the 79th Street Causeway. The bay deepened in the center south of the Miami River, and some of the tidal channels connecting to the ocean could provide 2 to 3 m of water. Indian Creek, running parallel to Miami Beach, was as deep as 3 m in places, because it once connected to the ocean as the Boca Ratonnes Inlet (Romans, 1776; see also Chardon, 1975, 1976). The deeper scars of two ancient tidal channel complexes that once breached the barrier islands were discovered in the 1925 aerial photographs (Figure 13). One channel complex was located bayward of Miami Beach at the north terminus of Indian Creek (at Stillwater Point) and a second set appears to cut through Virginia Key in at least three places (Figure 13b). When the Virginia Key channels were active is unknown, but Chardon (1976, p. 236) suggests that Indian Creek (Boca Ratonnes Inlet) was closed by a storm in 1822. The Bay bottom was shallowest along the eastern Bayshore (except in the tidal channels), in the cross-Bay shoal running east-southeast from Little River and along the western shore south of the Miami River.

The basin-like bedrock bottom of the Bay was filled to different depths by a thin blanket of sand and muds that generally thickened to the east near the barrier islands (Figure 8). Bedrock features are visibile in the aerial photographs along portions of the shallow bottoms to the southwest where overlying sands are only a few centimeters in thickness (Wanless, 1969).

Historical Developments Prior to 1925

Miami's population was about 1500 in the spring of 1896 at the opening

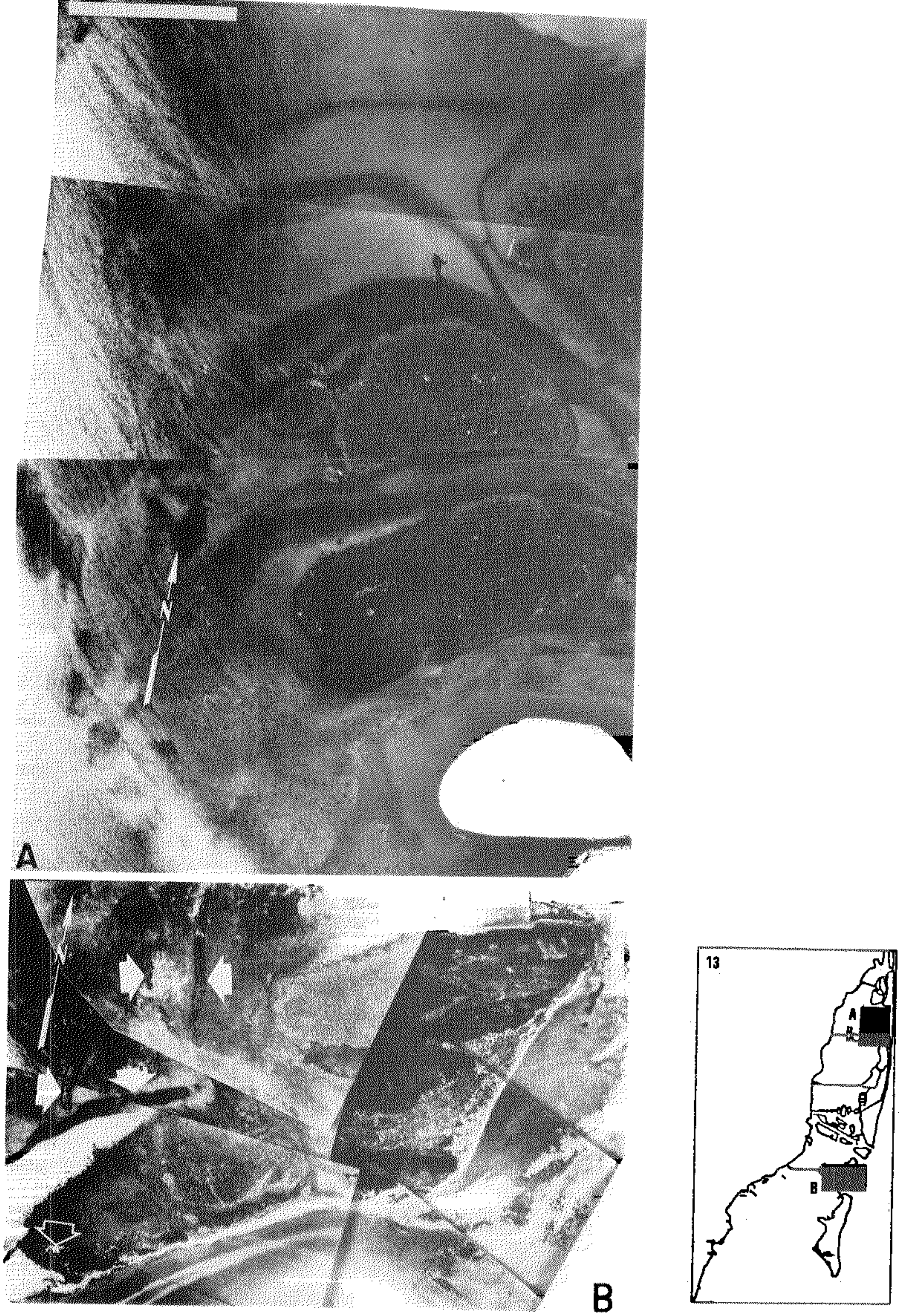


Figure 13. A: 1925 photomosaic of orginal mangrove Normandy Islands shows the tidal channels and tidal delta associated with the Boca Ratonnes Inlet that closed in the 1800's. Note the decrease in benthic vegetation from north to south (Miami-Dade Library). B: 1925 photomosaic of Virginia Key shows the abandoned tidal channels on the bay side of Virginia Key. Note that the channels cross-cut each other and some connect to the low areas and ponds on the Key (Miami-Dade Library).

of the Florida East Coast Railroad (Smiley, 1973). By 1900, Dade County had a population of 4,955 with 1600 of those living in Miami proper. In 1910 the county to city population ratio was 11,933 to 5,500 (3:1), and by 1920 was 42,753 to 30,000 (4:3) (Hollingsworth, 1936, p. 34; Smiley, 1973). Miami, with its railroad, new deep port and location on the largest local river, was becoming the urban center of the county. Miami was incorporated on July 28, 1896 (Hollingsworth, 1936, p. 35), Miami Beach on March 26, 1915 (Lummus, 1940), and Coconut Grove in 1919 (Hollingsworth, 1936, p. 61).

Prior to the founding of any of these cities, the Florida Coast Line Canal and Transportation Company began dredging a navigable channel through the coastal mangroves and bays of east Florida in an attempt to open an inland waterway connection between the St. Johns River and Biscayne Bay. The exact date that the southern portion of this canal opened is not certain but it can be bracketed. Smith (1896, p. 183) noted in February of 1895 that a good deal of its "excavation has already been done," and speculated an opening date in 1896. He stated in a footnote (added in 1896 before publication) that the canal had been completed "some months" before the railroad. Handbury (1896), also in Febraury 1895, described the canal as being 1.5 m (5 feet) deep and 15 m (50 feet) wide. He felt it would be open by March 1895 from Palm Beach to New River, forty miles north of Miami. Voss (personal communication) stated that the channel was 23 m (75 ft) wide and that it was not completed to Miami until late 1896 or 1897. Therefore, the F.C.L.C. & T.C. Canal was completed between March of 1895 and sometime in 1896. This canal can still be found in parts of the Bay and is discussed again in the core discussion.

The Florida East Coast Railroad's first train reached Miami on April 15, 1896, with the first passengers arriving on the first scheduled trip of April 22, 1896 (Seth Bramson, personal communication). The railroad brought more people to the area, both settlers and tourists, but its most important role during this period was in bringing supplies to town and taking local products to northern markets.

Miami Harbor did not exist in 1895 because of the limiting water depth found in the Bay, but this situation changed in 1896 when a channel was dug between the Miami River and Cape Florida on the south end of Key Biscayne. Handbury (1896) noted prior to its construction that a larger 3.3 m (11 feet) deep canal could be dug along this route, but felt it would not maintain itself. According to a United States Army Corps of Engineer's report (1900) the first Cape Florida channel was dug to 2.7 m (9 feet) and ran to the mouth of the Miami River. It was dug by the Florida East Coast Railway Company who wanted to connect the railroad to ocean shipping. "Subsequently (in 1897) the river dock was abandoned and a new one built, the railroad carried down to it, with a twelve foot deep channel extending from this basin to the twelve foot depth contour in the bay, and a twelve foot deep channel across the bar" (United States Army Corps of Engineers, 1900, p. 5). This report noted that 10,945 passengers and 21,000 tons of freight passed through this channel in the year 1899.

By 1900 the need for a better ship channel was felt by local interests and so the various options were contemplated. Should the existing Cape Florida channel be improved and maintained or should a new channel be dug to Bear Cut or Norris Cut? The Cape Florida channel was ruled out because a jetty would be necessary for maintenance and this (besides being expensive) might "produce unforseen evil results" (United States Army Corps of Engineers, 1900, p. 6). The Corps of Engineers finally recommended a modified Norris Cut route to be dug through the southern terminus of Miami Beach as least expensive and potentially most easy to maintain. This breach through the beach became Government Cut. Dredging on the cut proper began in 1904, and the last shovelful of sand (literally, see Muir, 1953) was removed in 1905 connecting the Bay to the ocean (United States Army Corps of Engineers, 1912). The new cut immediately filled up with sand eroded off the beaches from the north and south. The initial plan required only one short jetty on the north side and although this retarded southerly drifting sands driven by northeast winds, it acted as a trap for sand moving north from Fisher Island. This effect rendered the channel useless to vessels drawing more than 1.5 to 3 m (5 to 10 feet). In 1908 the channel in the cut was widened to 34 m (110 feet), a 519 m (1,700 feet) south jetty started (finished in 1912), and the north jetty extended to 498 m (1,634 feet) (United States Army Corps of Engineers, 1912). Even upon completion of this phase, the cut was not utilized by large ships because the Florida East Coast (FEC) Railway Channel (Fisherman's Channel) that led from the FEC Railway docks near the Miami River to Government Cut (Figure 18) was too narrow and of insufficient depth.

The FEC Railway Channel was constructed by the railway as part of an agreement with the Federal Government. The Corps of Engineers could not start to dig Government Cut until a channel was dug from Miami. This channel would provide access for the Government Cut dredges and, after completion of the cut, would become the ship channel across the Bay. The FEC Railway Channel was cut 3 m (10 feet) in depth and 18 m (60 feet) in width and was completed by November 1903 (United States Army Corps of Engineers, 1912). It was to be enlarged to 5.4 m (18 feet) in depth by about 30 m in width. The railroad stopped work on the expansion in 1906 because of difficulty in maintaining project depth (United States Army Corps of Engineers, 1943). Someone redredged the eastern end of this channel, along Fisher Island, in the 1920's, but otherwise most maintenance ceased. Spoil dumped along the channel banks remains today in the form of low submerged ridges that run parallel to the channel (Figure 35a). Prior to the opening of Venetian Causeway this channel was the principal route to Miami Beach (United States Army Corps of Engineers, 1912).

Thomas Handbury (1896) discussed the possibility of draining the Everglades thereby making available large acreages of useable land. He suggested that "excavating through this,"[the Atlantic Coastal Ridge,]"the level of water would undoubtedly be lowered and much valuable land reclaimed" (Handbury, 1896). Drainage of the southeastern Everglades started about 1903 (Muir, 1953) and by 1910, 4.25 miles of the Miami Canal had been completed. By 1911, the canal was ten miles long (United States Army Corps of Engineers, 1912). Other shorter canals include the Snapper Creek Canal, the Cutler Canal and the Coral Gables Waterway, all dredged between 1912 and 1913 (United States Army Corps of Engineers, 1912). The rapids of the Miami River, a short distance west of the mouth, were dynamited in 1908 (Muir, 1953).

On Key Biscayne, William Matheson bought a large tract of land on which he planted coconuts. By 1915, he had built fifteen miles of road on the island and some small dredgings, such as Hurricane Harbor (Figure 15c), were undertaken along the Key's bayshore during this period (Woodman, 1961). On the west side of the Bay, the palatial Vizcaya was started in 1914, and a channel was dredged perpendicular to shore from Vizcaya to the 2 m depth contour sometime between 1914 and 1919. Spoil formed three small islands along the sides of the channel. Other smaller channels can be seen in the aerial photographs and maps of the southwestern bayshore (Figure 18) that were dug prior to 1925.

About 1912, John Collins began to dig the Collins Canal through part of Miami Beach. He intended to connect Pancoast Lake, a small body of water at the southern terminus of Indian Creek, to the Bay at the point where his cross-bay bridge (Venetian Causeway) would end (Muir, 1953). The mangroves west of southern Miami Beach were cut down between 1913 and 1914, and the remains covered by a thick layer of bay bottom fill dredged and dumped behind retaining bulkheads.

MacArthur Causeway was constructed with spoil produced in an enlargement of the Turning Basin (Figure 22c) at downtown Miami and in the digging of a new straight ship channel, started in 1917 (Smiley, 1973) and finished in 1920 (Muir, 1953). This is the present Miami Ship Channel.

Belle Island (formerly Bulls Island, see Lummus, 1940) at the eastern end of Venetian Causeway, was bulkheaded and filled sometime between 1918 and 1922 (United States Army Corps of Engineers, 1918a, 1922) as was the first true fill island (totallly constructed by bulkheading in previously open water), Star Island. Palm Island (Figure 18) along MacArthur Causeway, Rivo-Alto Island, and Di-Lido Island along the Collins Bridge (Venetian Causeway) were constructed between 1918 and 1922 (United States Army Corps of Engineers, 1922). The Flagler Monument was built in 1922 on a small, round spoil island produced during construction of a motorboat race course between Star Island and Miami Beach. Construction was started on the fill islands Hibiscus, San Marino and San Marco between 1922 and 1925; Hibiscus was completed in 1925. The large mangroves of Miami Beach were cut down (Figure 28) prior to 1920 and the swamps filled.

For the period of 1896 to 1925, Tannehill (1945) recorded the tracts of nine hurricanes that passed close to Miami (Table 2). The 1906 storm killed 124 workers in southern Dade County who were working on the railroad to Key West. The 1919 storm passed to the south of the Bay, but winds of 60 miles per hour were recorded in Miami. There is no record of significant environmental damage in the northern Biscayne Bay region resulting from these storms or the seven others (1899, 1901, 1903, 1904, a second in 1906, 1916 and 1924). We know that Governemnt Cut opened for the first large vessel twenty years after the initial dredging. This delay must have been caused, in part, by the pre-1925 hurricanes.

Munroe (Munroe and Gilpin, 1930) has a few notes on frost occurring in the Bay region. He describes frost in Miami in 1897 and in 1917. The first killed many mangroves to the north and the second, in 1917, killed fish in the Bay. Deuver et al. (1977, p. 15) report freezes in 1895, 1898, 1899, 1905, 1906, 1917, 1928, 1934, 1940, 1947, 1957-58, 1962, 1970, 1971 and 1977.

Historical Developments After 1925

From 1925 to date, development of the Biscayne Bay region can be monitored with the available historical aerial photography. Although a great deal of detail can be documented from these photographs, only the major changes are discussed here.

Bakers Haulover Cut was completed in 1925 at the height of "the Boom" in urban development. The effect of opening this waterway appears to have been significant to the ecology of the Bay (Teas et al., 1976; Wanless, 1976b; Michel, 1976). In 1927 and 1928, after the great 1926 hurricane, groins were built on Miami Beach near its midpoint (Figure 14b). In 1927 the Corps of Engineers redredged Government Cut to 7.8 m (62 feet), 44 groins were built on the beach north of Bakers Haulover Cut, and the 79th Street Causeway was started. The Corps again widened the Miami Ship Channel to 60 m (200 feet) in 1928 and increased the depth to 7.5 m (25 feet) the next year (United States Army Corps of Engineers, 1943). The first Intracoastal Waterway extending north-south along the west side of the Bay opened by late 1929, and the large rectangular Dinner Key seaplane basin off of Coconut Grove was dredged after 1932 (U.S. Army Corps of Engineers, 1932). Two ship turning basins were enlarged, one opposite the mouth of the Miami River (started in 1896) and the other large basin adjacent to the FEC docks at the west end of the ship channel. The latter (the present Turning Basin) was finished by 1933 (United States Army Corps of Engineers, 1943). Deepening of Government Cut, the Miami Ship Channel and the Turning Basin to 9 m (30 feet) was completed by early 1935. The 1935 hurricane season forced the Corps to redredge these areas in 1938 and 1939, again to 9 m. The latest redredging occurred during the 1970's and provided depths of 13 m in the ship channel.

Rickenbacker Causeway, begun in 1941 as part of a proposed expansion of Virginia Key, was finished and opened to traffic in 1947 (Muir, 1953). Commercial interests bulkheaded and filled the predominantly mangrove southern one-fourth of Key Biscayne in 1950 (Figure 25e). Active dredging

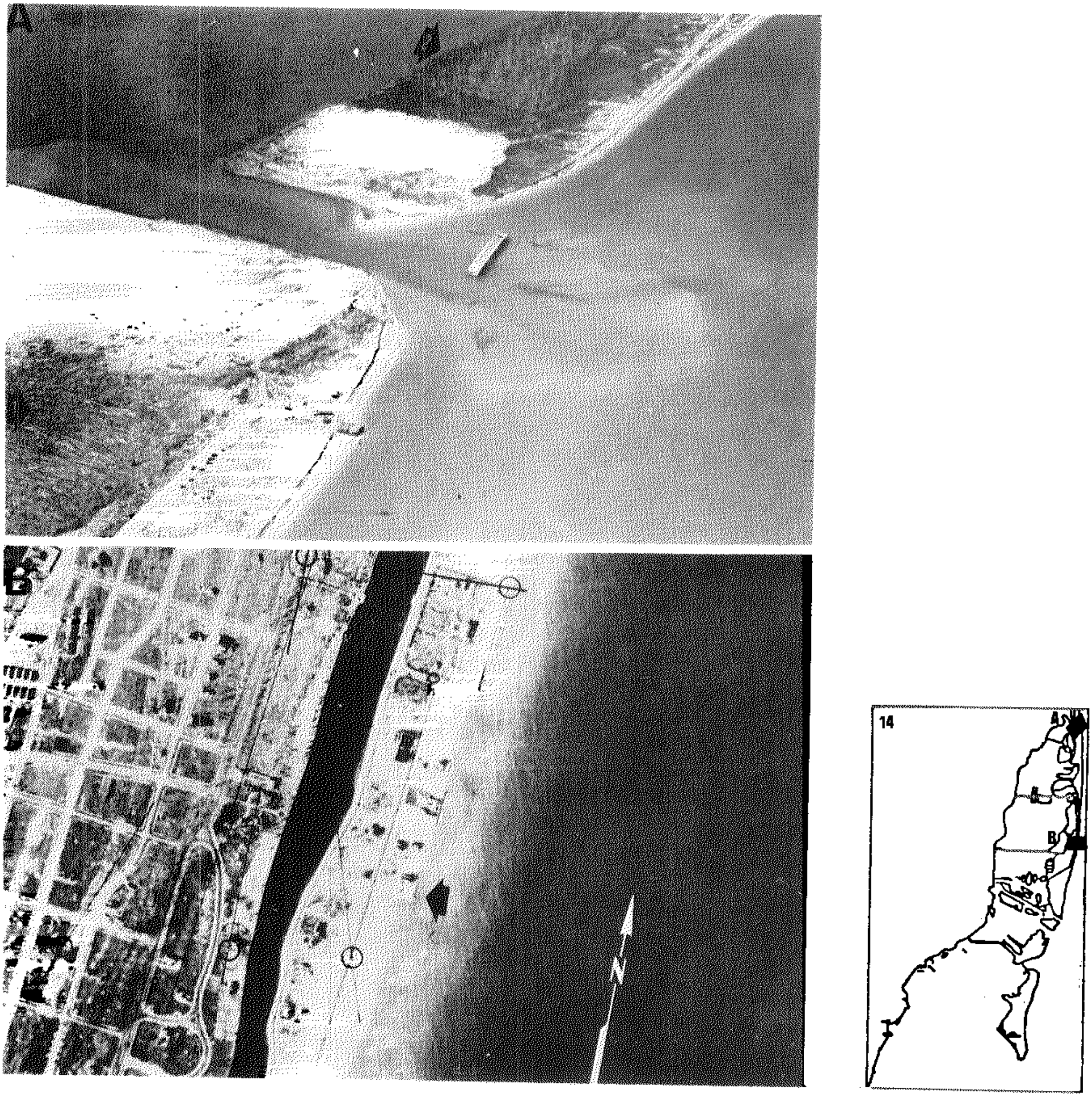


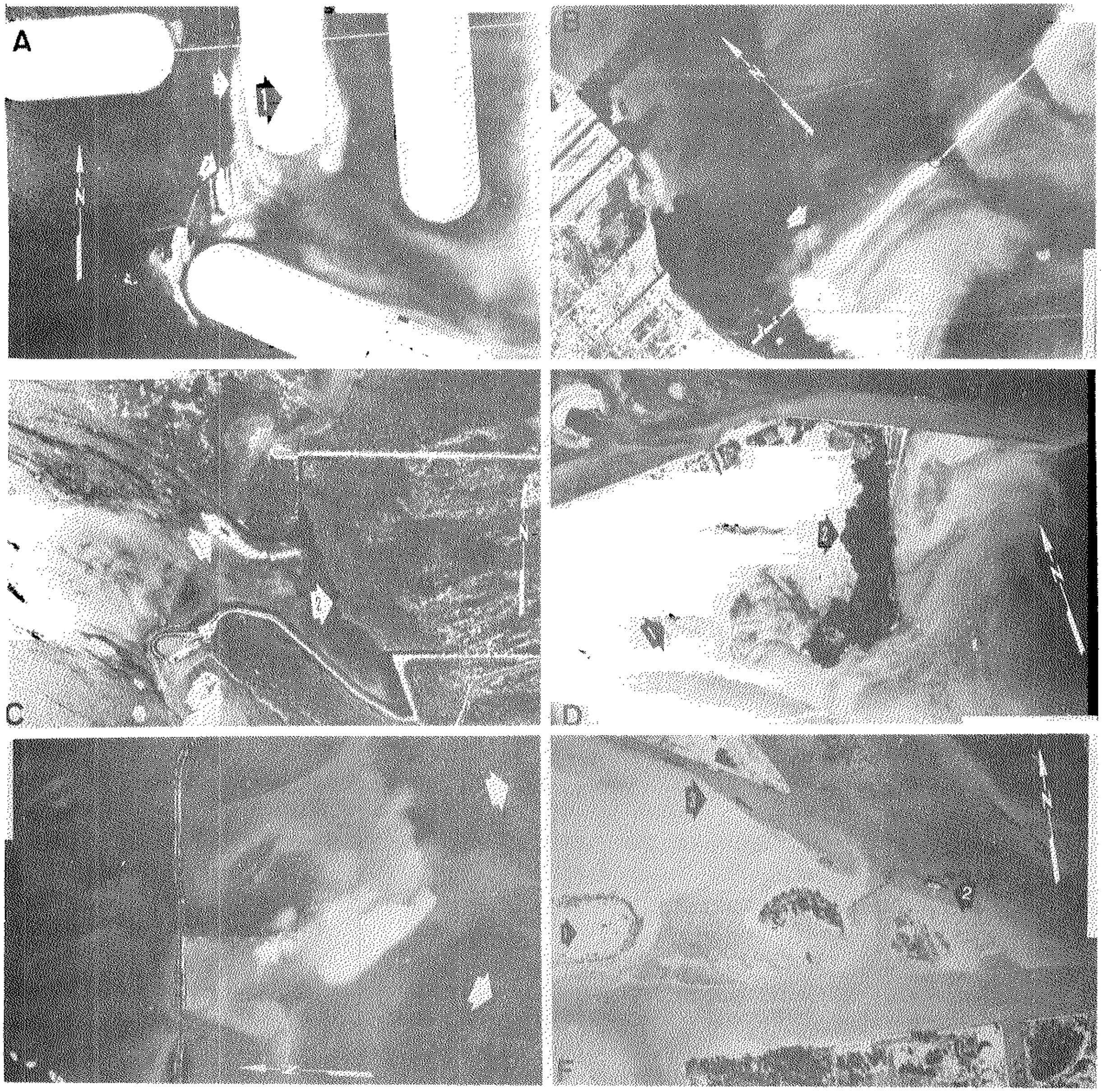
Figure 14. Coastal damage from the 1926 hurricane: A: October 1926 view of Bakers Haulover Cut which had been recently opened. Note the flattened mangroves at lower left (1) and the upright, but defoliated, trees north of the Cut (2) (Hoyt, 1687). B: 1928 view of Miami Beach shows a large building (arrow) left standing in the new surf zone of the eroded beach near 41st Street (NOAA, 687-111. Small circles and lines are artifacts).

is shown in Figure 15.

During the early 1950's the Everglades Flood Control Districts became operational in response to the hurricane floods of 1928 south of Lake Okeechobee. Broad Causeway was constructed at the same time while Julia Tuttle Causeway was finished in 1960. Dodge Island (Port of Miami) steadily grew from a line of spoil islands that first appear in the 1928 photographs. Major expansion (by dredge and fill) of Dodge Island occurred in the early 1960's and another is planned for the near future.

The most recent activities in the Bay have been limited to maintenance redredging of channels, the emplacement of cross-bay utility lines (gas, water, electric and sewer), and the continual increase in the number and size of marinas. Terrestrial developments have been continuous since 1925 except for an occasional slowdown during poor economic years. A new trend is appearing as many older bayshore dwellings are replaced by large, higher density condominiums and apartments. The effect of a concentrated human population located along the bayshore remains to be seen.

Northern Biscayne Bay has been shown to have pollution problems (Moore et al., 1955; Hela et al., 1957; McNulty, 1961, 1970; Austin, 1971; D'Amato, 1973; Buck, 1976; Sigel et al., 1976; Voss, 1976; Thorhaug, 1976; Waite, 1976; Lee and McGuire, 1973). In spite of this knowledge, no changes have been seen in the aerial photographs that cannot be explained by other processes, but since large areas in northern Biscayne Bay have been directly affected by dredging, this failure to recognize pollution damage is not surprising. It should be noted that the majority of the original sample stations in the pollution study by Moore et al. (1955) are located in disturbed bottom areas. This factor may have been overlooked in



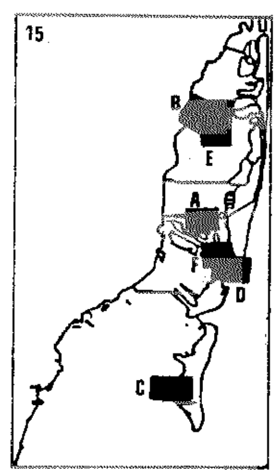


Figure 15. Dredging operations: A: 1925 view shows the final filling of San Marino Island (1). Sediment laden water can be seen leaking from the transport pipe (2) and running off of the island (3). (Miami-Dade Library). B: 1928 photomosaic shows turbid plumes emanating from the 79th Street Causeway during construction. Dredge is just below photo center (arrow) (NOAA, 697-465). C: 1925 view of dredge (1) in Hurricane Harbour. The original mangrove swamps on the bay side of Key Biscayne can be seen (2) (Miami-Dade Libary). D: 1925 view of the dredging of Vanderbilt Channel (1). This is the only known vertical aerial photograph of the original shape of Fisher Island (2) and shows a narrow beach backed by mangroves (Miami-Dade Libary). E: 1940 view of the initial filling of North Bay Island along 79th Street Causeway. Note the benthic vegetation of the cross-bay shoal just below the turbid plumes (arrows) (USGS, CJF-14-72). F: 1935 view of the filling of Lummus Island (1) with material dredged from the Miami Ship Channel (2). Turbidity (3) is moving to the northwest along MacArthur Causeway (NOAA, 119-100).

later pollution interpretations based on these stations.

During the course of this study an attempt was made to confirm the reported pollution problem that necessitated the opening of Bakers Haulover Cut (Michel, 1976; U.S. Army Corps of Engineers, 1946b). Hugh Smith (1896), states:

> "Even in the upper section an inlet seems to be needed which, while providing for a freer movement of the water, will at the same time prevent excessive freshening of the upper bay, which occasionally results from heavy rainfall in the Everglades and jeopardizes the oyster life. At a point known as 'Bakers Haulover', only a narrow piece of sandy land intervenes between the ocean and bay, a communication between could easily be established at little cost. The existence of such an inlet would doubtless greatly improve the general fishery resources of the entire bay, and is much desired by the people of the section."

He mentions nothing about pollution and the only health discussed is that of the local oysters. As to why the "people of the section" wanted a cut, we can only speculate that besides the hoped for improvement of local fisheries, a cut would shorten Bay to ocean travel times, allow larger vessels to operate further north, and increase local land values. According to the Corps of Engineers (1946b), the special act of the Florida Legislature, Chapter 9424 (No. 306) for 1923 authorized the opening of a cut through Bakers Haulover for the "public health". The act referred to is brief on the subject and states, "The opening, cutting and maintanence of said inlet is hereby found and declared to be necessary for the maintenance of the health of the inhabitants and for the convenience, comfort and welfare of said District, and the inhabitants thereof" (Florida Legislature, 1923). What was the reason for digging a cut through the narrow barrier island and forever changing upper bay ecology? Was it for the public health, or for the "convenience, comfort and welfare" of the local inhabitants? Of course there could have been early pollution in northernmost areas. Indeed, Simpson (1920) mentions the dumping of sewage into local streams, although he gives no details. But it is Simpson (1932) who describes "a scheme has long been urged to dig a channel across Bakers Haulover, at the head of Biscayne Bay, the claim being made that the waters of the upper bay were stagnant and that such a ditch would greatly freshen them and be the cause of better fishing for the tourists." Suffice to say here that how much pollution existed prior to 1925 when Haulover Cut was first dug remains to be proven. Further comments on pollution in the early development years can be found in Munroe and Gilpin (1930).

The 1926, 1929 and 1935 hurricanes that passed over south Florida have produced changes seen in the aerial photographs (Figures 14, 25, 31, 31). The following descriptions of these storms are intended as background for readers unfamiliar with South Florida hurricanes.

1926 Hurricane

The 1926 hurricane of September 14-22 advanced on South Florida at a rate of over 18 miles per hour until the 17th when it crossed the coast at Miami and slowed down to 11 miles per hour (Mitchell, 1927). The eye of the storm passed over Miami and Homestead at 6:45 on the morning of the 18th, passing just to the south of Little River (Simpson, 1932). Winds, reported by the local weather bureau, were 8 miles per hour the evening before, 57 miles per hour at 1:50 a.m. on the 18th, and had peaked at about 115 miles per hour (indicated) from the northeast at 5:00 a.m. when the instrument was blown into the street. An hour and one-half later, as the eye passed, the wind was variable at 10 miles per hour. Most of the 242 deaths attributed to this storm occurred after the eye passed as people were caught unprotected on the streets and causeways. At least one hundred million dollars of property damage was incurred in a period of hours. Between Ft. Lauderdale and Miami 4,725 homes were destroyed and another 9,100 damaged. The highest storm tide along Miami and Miami Beach bayshores coincided with the second phase of the storm, after the eye passed, as the 120 miles per hour plus wind changed direction to the east and southeast. Besides inundating the city of Miami Beach, a tidal surge in the Miami River wrecked large numbers of boats put there for safe anchorage. The storm tide in the Miami Canal at Hialeah reached 3 m (U.S. Army Corps of Engineers, 1946a). Storm tides of 2.3 m (7.5 feet) occurred north of MacArthur Causeway, 3.6 m (11.7 feet) at the Miami River mouth and 3.3 m (10.6 feet) at Miami Beach, both south of the causeway (Mitchell, 1927).

1929 Hurricane

The Great Nassau Hurricane of 1929 crossed over South Florida on September 28.

> "The morning reports of the twenty-eighth indicated that the hurricane was advancing through the Florida Straits with center almost due south of Miami. The northeast storm warnings south of Miami to Key West were changed to hurricane at 9:00

a.m., and northeast storm warnings were displayed north of Key West to Tampa. At 8:00 p.m. the center was about halfway between Key West and Ft. Myers and advancing northwestward over the Gulf of Mexico" (Mitchell, 1929).

At Miami maximum reported wind velocities were 56 miles per hour from the east. Winds at Key Largo were estimated at 150 miles per hour (Mitchell, 1929; Muir, 1953) and this storm was considered to be larger than the 1926 storm, there. The Miami Herald newspaper for the three days after the storm (the 30th, 1st and 2nd) recorded extensive damage to Homestead and noted that fish were literally thrown out of the heavy surf along Miami Beach. Tornadoes were reported from Miami and Ft. Lauderdale and 12 miles of roadbed of the "Overseas Railway" were damaged south of Florida City (Mitchell, 1929).

1935 Hurricanes

The 1935 hurricane season brought three hurricanes near Miami: the storms of September 2, 1935; September 28, 1935 and November 4, 1935. The first September storm called the "Labor Day Hurricane" devastated Key Largo and southernmost Biscayne Bay with winds in excess of 150 miles per hour (possibly over 200). The "Overseas Railway" was destroyed in many places by a "wall of water" that swept over the Upper Keys (McDonald, 1935). Peak winds at Miami of 40 miles per hour from the southeast followed high tide by about an hour. The Miami Herald (September 3, 1935) reported large waves breaking on the bayshore of Key Biscayne at Cape Florida.

The second 1935 storm, late in September, moved up the Straits of

Florida past Miami on the 28th. A 40 mile per hour wind from the northeast was recorded at Miami and maximum winds at Fowey Rock Light (southeast of Key Biscayne) were put at 75 miles per hour (Miami Herald, September 29, 1935). The eye passed at about 6 or 7 p.m. about an hour and a half before local high tide. The surf was reported to be heavy along the ocean beaches (Miami Herald, September 29-30, 1935).

The "Yankee Hurricane" came early in November the same year, moving in an unusual north to south direction. The eye produced a lull of an hour as it passed Miami where winds had reached 75 miles per hour. (Tannehill, 1945). As low tide was occurring (about 2:00 p.m.) the eye crossed the mainland south of Miami. By 2:15 p.m. The wind rose to 75-80 miles per hour from the southeast. The strength and direction of the winds pushed on an incoming tide which produced severe damage along most of the bayfront, destroyed the Miami Docks, tossed boats and barges onto land, and threw large rocks (from spoil?) up on to 79th Street Causeway (Miami Herald, November 4-5-6, 1935; Byers, 1935; Hurd, 1935).

THE MAJOR CHANGES IN NORTHERN BISCAYNE BAY

Figures 16 through 21 are three paired sets of interpretive maps. Figures 16, 18 and 20 are the "before" maps based on aerial photography from 1925 to 1940. Figures 17, 19 and 21 are the "after" maps that are interpreted from the 1976 aerial photography. Figures 16 and 17 show the before and after distribution of developed terrestrial areas. Figures 18 and 19 show the distibution of dredged, spoil and filled areas within the Bay. The filled areas are modified from maps in U.S. Department of Agriculture (1958). FIgures 20 and 21 show the distribution of benthic vegetation. The past or present shoreline is shown on each, and if the maps are removed from the text, they can be superimposed one upon the other for shoreline comparisons.

For ease of discussion, northern Biscayne Bay is divided into seven Areas (Figure 12). The west and east boundaries of the seven Areas are, in general, the Florida East Coast Railway on the crest of the mainland coastal ridge and the ocean surf zone, respectively. The approximate north and south boundaries are defined by the following:

Area I: North of Broad Causeway

Area II: Broad Causeway to 79th Street Causeway

Area III: 79th Street Causeway to Julia Tuttle Causeway (I-195)

Area IV: Julia Tuttle Causeway to Venetian Causeway

Area V: Venetian Causeway to MacArthur Causeway (I-395)

Area VI: MacArthur Causeway to Rickenbacker Causeway

Area VII: South of Rickenbacker Causeway

This division is totally arbitrary and based on convenient physical features (causeways). The same seven Areas are used when referring to the

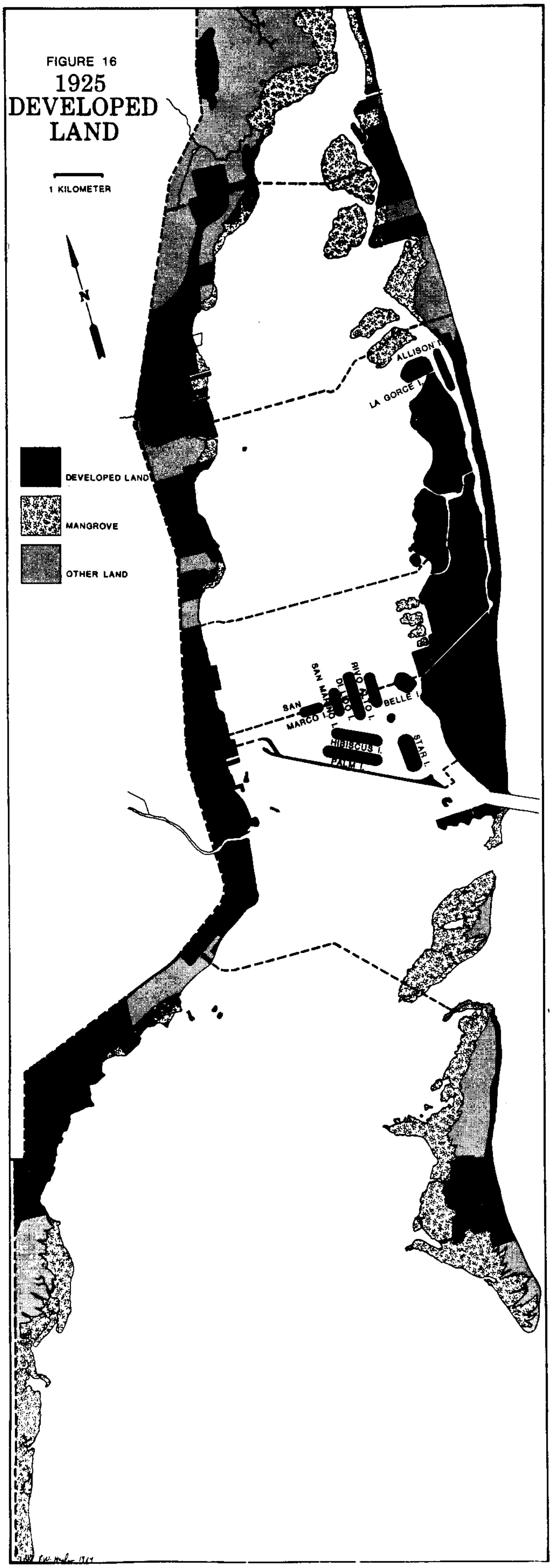


FIGURE 16
1925
DEVELOPED
LAND
1 KILOMETER
N
DEVELOPED LAND
MANGROVE
OTHER LAND
ALLISON I.
LA GORCE I.
SAN MARINO I.
DI LIDO I.
RIVO ALTO I.
BELLE I.
SAN
MARCO I.
HIBISCUS I.
PALM I.
STAR I.

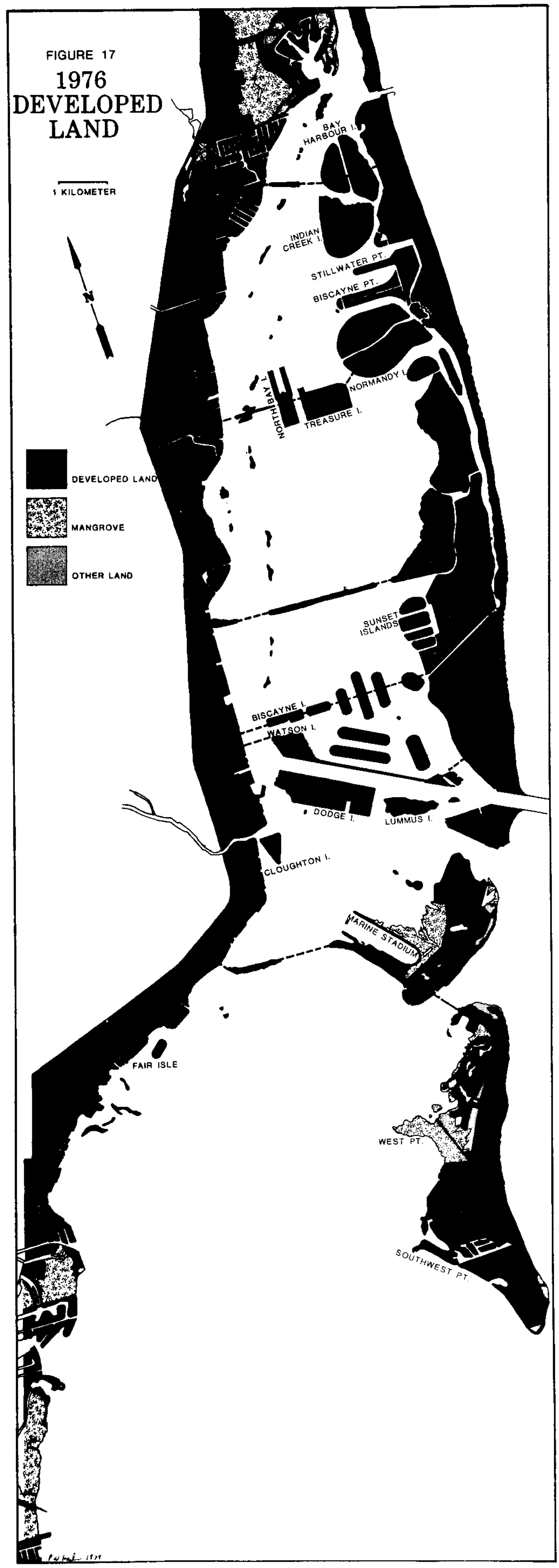


FIGURE 17
1976
DEVELOPED
LAND
1 KILOMETER
N
DEVELOPED LAND
MANGROVE
OTHER LAND
BAY
HARBOUR I.
INDIAN
CREEK I.
STILLWATER PT.
BISCAYNE PT.
NORMANDY I.
NORTH BAY I.
TREASURE I.
SUNSET
ISLANDS
BISCAYNE I.
WATSON I.
DODGE I.
LUMMUS I.
CLOUGHTON I.
MARINE STADIUM
FAIR ISLE
WEST PT.
SOUTHWEST PT.

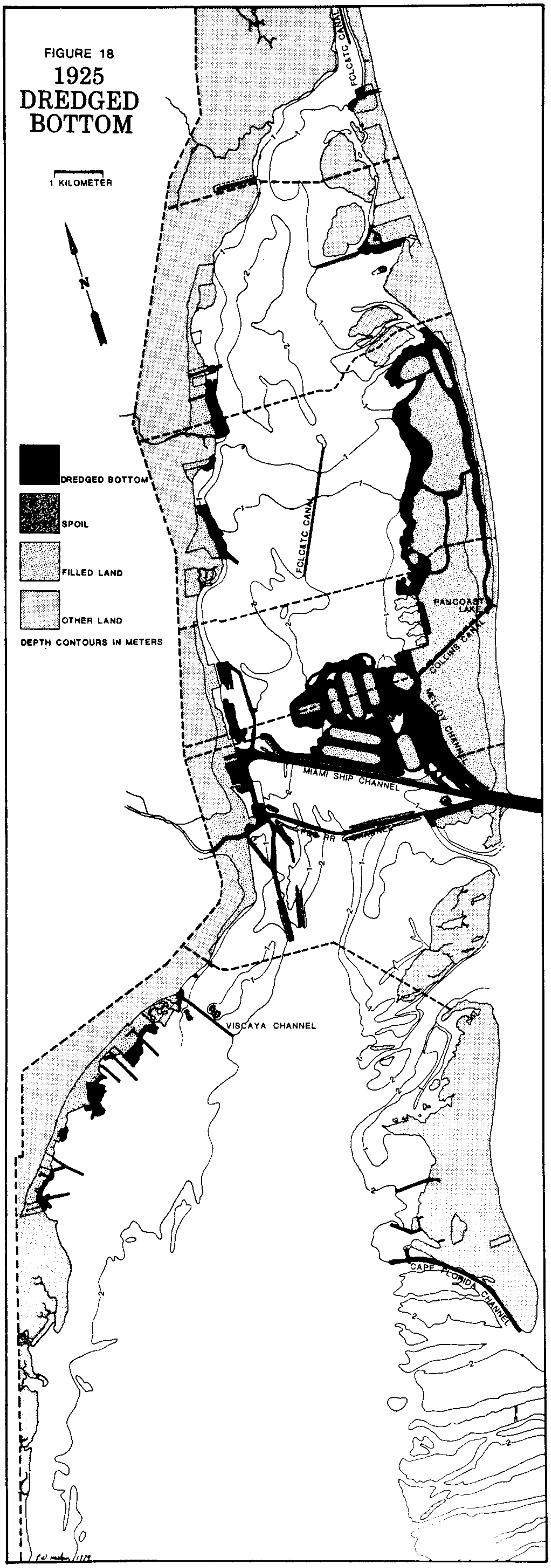


FIGURE 18
1925
DREDGED
BOTTOM
1 KILOMETER
N
DREDGED BOTTOM
SPOIL
FILLED LAND
OTHER LAND
DEPTH CONTOURS IN METERS
FCLC&TC CANAL
PANCOAST LAKE
COLLINS CANAL
MELLOY CHANNEL
MIAMI SHIP CHANNEL
VISCAYA CHANNEL
CAPE FLORIDA CHANNEL

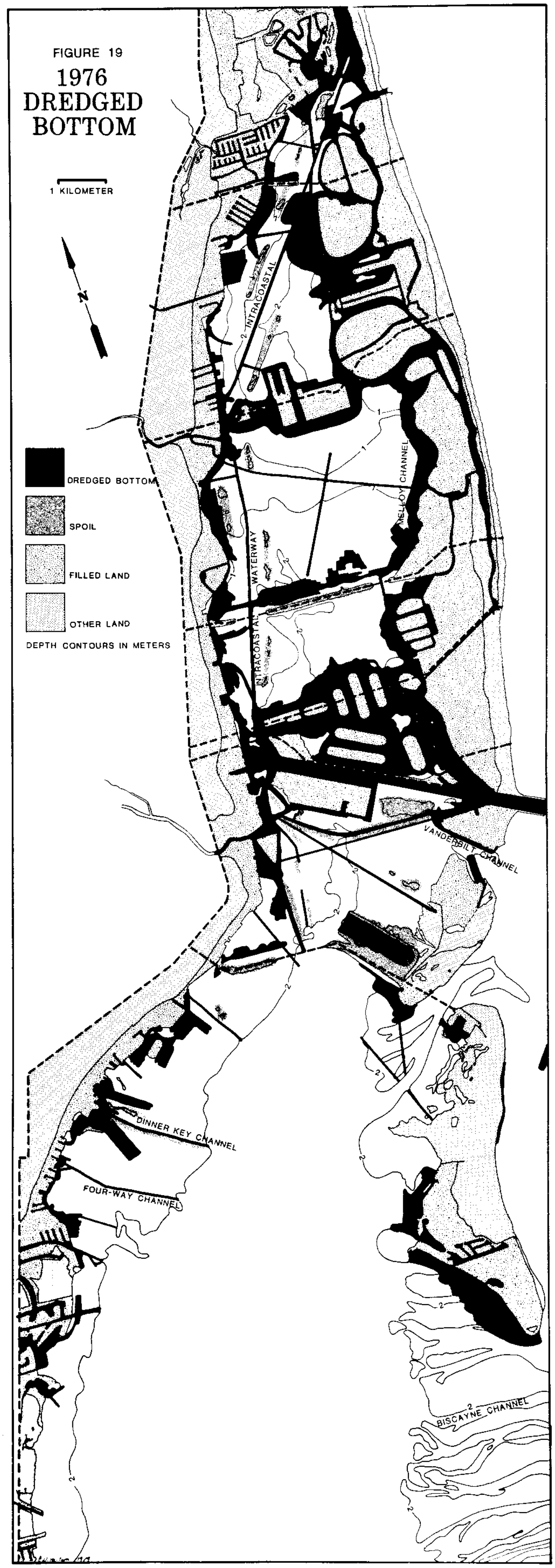


FIGURE 19
1976
DREDGED
BOTTOM
1 KILOMETER
N
DREDGED BOTTOM
SPOIL
FILLED LAND
OTHER LAND
DEPTH CONTOURS IN METERS
INTRACOASTAL
INTRACOASTAL
WATERWAY
MELLOY CHANNEL
VANDERBILT CHANNEL
DINNER KEY CHANNEL
FOUR-WAY CHANNEL
BISCAYNE CHANNEL

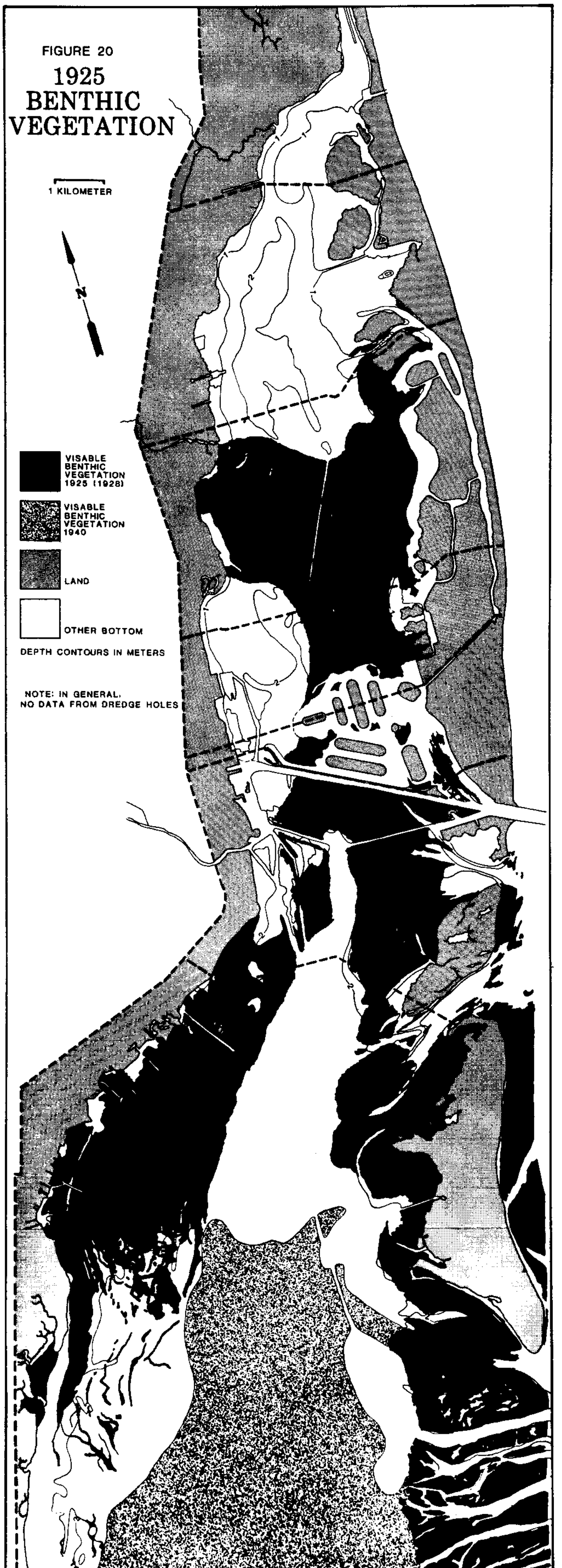


FIGURE 20
1925 BENTHIC VEGETATION

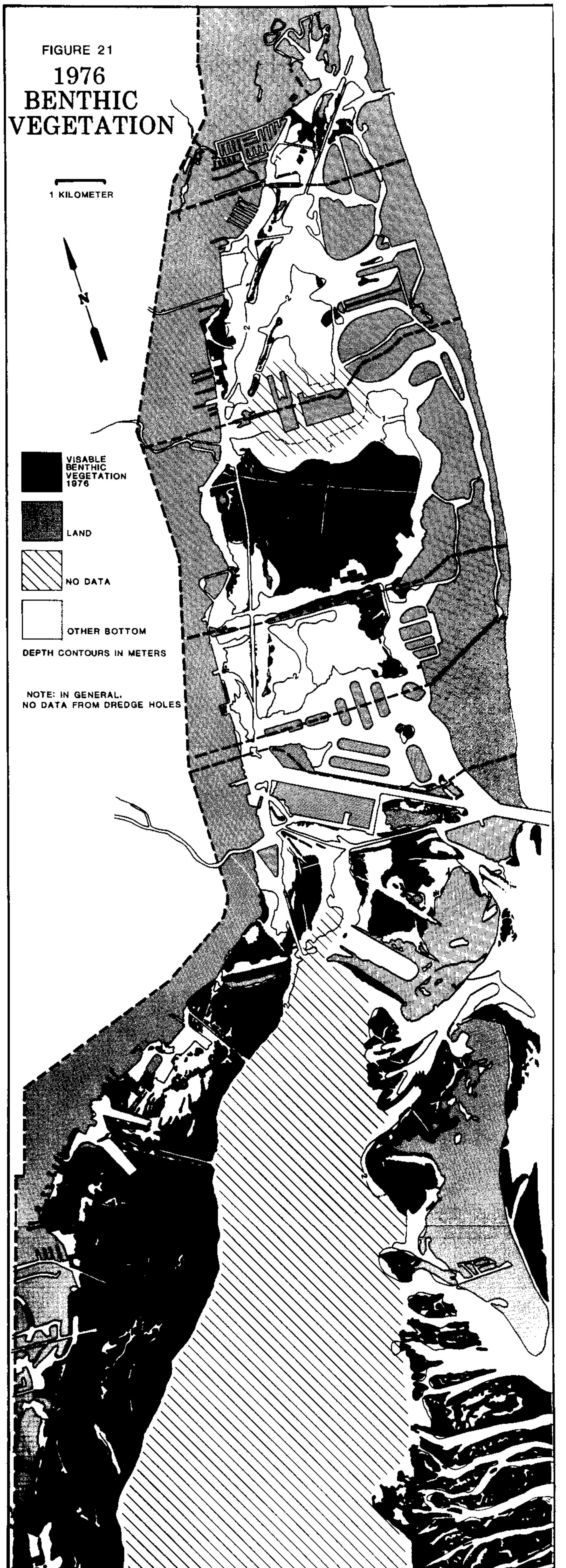


FIGURE 21
1976 BENTHIC VEGETATION

"before" maps even though many of the causeways were not constructed at the time. The author recognizes a danger that some readers will assumes that these artificial boundaries are real and thereby assume that an Area is a separate body of water. The seven Areas are connected to one another at breaks in the causeways.

The following sections describe major changes in selected features as interpreted from the aerial photography. Data discussed is presented in Tables 3 through 10 and was obtained by planimetering features shown in Figures 16 through 21. Shoreline data presented here was obtained from a redraft of the 1887 U.S. Coast and Geodetic Survey coast Chart #165 and therefore yields data from an essentially pristeen Bay and not the Bay of 1925. All other data spans the 1925-1976 period.

Measurements were made of the total area studied and all land and water areas within the boundaries described. North and south boundaries are the map edge and the limits of each of the seven Areas as described previously. It should be noted that many features had to be subjectively generalized during map production, and, to avoid possible misinterpretation of mapped data, the following definitions and qualifications should be understood:

1) Land area is that portion of the bay region that has surface elevations above mean low water level. This includes all mangrove and coastal swamps.

2) Developed land areas are those portions of the land area that have observable man-made features including but not restricted to buildings, roads (unimproved as well as improved), canals (excluding mosquito ditches), agriculture, forested timber (as

in many mangrove areas in 1925) and all exposed portions of spoil islands. Non-agricultural vegetated areas that have undergone changes in plant species as a result of human intervention are not mapped as developed land.

3) Mangrove areas are those portions of the land area that have living mangrove trees growing on them in sufficient abundance to be mapped at a scale of 1:40,000. Inevitably, small patches have been missed, but they should be more than made up for by the inclusion of small holes in mangrove areas mapped as mangrove.

4) Other land areas are those portions of the land that have not been developed and, if vegetated, are not mangrove.

5) Three types of shoreline have been identified.

   a) Mangrove shorelines are those having mangrove trees growing at the water's edge without an intertidal or supratidal beach visible in the air photographs. All mangrove vegetated coastline in 1887 is included here.

   b) Vertical bulkheaded shorelines are shorelines that have essentially vertical intertidal zones composed of rock or any of several artificial construction materials. Vertical rock outcrops, seawalls and bulkheads at the shoreline are included.

   c) Sloping shorelines are those having a sloping shore composed of unconsolidated sediment. All beaches are included here as are spoil islands and so called "rip-rap" (rubble) shorelines.

6) Open water area is that portion of Biscayne Bay covered by water at mean low tide. All waterways, canals and rivers having narrow openings to the bay are excluded. As an example, the present Interama property in Area I has a large, dredged central basin with many small "finger" canals leading from it. The central basin is included in open water area, but not the canals which are excluded from land areas as well.

7) Dredged bottom areas are those portions of the water area that were, at any previous time, increased in depth by dredging. No distinction is made for those areas that have regraded to original depths subsequent to the dredging. If they have been filled or buried with recognizable spoil, they are included in spoil bottom areas.

Dredging of submerged bottom lands in northern Biscayne Bay has produced a patchwork of poorly connected holes. The geomorphic pattern produced by this bottom modification is similar to the topographic pattern found in terrestrial areas with unreclaimed strip mines. Most have steep-sided "walls" and their bottoms range in depth from about 2 m to well over 10 m. The average is probably close to 3 m. Dredged holes vary in morphology but most are found along artificial shorelines. The following types of dredge holes are seen in the aerial photography:

a) Borrow pits are holes dug for the purpose of mining the bottom sediment for use as fill material or as an economic resource. Borrow pits dug for fill are morphologically diverse and many abutt against bulkheaded shorelines (Figure 22). Isolated borrow pits are usually associated with causeway construction. Borrow pits are especially common along the entire mainland shoreline (Figure 22b) and one can be found north of Rickenbacker Causeway (Figure 22d) and just north of Broad Causeway.

b) Shoreline channels are interconnected borrow pits which parallel a filled or spoil shoreline and are long enough to be used as a waterway by boats or ships. Much of Miami Beach is bordered by a shoreline channel (Melloy Channel). Other examples include Vanderbilt Channel, the Cape Florida Channel (Figure 22e) and the Julia Tuttle Causeway borrow pit.

c) Navigation channels (navigable waterways) are elongate trenches dredged to provide a traversable route through areas of shallow bay bottom. They are usually very narrow and most are straight. The Miami Ship Channel and Government Cut comprise the deepest and widest navigation channels in the Bay (Figure 15d, f). The Intracoastal Waterway (Figure 19) is the longest. The oldest, the abandoned Florida Coast Line Canal and Transportation Company Channel is still visible in Area III. The old FEC Railway Channel in Area VI (now called Fisherman's Channel) is easily located in the aerial photographs (Figure 35a).

d) Utility dredged lines usually take the form of a long,

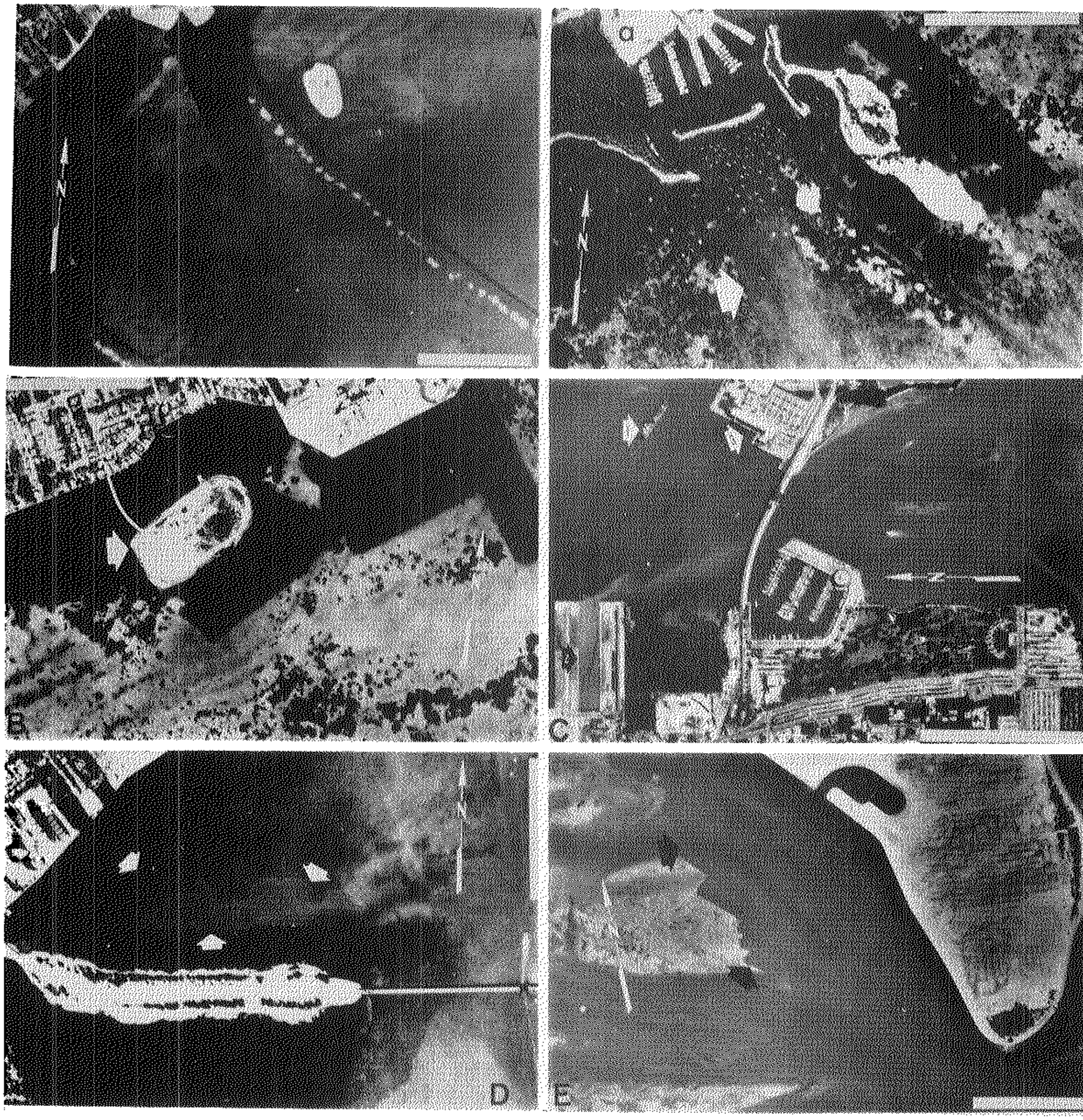
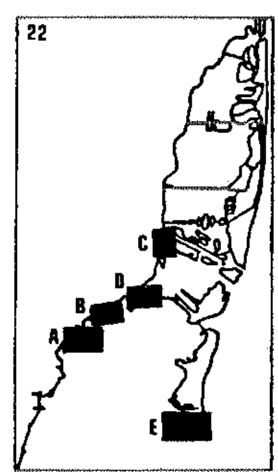


Figure 22. Holes produced by dredging: A: 1940-1976 photopair of Pan American seaplane operating basin at Dinner Key (arrow). This large feature is now partially used as a marina (USGS, CJF-14-82; Fla. Dept. Transportation, PD 1638-22-21). B: 1976 view shows dredge holes along mainland shore of Area VII. Fair Isle, a fill island, is in the center (arrow) (Fla. Dept. Transportation, PD 1638-22-23). C: 1973 view of active dredging in the Turning Basin (1) and infilling of old dock area north of Bayfront Park (2). Dodge Island is at the top (3) (Fla. Dept. Transportation, PD 1274-12-07). D: 1976 view of dredge hole created during the construction of Rickenbacker Causeway (arrows) (Fla. Dept. Transportation, PD 1638-21-26). E: 1951 view of Cape Florida Channel shows extensive dredge scars on bottom (arrow). South end of Key Biscayne was bulkheaded and filled the previous year. Filled area is now Bill Baggs State Park (USGS, 0-3621).



straight and very shallow trench dredged into the bottom. An electrical, gas, water and sewer pipeline is placed in the trench and often covered with sediment or buried by natural processes. These features can be seen as long, thin black lines crossing the Bay in Figure 19.

e) Dredged marinas are basins dredged to provide anchorage for boats or ships with drafts in excess of natural bottom depths (Figure 23). Actually few bayshore marinas are dredged for boat usage, since most marinas are built in previously dredged borrow pits which reduces construction costs. One feature, possibly unique to Biscayne Bay is the abandoned Pan American Airway Dinner Key seaplane landing strip. This large, shallow rectangular dredge hole is in part used as Dinner Key Marina. For a description of the landing strip as planned see the United States Army Corps of Engineers' report dated 1932 (Figure 22a).

f) Ship turning basins are dredged holes that are connected to navigable channels. They provide maneuvering room for large ships and, therefore, are dredged as deep as the largest channel to which they are attached. There are two ship turning basins in northern Biscayne Bay (Figure 25c).

8) Spoil bottom areas are those portions of the water area that have unconsolidated dredged material covering the preexisting bottom (whether original or dredged). Their boundaries in Figures 18 and 19 are generalized because it is rarely possible to determine

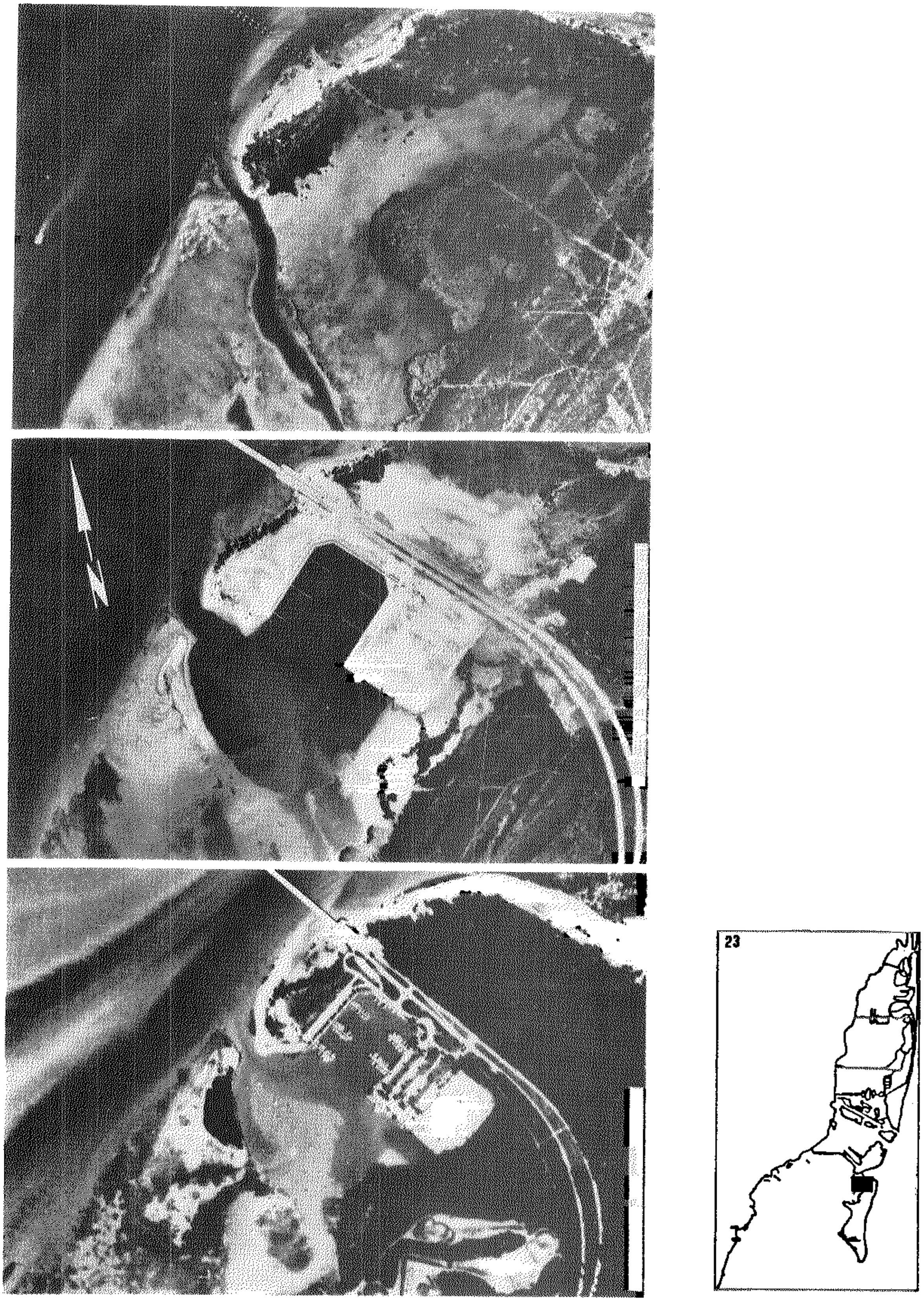


Figure 23. 1945-1951-1976 sequence of the north end of Key Biscayne The development of Crandon Marina can be seen (USGS, C-1616: USGS, 3625; Fla. Dept. Transportation, PD 1638-20-22).

the boundary between spoil and other bottom areas with any precision. Since some benthic plants can recolonize spoil, the boundary between the vegetation and bare spoil, although distinct in the photography, may not define the extent of the spoil.

9) Disturbed bottom area is the sum of all dredged bottom areas and all spoil bottom areas. Because these have been defined as a part of the open water area, total disturbed area does not include the exposed portions of man-made spoil islands and fill islands.

10) Benthic vegetation areas are those portions of the water area that have visible bottom vegetation. Since only visible vegetation is mapped, readers are cautioned not to interpret "other bottom" areas as devoid of benthic vegetation. This is not the case as some bare areas are bound by blue-green algal mats or very sparse macrofloras that are not visible in the photography. No distinction is made between different seagrass or algal species.

11) "Grass" index is defined as the total benthic vegetation area, as observed in the aerial photographs, divided by the total amount of undisturbed bottom area and expressed as a percent. The "grass" index can be expressed by a formula as follows:

$$V = \frac{BV}{U} \times 100$$

where V = the "grass" index

BV = the total area of mapped benthic vegetation

U = the total undisturbed bottom area (total open water area minus the total disturbed area)

This index is used to assess the extent to which various vegetation types utilize the remaining natural bay bottom in each Area. However, since no distinction has been made between plants growing on spoil (disturbed bottom) and plants growing on undisturbed bottom, the "grass" index is not a pure number. There may be less natural bottom colonized by benthic plants than the index would indicate, although, since spoil areas are generally small, the difference is usually less than 5%.

The Major Changes by Area

Area I

Area I covers about 12.6 sq km of which 9.5 km^2 (75%) are land areas and about 3 km^2 are open water in 1925 (Table 3). By 1976, 0.6 km^2 of land have been converted to water area, principally due to canal construction and dredging of the Interama property.

The 1.5 km^2 of developed land in 1925 (at Bal Harbour) increases to 7.5 km^2 in 1976 which is 85% of the present land area. In 1925, 2.6 km^2 of mangroves lined the bayshore, but by 1976 this acreage has been reduced to 1.4 km^2, a reduction of 46%. The majority of the living mangroves on the Interama property occur in what was a freshwater marl prairie in 1925 (Teas et al., 1976).

There has been a slight increase in shoreline length from 10.4 km^2 to 11.1 km, since 1887. The entire shoreline of Area I was mangrove lined in 1887 (U.S. Coast and Geodetic Survey, 1887) whereas only 0.4 km (4%) of mangrove shoreline is seen in the 1976 photographs. Forty-one percent of

Table 3

Area I -- North of Broad Causeway

Total Area 12.6 km^2

Percent of Northern Biscayne Bay 6%

	A		B		(B-A)	$\frac{B-A}{A}(100)$
	km^2	%	km^2	%	km^2	%
Total Land	9.5	75	8.9	70	- 0.6	-6
Developed	1.5	16	7.5	85	6.0	400
Mangrove	2.6	27	1.4	15	- 1.2	-46
	C		B		(B-C)	$\frac{B-C}{C}(100)$
Total Shoreline	10.4	13	11.1	6	0.7	7
Mangrove	10.4	100	0.4	4	-10.0	-96
Vertical/Bulkhead	0		6.1	55	6.1	
Sloping	0		4.6	41	4.6	
	A		B		(B-A)	$\frac{B-A}{A}(100)$
Total Water Area	3.1	25	3.1	25	0	
Dredged	0.3	9	2.0	65	1.7	567
Spoil	<0.1	1	0.1	4	<0.1	>100
Disturbed	0.3	10	2.1	69	1.8	600
Benthic Vegetation	0		0.3	10	0.3	
"Grass" Index	0		28%			

A = 1925
B = 1976
C = 1887

the present shoreline in Area I is sloping and 55% (6.1 km) is bulkheaded.

Dredging of the Florida Coast Line Canal and Transportation Company Canal and work on the as-yet unopened Bakers Haulover Cut had disturbed 0.3 km^2 of the bay bottom in Area I as of 1925. Sixty five percent (2.0 km^2) of the present bottom has been dredged and about 4% (0.1 km^2) covered with spoil for a total of 69% of the bottom. This is the second highest percent of disturbed bottom by Area in the Bay.

In spite of the extensive bottom modifications, there has been a net increase in benthic vegetation since 1925 (Figure 24). The "grass" index has increased from zero to 28%. This is largely related to the opening of Bakers Haulover Cut in 1925 and the resulting changes in water chemistry and circulation.

In summary, Area I is the only Area to show a significant increase in open water area, which is largely the result of the Interama dredging. The only substantial mangrove community north of MacArthur Causeway is found at Interama (Figure 17), but most of the trees are not isolated from the present shoreline. A large percent of the original mangrove coastline has been convereted to sand and spoil beaches (sloping shoreline) while the majority (55%) of the shoreline is now bulkheaded. Only Area V has a higher percentage of disturbed bottom, yet the aerial photography shows a significant increase in the amount of benthic vegetation. The increase in Area I's grass index results from the colonization of the shallower undredged Bay bottoms after the opening of Bakers Haulover in 1925.

Area II

Area II comprises 23.3 km^2 which is split relatively evenly between

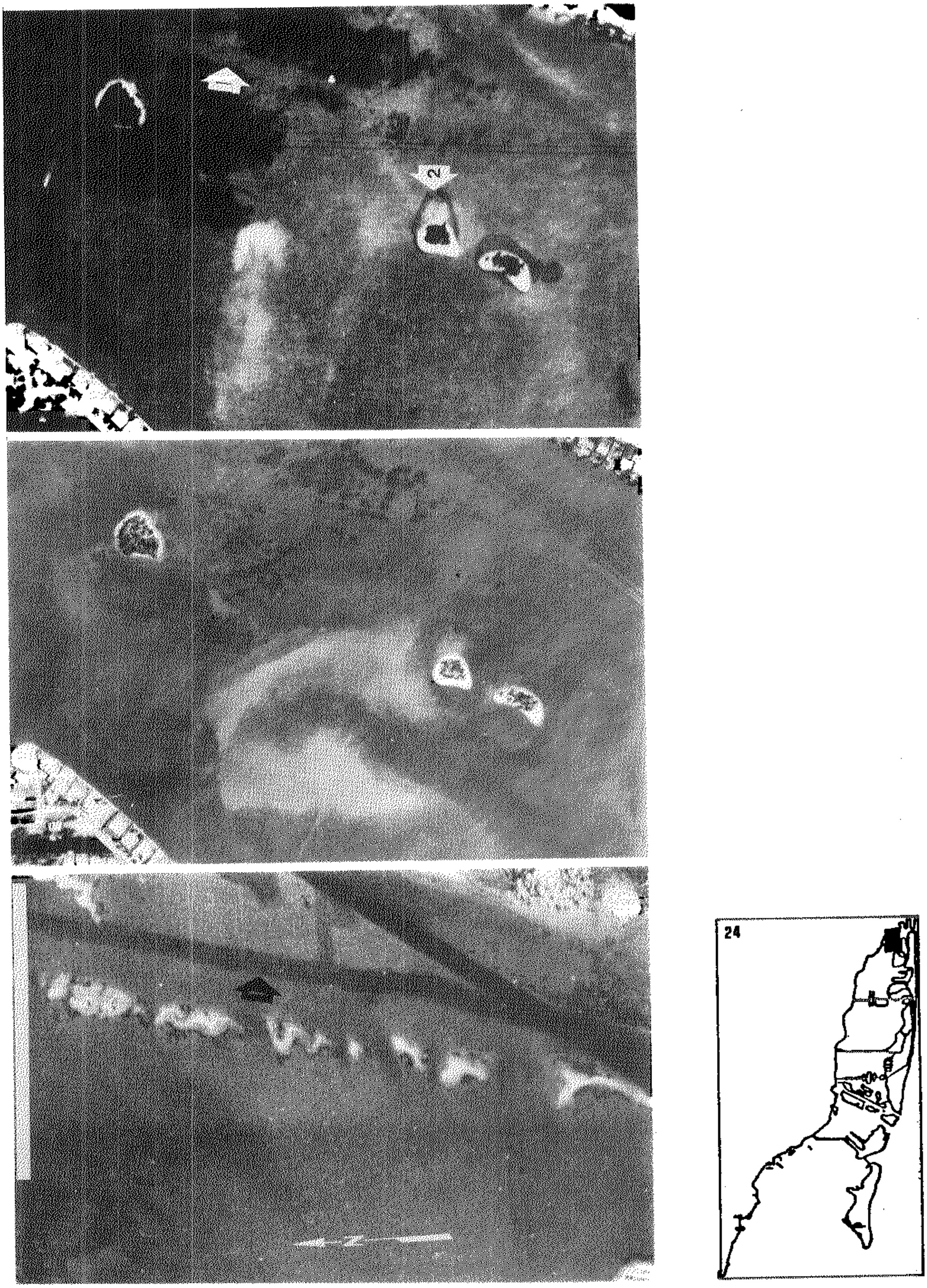


Figure 24. 1940-1973-1976 sequence from Area I. Benthic vegetation increases significantly on both sides of the abandoned waterway (1). The long row of spoil islands seen in 1940 is not seen in later photos. Note the dense vegetation growing on the submerged portions of the two small spoil islands (2) in 1976 (see Figure 33) (USGS, CJF-15-02; Fla. Dept. Transportation, PD 1274-14-13; Fla. Dept. Transportation, PD 1628-21-35. Thin vertical black lines are artifacts).

land and water areas (Table 4). Since 1925 fill island construction has increased land area from 9.3 km^2 to slightly more than 12 km^2 in 1976. Open water area has been reduced by 25% due to the construction of North Bay Village, Stillwater and Biscayne Points, and the enlargement of Normandy and Indian Creek Islands.

Seventy-two percent of the available land in 1925 had been developed, but by 1976 the entire 12 km^2 is modified for human use. The thin mainland mangrove swamps and those that once dominated the eastern shores of Area II, were reduced to 1.6 km^2 by 1925 and entirely eliminated by 1976.

Island construction and expansion has increased the shoreline length of Area II from about 15 km to 29.3 km, a 93% increase. The present shoreline comprises 5.4 km (18%) of sloping intertidal shoreline and 23.9 km (82%) bulkheaded shoreline. Area II has the largest percentage of bulkheaded shoreline in northern Biscayne Bay.

Thirty-eight percent (3.9 km^2) of the present day bottom in Area II has been dredged, up from only 4% in 1925. Spoil covers about 5%. The greatest natural depths north of MacArthur Causeway and exclusive of Indian Creek occur in Area II. A depth of 2.4 m (8 feet) is found on the 1887 nautical chart (U.S. Coast and Geodetic Survey, 1887) a short distance northeast of Little River, just above 79th Street Causeway.

Area II also shows a net increase in benthic vegetation since 1925. In 1925 only one percent of the bottom had visible plant cover while today this figure is up to 11% (1.2 km^2). There was more benthic cover by 1928 than there is presently, because large portions of the more shallow eastern half of Area II were still undisturbed. Dredging along Miami Beach after 1928 eliminated grass and algal beds that had colonized these shallow

Table 4

Area II -- Broad Causeway to 79th Street Causeway

Total Area 23.3 km^2

Percent of Northern Biscayne Bay 11%

	A		B		(B-A)	$\frac{B-C}{C}(100)$
	km^2	%	km^2	%	km^2	%
Total Land	9.3	40	12.1	52	2.8	30
Developed	6.8	72	12.1	100	5.3	78
Mangrove	1.6	17	0		- 1.6	-100
	C		B		(B-C)	$\frac{B-C}{C}(100)$
Total Shoreline	15.2	19	29.3	17	14.1	93
Mangrove	15.2	100	0		-15.2	-100
Vertical/Bulkhead	0		23.9	82	23.9	
Sloping	0		5.4	18	5.4	
	A		B		(B-A)	$\frac{B-A}{A}(100)$
Total Water Area	13.6	58	10.2	44	- 3.4	-25
Dredged	0.6	4	3.9	38	3.3	550
Spoil	<0.1	0.3	0.5	5	>0.4	>1000
Disturbed	0.6	4	4.4	43	3.8	633
Benthic Vegetation	0.1	1	1.2	11	1.0	1000
"Grass" Index	10.9%		18.9%		8.0%	

A = 1925
B = 1976
C = 1887

bottoms following opening of Bakers Haulover Cut. The "grass" index increases from 10.9% in 1925 to 18.9% today.

In summary, Area II has more land now than in 1925; all of the present land is developed. The original mangrove shoreline has been replaced by one that is largely bulkheaded and twice as long. Over 40% of the present Bay bottom has been disturbed, in spite of which there has been a significant increase in benthic vegetation. Slightly less than 20% of the undisturbed bottoms in Area II are covered with benthic plants in 1976, up from less than 1% in 1925.

Area III

Area III incorporates 26.5 km^2 of which about two-thirds is open water area (Table 5). Land area has been increased by 11% (8.3 to 9.2 km^2) since 1925 and open water area has decreased correspondingly. Most of this change is attributed to the construction of the 79th Street Causeway, the attached North Bay Village Islands, Julia Tuttle Causeway, and the enlargement of Normandy Isle, Allison Island in Indian Creek, and the Mt. Sinai Hospital grounds.

In 1925, 84% of the land area in Area III was partially developed or completely altered. Only 5% (0.4 km^2) of the 1925 land area had living mangroves with most of these growing on the undisturbed southern Normandy Isle. Today, the entire land area of Area III is developed.

Since 1887 shoreline length has increased from 8.3 km of mangrove shoreline to 25. 2 km. Eight kilometers of presnt shoreline is sloping; 17.2 km (68%) is bulkheaded. The sloping shoreline here consists almost entirely of unconsolidated spoil that lines a portion of 79th Street

Table 5

Area III -- 79th Street Causeway to Julia Tuttle Causeway

Total Area 26.5 km^2

Percent of Northern Biscayne Bay 12%

	A		B		(B-A)	$\frac{B-A}{A}(100)$
	km^2	%	km^2	%	km^2	%
Total Land	8.3	31	9.2	35	0.9	11
Developed	7.0	84	9.2	100	2.2	31
Mangrove	0.4	5	0		- 0.4	-100
	C		B		(B-C)	$\frac{B-C}{C}(100)$
Total Shoreline	8.3	10	25.2	15	16.9	204
Mangrove	8.3	100	0		- 8.3	100
Vertical/bulkhead	0		17.2	68	17.2	
Sloping	0		8.0	32	8.0	
	A		B		(B-A)	$\frac{B-A}{A}(100)$
Total Water Area	18.2	69	15.9	60	- 2.3	-13
Dredged	3.5	19	4.3	27	0.8	23
Spoil	<0.1	0.3	0.1	1	<0.1	>100
Disturbed	3.6	20	4.4	28	0.8	22
Benthic Vegetation	11.6	64	7.9	50	- 3.7	-32
"Grass" Index	79.6%		68.2%		11.4%	

A = 1924
B = 1976
C = 1887

Causeway, Julia Tuttle Causeway and the numerous spoil islands along the Intracoastal Waterway. Bird Key opposite Little River, was an original mangrove island that has subsequently been enlarged with spoil.

Area III now has 15.9 km^2 of open water area, down from its 18.2 km^2 in 1925. Nineteen percent of the bottom was dredged by 1925. This figure has increased to 27% (4.3 km^2). The total amount of disturbed bottom has increased since 1925 from 20 to 28%.

Early maps and aerial photographs show a broad shoal that crosses Area III from the Little River on the west to Mt. Sinai Hospital on Miami Beach. This shoal is similar in form to Cutter Bank and Card Bank dividing Card Sound (in southern Biscayne Bay). Most of this shallow (1-2 m deep) bottom remains intact, although it is isolated by channels dredged along the perimeter. The cross-bay shoal had sparse and patchy benthic plant cover in 1925 which since has become lush (Figure 25a). Most of the shoal retains a lush cover of algae and seagrass today, but the northeast corner is less dense as is the southeast corner in Area IV.

Figure 20, the "before" vegetation map, was compiled with a composite of 1925 and 1928 aerial photographs because the 1925 surveys pictures of the center of Area III no longer exist. The combined photography shows that 64% of the bottom (11.6 km^2) was vegetated but most of the plant cover was extremely sparse in 1925 (Figure 25a); the "grass" index was 79.6%. Today 50% of the bottom is still vegetated by generally lush growth and the "grass" index is 68.2%. Area III has the highest "grass" index value for northern Biscayne Bay, in spite of complete coastal development and moderate dredging adjacent to the floral beds.

In summary, Area III has increased slightly in land area while all of

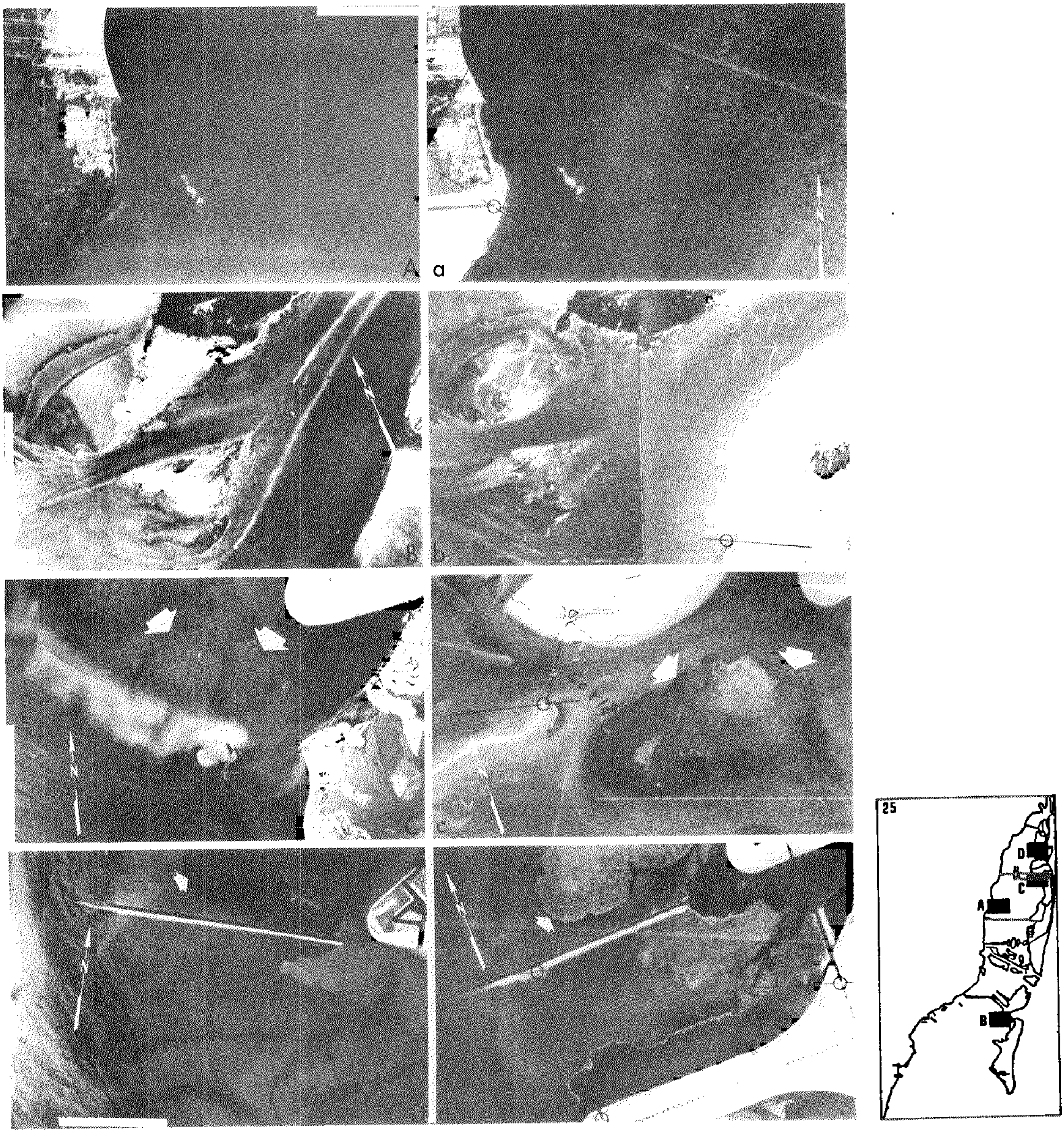


Figure 25. Changes in benthic vegetation: A: 1925 (left photo) and 1928 photopair of vegetated cross-bay shoal. New vegetation is very even and moderatly lush in 1928. Right photograph shows that vegetation does not extend into the deeper water to the south (Miami-Dade Library; NOAA, 697-461). B: 1925-1928 photopair shows erosion of tidal banks and seagrasses in Bear Cut by the 1926 hurricane (Miami-Dade Library; NOAA, 687-123. White lines on upper photos are artifacts). C: 1925-1928 photopair shows the increase in benthic vegetation in Area III after the opening of Bakers Haulover Cut, to the north. Original sparse patchy vegetation is lush and very even after three years (arrow) (Miami-Dade Library; NOAA. 687-465). D: 1925-1928 photopair shows the growth of new benthic vegetation on previously bare shallow bottom south of Indian Creek Island. Note that the vegetation is zoned in 1928 which indicates that more than one plant species is involved. Indian Creek Island is seen in original mangrove form but the trees are defoliated after the 1926 hurricane(arrows) (Miami-Dade Library; NOAA, 697-467). E: 1925-1928-1932 sequence of the Safty Valve banks just south of Key Biscayne. The lush plant cover seen in 1925 and 1928 shows severe erosional setback in 1932 from the effects of the 1929 hurricane (Miami-Dade Library; NOAA, 687-129; NOAA, 806-108, -110, -112).

the land is now developed. Shoreline length has nearly tripled, and bulkheads have largely replaced the original mangrove shorelines. Dredging disturbed about one third of the bottom, principally along the Bay margins. A shallow cross-bay shoal remains upon which grows most of Area III's abundant benthic vegetation. The "grass" index of 68.2% is the highest in the study area.

Area IV

In 1925, Area IV's 13.1 km^2 of total area was 35% land and 62% open water (Table 6). By 1976 land area had increased to 43% (5.6 km^2) and open water declined to 55%.

Ninety-two percent of the land area was developed prior to 1925, so there is very little change by 1976 when 100% is developed. Area IV has lost 0.4 km^2 of mangrove since 1925, however the total amount lost since 1887 must be greater as much of the bayshore of Miami Beach was mangrove swamp.

In 1887 Area IV had 6.7 km of mangrove shoreline (U.S. Coast and Geodetic Survey, 1887). An 8.7 km increase (for a total of 15.4 km) in total shoreline length by 1976 was the result of the construction of islands on the Venetian Causeway and Julia Tuttle Causeway. Sixty-five percent of the present shoreline is bulkheaded and 35% is sloping.

The reduction in water area is the result of dredge and fill projects. By 1925, 21% of the Bay bottom around Miami Beach and along the Venetian Causeway had been dredged. Thirty-one percent of the present bottom is disturbed.

There has been a sharp decrease in bottom vegetation in Area IV since

Table 6

Area IV -- Julia Tuttle Causeway to Venetian Causeway

Total Area 13.1 km^2

Percent of Northern Biscayne Bay 6%

	A		B		(B-A)	$\frac{B-A}{A}(100)$
	km^2	%	km^2	%	km^2	%
Total Land	4.5	35	5.6	43	1.1	24
Developed	4.2	92	5.6	100	1.4	33
Mangrove	0.4	8	0		- 0.4	-100
	C		B		(B-C)	$\frac{B-C}{C}(100)$
Total Shoreline	6.7	8	15.4	9	8.7	130
Mangrove	6.7	100	0		- 6.7	-100
Vertical/Bulkhead	0		10.0	65	10.0	
Sloping	0		5.4	35	5.4	
	A		B		(B-A)	$\frac{B-A}{A}(100)$
Total Water Area	8.1	62	7.2	55	- 0.9	-11
Dredged	1.7	21	2.2	30	0.5	29
Spoil	0		0.1	1	0.1	
Disturbed	1.7	21	2.2	31	0.5	29
Benthic Vegetation	2.9	36	0.5	7	- 2.4	-83
"Grass" Index	45.1%		9.4%		35.7%	

A = 1925
B = 1976
C = 1887

1925. Now only 7% (0.5 km^2) of the bottom is covered where as 36% was vegetated in the earlier photographs. The "grass" index has gone from 45.1% to only 9.4%. Most of the present benthic cover is located in the northeast corner of Area IV on the eastern end of the cross-bay shoal discussed previously. This cover has been diminishing and thinning since at least 1973.

In summary, Area IV's entire coastal land area has been developed and filling has produced a slight decrease in open water area. The orignal mangrove shoreline has been replaced by one that is more than twice as long and essentially bulkheaded. Thirty-one percent of the present bottom is disturbed. Area IV has very little benthic cover, and it, therefore, has the lowest "grass" index in the study area. There are large quantities of bottom here that have not been dredged or covered with spoil and that support little or no macro vegetation.

Area V

Area V is the location of the earliest major modifications in northern Biscayne Bay both on Miami Beach and downtown Miami. It is the focal point of most of the urban modification prior to 1925 and is directly adjacent to the Miami Harbor complex of artificial channels and islands in Area VI. The present 4.6 km^2 of land is entirely developed as was 99% of 1925's 4.3 km^3 (Table 7). None of the mangroves growing along the bayshore in 1887 remained in 1925, though they were still extensive prior to the late 1910's when Miami Beach construction started.

A total of 3.1 km of shoreline in 1887 has been increased to the present 19.6 km of which 78% is bulkheaded. This impressive 532% increase

Table 7

Area V -- Venetian Causeway to MacArthur Causeway

Total Area 8.3 km^2

Percent of Northern Biscayne Bay 4%

	A		B		(B-A)	$\frac{B-A}{A}(100)$
	km^2	%	km^2	%	km^2	%
Total Land						
Developed	4.3	52	4.6	55	0.3	7
Mangrove	4.3	99	4.6	100	0.3	7
	C		B		(B-C)	$\frac{B-C}{C}(100)$
Total Shoreline	3.1	4	19.6	11	16.5	532
Mangrove	3.1	100	0		- 3.1	100
Vertical/Bulkhead	0		15.4	78	15.4	
Sloping	0		4.3	22	4.3	
	A		B		(B-A)	$\frac{B-A}{A}(100)$
Total Water Area	4.1	49	3.7	44	- 0.4	-10
Dredged	3.1	76	3.5	93	0.4	13
Spoil	<0.1	1	0.1	0.2	<0.1	<100
Disturbed	3.1	77	3.5	94	0.4	13
Benthic Vegetation	0.7	17	0.1	2	- 0.6	-86
"Grass" Index	75.4%		25.0%		50.4%	

A = 1925
B = 1976
C = 1887

dramatizes the fill island construction activity focused in this area. The 1887 shoreline was entirely mangrove as was Belle Isle (Bulls Island in Lummus, 1940).

Because most of the development in Area V predates 1925, there is little change seen here since then. Intense pre-1925 dredge and fill activity disturbed 77% of the bay bottom. By 1976, 94% of the bottom is directly altered by dredging and the dumping of spoil.

Only 17% of the bottom between the Bay's first two causeways (Venetian and MacArthur) had benthic vegetation in 1925. Today about a 2% cover is growing on what is left of the original bottom and on spoil. Even though Area V's bottoms were well modified in 1925, the "grass" index was 75.4% while today it is only 25%.

In summary, Area V is the most modified area in northern Biscayne Bay. Its shores are entirely developed, and the shoreline, over five times longer than in 1887, is four-fifths bulkheaded. Ninety-four percent of the present bottom is disturbed, most of which occurred prior to 1925. There remains very little visible benthic vegetation growing on the unaltered 6%. The "grass" index has dropped sharply since 1925.

Area VI

Downtown Miami is located at the west side of Area VI's 23.8 km^2, just north of the Miami River. Only 27% of the total area was land in 1925, but the construction of two causeways, Fisher Island, the Marine Stadium on Virginia Key and the Port of Miami on Dodge Island have added 67% more land (Table 8). Dodge Island is presently being expanded, and a future enlargement of the Port of Miami is planned to include Lummus Island.

Table 8

Area VI -- MacArthur Causeway to Rickenbacker Causeway

Total Area 23.8 km^2

Percent of Northern Biscayne Bay 11%

	A		B		(B-A)	$\frac{B-A}{A}(100)$
	km^2	%	km^2	%	km^2	%
Total Land	6.4	27	10.7	45	4.3	67
Developed	3.9	60	10.2	96	6.3	162
Mangrove	1.9	30	0.5	4	- 1.4	-74
	C		B		(B-C)	$\frac{B-C}{C}(100)$
Total Shoreline	9.8	12	31.5	18	21.7	221
Mangrove	7.8	80	1.1	3	- 6.7	-86
Vertical/Bulkhead	0.6	6	14.8	47	14.2	2367
Sloping	1.5	15	15.6	50	14.1	940
	A		B		(B-A)	$\frac{B-A}{A}(100)$
Total Water Area	17.4	73	13.0	55	- 4.4	-25
Dredged	1.3	8	3.3	25	2.0	154
Spoil	0.3	2	1.1	9	0.8	266
Disturbed	1.7	10	4.4	34	2.7	158
Benthic Vegetation	10.2	59	3.5	27	- 6.7	-66
"Grass" Index	64.7%		37.0%		27.7%	

A = 1925
B = 1976
C = 1887

In 1925, 60% of the land area was developed while 30% remained mangrove. By 1976 these totals changed to 96% developed and 4% mangrove. Then as now most of the mangroves were located on Virginia Key; a few were growing on the south spit of Miami Beach (now Fisher Island; Figure 15d).

The shoreline length has increased from 9.8 km to 31.5 km since 1887. The old shoreline was 80% mangrove, 15% sloping beaches, and the rest rocky (vertical/bulkheaded). The latter is an extension of the Miami Oolite ridge that once outcropped at the shoreline just north of Coconut Grove (see photographs in Parks, 1977). Area VI's present shoreline comprises 14.8 km of bulkheads (47%), 15.6 km of sloping shoreline (50%) and 1.1 km of mangrove (3%). This is the only Area that has more sloping shoreline than it has bulkheaded shoreline.

Water area in Area VI has decreased through time due to island and causeway construction. Dredging of deep water ship channels to connect from the ocean to the Miami River had disturbed 10% of the 1925 bottom. The Miami Ship Channel, two turning basins, their connecting channels, the Intracoastal Waterway, the Marine Stadium and various subsurface utility pipelines have raised the total of disturbed bottom to 34%.

Benthic vegetation drops sharply from 59% of the 1925 bottom to only 27% in 1976. Area VI's "grass" index has dropped correspondingly from 64.7% in 1925 to 37% in 1976. This change is largely attributable to the loss of seagrass beds that once covered the shallow bottom just west of Norris Cut.

Area VI has become the focus of man's activity since the early 1920's, whereas Area V was the focus prior to 1925. Fully half of all the land created by man since 1925 lies in Area VI, most of it associated with port construction. With the exception of a small tract of mangroves on Virginia Key, all the coastal land had been developed. Shoreline length has increased by more than 200%, and about half of the present shoreline is bulkheaded and half is sloping sand and spoil beaches. Over one-third of the present bottom is disturbed and more than half of the seagrass and algal beds visible in the 1925 aerial photographs have been lost. The "grass" index is reduced accordingly.

Area VII

Fourteen percent of the total area of Area VII was, and is, land; water occupies the other 86% (about 94 km^2). Area VII contains the largest body of water in the study area (Table 9).

In 1925 the land of Area VII was 44% developed and 35% mangrove. The remainder consisted of areas of upland vegetation most of which was located on Key Biscayne. Today, 86% of the land is developed while mangroves have been reduced to the 2.1 km^2 on Key Biscayne (14% of the present land area).

Total shoreline length has doubled since 1887 and is now 41.5 km The extreme complexity of canals, small spoil islands, filled bay front and the construction of Rickenbacker Causeway have added the extra 14.3 km. From 1887 to 1976 shoreline changes are: for mangrove - 43 to 23%, for sloping - 54 to 30% and for vertical/bulkhead - 2 to 47%.

Bottom dredging in Area VII has increased from 1% to 6%, and spoil has increased to 1% of the present bottom. The present 7% disturbed bottom in Area VII is located principally along the Bay margins.

Area VII seems to have a large drop in benthic vegetation (64% cover to 39%) and the "grass" index has gone from 65.1% to 41.5%. This drop is

Table 9

Area VII -- South of Rickenbacker Causeway

Total Area 110.4 km^2

Percent of Northern Biscayne Bay 51%

	A		B		(B-A)	$\frac{B-A}{A}(100)$
	km^2	%	km^2	%	km^2	%
Total Land	15.8	14	15.6	14	- 0.2	-1
Developed	7.0	44	13.5	86	6.5	93
Mangrove	5.5	35	2.1	14	- 3.4	-62
	C		B		(B-C)	$\frac{B-C}{C}(100)$
Total Shoreline	27.2	34	41.5	24	14.3	53
Mangrove	11.8	43	9.6	23	- 2.2	-19
Vertical/Bulkhead	0.6	2	19.3	47	18.7	3117
Sloping	14.8	54	12.6	30	- 2.2	-15
	A		B		(B-A)	$\frac{B-A}{A}(100)$
Total Water Area	94.6	86	94.8	86	0.2	0.2
Dredged	0.8	1	5.7	6	4.9	613
Spoil	0.1	0.1	0.9	1	0.8	800
Disturbed	0.9	1	6.6	7	5.7	633
Benthic Vegetation	60.9	64	36.8	39	-24.1	-40
"Grass" Index	65.1%		41.5%		23.6%	

A = 1925
B = 1976
C = 1887

largely the result of poor aerial photographic coverage of the central deep axis of Area VII. The "before" vegetation map (Figure 20) uses 1940 photography here, and data is lacking for 1973 and 1976 because of turbidity. Maps presented in Roessler and Beardsley (1974) and Thorhaug (1976) suggest that some of this loss could be real (compare Figure 11 and Figure 21).

In summary, Area VII is the southernmost studied and it can be considered to be a transition zone between north and south Biscayne Bay. Four-fifths of the coastal land has been developed, and its shoreline length has doubled. Over half the mangroves present in 1925 have been lost with the only substantial communities now found on Key Biscayne.

Most of Area VII is open water area of which only 7% is disturbed. This seems like a small number, but of the total 25 km^2 of dredged bottom in northern Biscayne Bay (Table 10) 23% occurs south of Rickenbacker Causeway in Area VII. About two-fifths of the bottom of Area VII has vegetative cover and the "grass" index has decreased through time. As noted previously, the present benthic cover might be more abundant because photographic coverage of the central deeper portions of this Area is limited.

Summary of Major Changes

Table 10 summarizes the major changes in the categories examined for the entire study area. Total values are provided both for the seven Areas discussed above, and for the northernmost six (I-VI). The latter is provided because many previous workers consider northern Biscayne Bay to be the Bay north of Rickenbacker Causeway.

Table 10

Total Bay (I-VII)

Total Area 218.0 km^2

Percent of Study Area 100%

Areas I-VI Only

Total Area 107.6 km^2

Percent of Study Area 49%

	A		B		(B-A)	$\frac{B-A}{A}(100)$	A		B		(B-A)	$\frac{B-A}{A}(100)$
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Total Land	57.9	27	66.1	30	8.2	14	42.1	39	50.4	47	8.3	20
Developed	34.4	59	62.1	94	27.7	81	27.4	65	48.6	96	21.2	77
Mangrove	12.4	21	4.0	6	- 8.4	-68	6.8	16	1.8	4	5.0	74
	C		B		(B-C)	$\frac{B-C}{C}(100)$	C		B		(B-C)	$\frac{B-C}{C}(100)$
Total Shoreline	80.7	100	173.6	100	92.9	115	53.5	66	132.1	76	78.6	147
Mangrove	63.3	78	11.1	6	-52.2	-82	51.5	96	1.5	1	-50.0	-97
Vertical/Bulkhead	1.2	1	106.7	61	105.5	8792	0.6	1	87.4	66	86.8	14467
Sloping	16.3	20	53.3	31	37.0	227	1.5	3	40.7	31	39.2	2613
	A		B		(B-A)	$\frac{B-A}{A}(100)$	A		B		(B-A)	$\frac{B-A}{A}(100)$
Total Water Area	159.0	73	147.9	68	-11.1	-7	64.5	60	53.1	49	-11.4	-18
Dredged	11.3	7	24.7	17	13.4	119	10.5	16	19.1	36	8.6	82
Spoil	0.6	0.3	2.8	2	2.2	367	0.5	1	1.9	4	1.4	280
Disturbed	11.9	7	27.5	19	15.6	131	11.0	17	21.0	40	10.0	91
Benthic Vegetation	87.5	55	50.2	34	-37.3	-43	26.5	41	13.4	25	-13.1	-49
"Grass" Index	59.4%		41.7%			17.7%	49.6%		41.7%			79%

A = 1925
B = 1976
C = 1887

Figure 26 shows graphically the major changes by Area as discussed above. The first three graphs in Figure 26 show changes in terrestrial environments, the second three show changes in shoreline, and the remaining four pertain to bay bottom features. Note that the shoreline graphs plot data from 1887 maps; the rest use data obtained from the historical aerial photography. The solid lines represent the older data, while the most recent data is plotted as a dotted line. Average values taken from the total northern Biscayne Bay values on Table 10 are plotted to the right of the data from the seven Areas. Both total northern Biscayne Bay averages and those from the Bay north of Rickenbacker Causeway are plotted with a small arrow that shows the historical trend, either up or down.

As Figure 26 shows, land area has increased throughout the Bay except in Area I and VII. Developed land areas have increased except in Area V where most of the development predates 1925. As one might expect, the majority of new development occurred well north and south of the central older urbanized Areas. Mangrove land showed a corresponding decrease throughout time as land development continued.

The total shoreline length has doubled since 1887 and most of the original mangrove shoreline has been lost. The amount of wave reflecting bulkheaded shoreline has increased dramatically in all seven Areas. Spoil island construction has produced large amounts of new sloping shoreline in the northern six Areas.

Forty percent of the Bay north of Rickenbacker Causeway has been disturbed by dredging and spoil emplacement. The average amount of disturbed bottom for all seven Areas is only 20%, however. Both the amount of dredged bottom and the amount of disturbed bottom have increased since

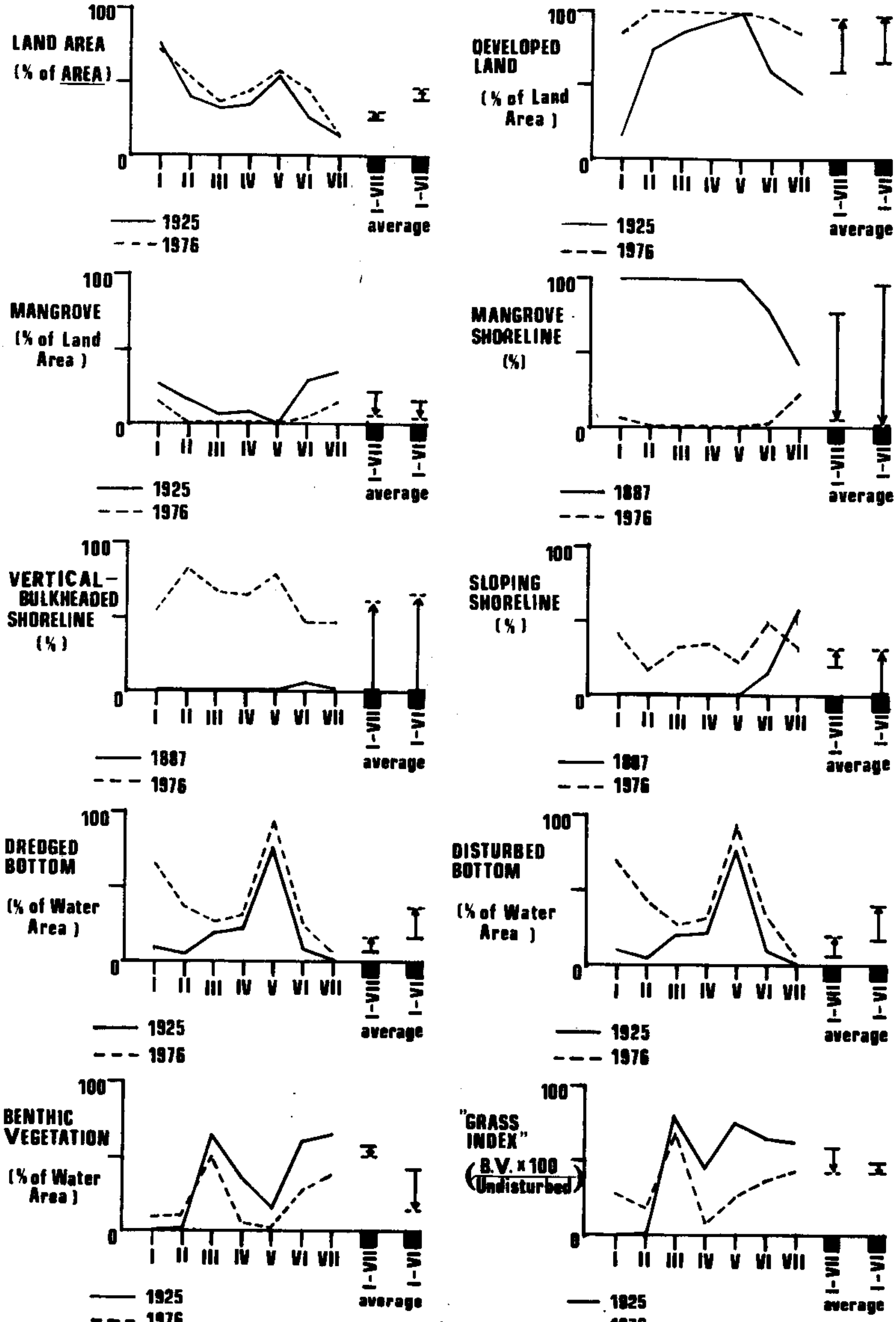


FIGURE 26. SUMMARY OF MAJOR CHANGES

1925.

The amount of benthic vegetation seen in the aerial photographs has increased in Areas I and II, but there are substantial decreases in the five Areas farther south. The Bay averages for benthic cover have decreased through time as has the "grass" index. The latter fact means that overall there is less benthic vegetation found on the undisturbed bottoms today than there was in 1925.

Turbidity

Turbid water areas can be seen in all aerial photograph sets used in this study. The actual components that produce these turbid patterns can be organic or inorganic particulates of sufficiently small size to stay suspended in the water under the prevailing wave-current energy conditions. Turbidity has been seen in historical aerial photography, during overflights of the bay, and during field excursions to the bay. Based on this limited number of experiences, the following turbidity observations are presented:

1) During the period covered by vertical aerial photographs (1925-1976), there is an apparent overall increase in turbidity. More Bay bottom is obscured in the more recent photographs. The water area around 79th Street Causeway, clear in 1925, is obscured in all later photos, as is the case for most of Areas IV, V and part of VI. Water in the center of Area VII parallel to the Bay's axis is clear in 1940 but obscured in 1973 and 1976. Increases in wave reflecting shorelines, dredged bottom areas, spoil, runoff, marinas and the number of boats are important influences on turbidity levels. Turbidity levels can be expected to increase until there

is a significant reduction in one or more of these influences.

2) Presently there are two water areas where turbidity appears most persistent: the area north and south of 79th Street Causeway and the area around Dodge Island, especially in the vicinity of the Turning Basin. The bottom in these two regions has been obscured by turbidity in all the aerial photography since 1925.

The abundant, persistent turbidity around 79th Street Causeway is influenced by one or more of the following factors:

a) The area is the nodal point for tides in the bay and therefore poorly flushed (Michel, 1976).

b) With the exception of the abundant spoil shorelines, the adjacent Areas II and III are entirely bulkheaded. Wind wave and boat wave energy, reflected off bulkheads, is accentuated.

c) A relatively large percent of the bottom in Area II is naturally deep or dredged. Below 2 m deep these bottoms are essentially bare and dominated by soft muddy sediment.

d) Boat traffic is concentrated over bare dredged bottom areas. Boat waves can cause resuspension of bottom sediments (Appendix B).

e) The extensive vegetated shallow bottom in nearby Area III is a potential source of large quantities of suspended sediments.

Persistent turbidity in the Miami River-Harbor area is also influenced by adjacent bulkheaded shorelines, adjacent deeper bare and disturbed bottoms, boat traffic, and nutrient influx. The Miami River discharges large quantities of nutrients into this area. These nutrients are a source for maintaining high phytoplankton levels (D'Amato, 1973).

The Miami River also releases large volumes of turbid waters into the Bay. Much of which is organic material from high phytoplankton levels within the Miami River (D'Amato, 1973). The abundance of locally concentrated large to very large boat and ship traffic in the river and harbor provides continual agitation for the deep bare mud bottoms. This agitation can resuspend particulates and river-borne nutrients (Figure 27).

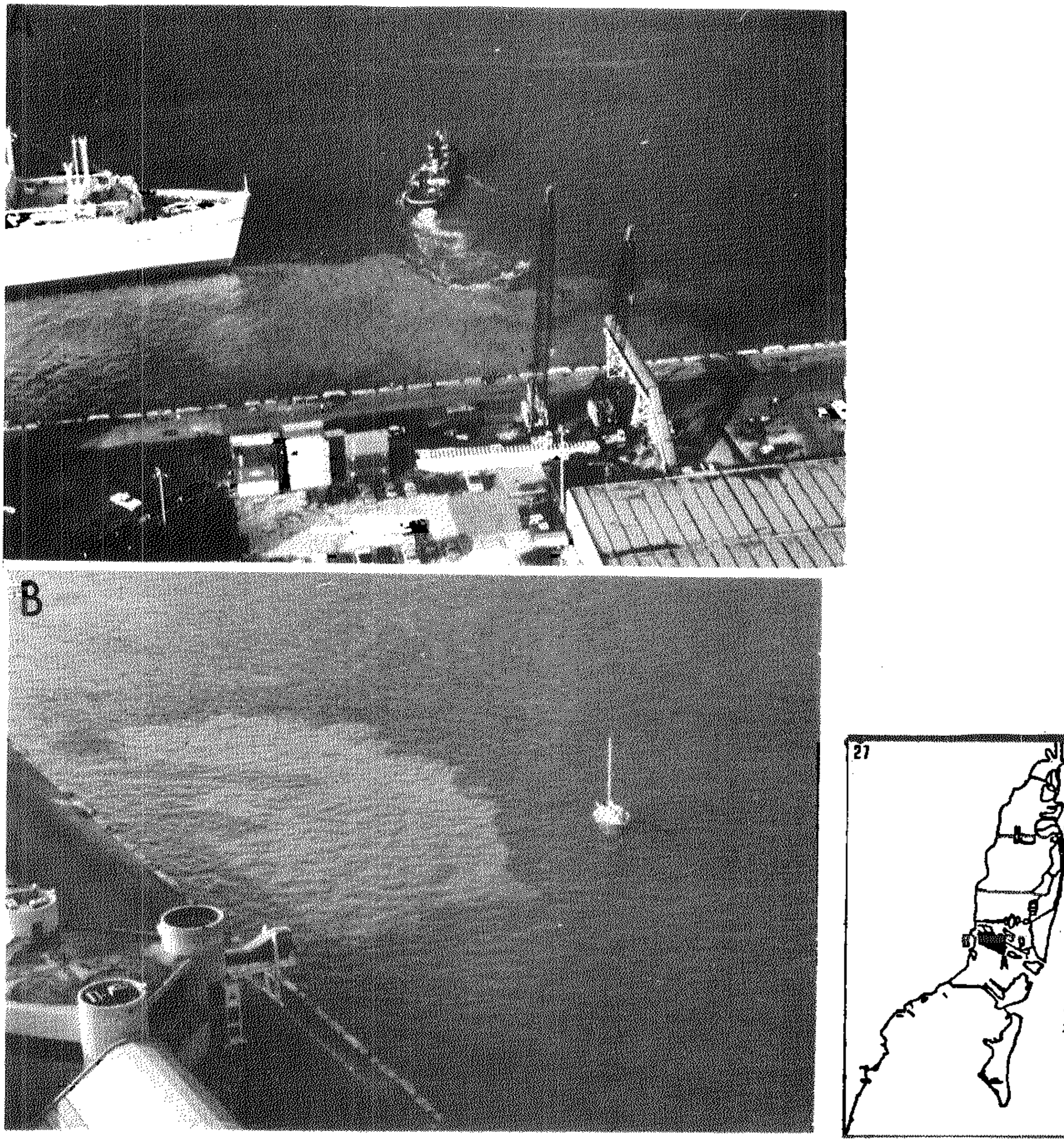


Figure 27. Turbidity produced by vessels using Dodge Island: A: 1978 oblique view of turbid plume produced by tugboat propeller wash (photo by author). B: 1978 oblique view of turbid plume produced by side thrusters of cruise ship that left dock about five minutes prior to photography (photo by author).

DISCUSSION

Figure 26 summarizes the major changes in the terrestrial, shoreline and marine environments of northern Biscayne Bay. Obviously the trends shown are more complex than the graphs indicate, and should, therefore, be analyzed in more detail in order to determine when the changes occurred, and at what rate. The historical aerial photography can be used to locate specific detailed changes within each Area, and the timing of these events can be determined by bracketing between different age photographs. Once the location and timing is known, one can commonly correlate the observed change to one or more natural or artificial process that were known to be active in that area at that time. The discussion that follows uses historical aerial photographs to show how the various environments evolved and how northern Biscayne Bay works as a system.

Terrestrial Changes

Except for Areas I and VII, northern Biscayne Bay has more land area now than it had in 1925 (Figure 26, Tables 3 through 10). The largest increases in land area occur in Area II, Area VI and to a lesser extent in Area IV. A large increase in land from fill island construction occurred in Area V prior to 1925. The extremely small reduction in land in Areas I and VII (less than 1 km^2 -- about 2 acres) is offset by a 9 sq km increase (about 23 acres) in the other five Areas. Since 1925 various processes have increased the total land area in northern Biscayne Bay by 8.1 sq km (20 acres).

The small losses in land area can be attributed to the construction of cuts through islands (Figure 14), drainage canals and finger-canals or waterways for residential developments (Figure 15). Increases in land area are mainly the direct result of fill island construction (Figure 15a), causeway and spoil island construction and the enlargement of coastal property with fill (Figures 22 and 15). In addition, natural processes, especially hurricanes, can produce new land and erode exposed areas (Figure 14).

The overall construction of new land in northern Biscayne Bay has produced significant changes in terrestrial and marine environments. The majority of the new land is subsequently developed, although some small areas, notably spoil islands, are later colonized by opportunistic plants such as Australian pines (Cassurina) or occasionally mangroves. The direct effect of land construction is, of course, the destruction of previous marine habitats.

Water circulation and current patterns have changed in northern Biscayne Bay as a result of fill island, spoil island and causeway construction (Michel, 1976). These structures block and deflect currents and both areas of stagnant and improved circulation will be produced by their construction (Bruun, 1959, p. 6).

Causeways are the most efficient blocks to natural water circulation. This fact was realized by Munroe and Gilpin (1930) who observed that storm flooding in the Great Miami Hurricane of 1926 was intensified by the blocking of storm tides by MacArthur Causeway. As a result, there was extensive flood damage on South Miami beach, the destruction of the downtown bayfront (see photographs in Smiley, 1973), and focusing of a tidal bore up the Miami River that sank many boats. If their interpretation is correct, then a future storm with attributes similar to the 1926 hurricane can be expected to interact with Rickenbacker Causeway to produce severe flooding on Virginia Key and Coconut Grove shorelines.

The calcareous green algae Halimeda appeared in Area III about 10 to 15 years ago (see Core discussion), closely following the construction of Julia Tuttle Causeway in 1960. Prior to 1960, this area had received incoming tidal water from Area IV to the south (Area III is south of the tidal nodal point -- see Michel, 1976) an area that had been highly disturbed and turbid since 1925. The new causeway must have blocked much of the northward flowing tide and focused the tidal flow in the two narrow openings at the Intracoastal Waterway and Melloy Channel. Indeed, focused tidal currents produced dune-like bedforms on the bottom aligned perpendicular to the causeway bridges (Figure 35c). It is likely that the center of Area III is now partially protected from the influx of turbid water flowing north by Julia Tuttle Causeway, and by restricting tidal flow to channels at the causeway openings. Introduction of Halimeda is attributed to the resultant increase in water quality.

Two other problems can be related to an increase in land area. More land means more source area for storm water runoff that can contribute to turbidity and pollution levels in Bay waters. Finally, stagnant or reduced circulation of water, resulting from new land construction can increase sedimentation rates locally, although the reverse is possible if the area becomes isolated from its source of sediment.

The second graph in Figure 26 shows large overall increases in the amount of developed land. Most of this increase occurs north and south of Areas IV and V which were well developed prior to 1925 (Figure 16). By 1976, developed land area has increased 81% (28 km^2 -- about 69 acres) compared with the amount in 1925. About 60% of the land adjacent to the Bay was developed in 1925; today 94% of the land including newly created or expanded fill islands is considered to be developed.

Development of "reclaimed" swamp lands, upland areas and newly created land began in earnest upon the completion of the Florida East Coast Railroad in 1896. As the first economical and practical transportation system to the region it provided essential supplies, manpower and later, tourists.

Upland areas were cleared of native vegetation, and later developed for agricultural, commercial, or residential use. Low coastal swamps along both mainland and barrier island shorelines were "reclaimed" by bulkheading and filling. The Everglades lying just to the west was largely drained by an extensive canal network making available large acreages of land. With exception of spoil islands, the majority of the new land produced in the Bay was built for commercial or residential purposes. Many developed land areas have been subsequently redeveloped, sometimes more than once.

The principal direct effect of land development is the loss of the original natural environments. Upland development eliminated many scrub, pine and hardwood hammock habitats. Indirect effects have been significant in surviving undeveloped areas and in the Bay. Surface storm-water runoff to the canals and the Bay has increased, largely the result of increases in paved-over land and the construction of storm water drainage systems. Surface runoff can contain abundant chemical pollutants (Waite, 1976), nutrients (from fertilizers) and various particulates. These in turn can adversely affect the biological communities by modifying water quality and altering sedimentation.

The environmental impact of draining the Everglades is discussed by Chardon (1976), Buchanan and Klein (1976), Wanless (1976b) and Thorhaug et al. (1976). The most important indirect effect of this drainage has been a significant drop in drinking water supplies and freshwater flow into the Bay (Buchanan and Klein, 1976). The decrease in fresh water is also partially responsible for vegetation changes at Interama (see Teas et al., 1976). The drainage canals and channelized original streams (the Miami River, for example) have become significant point sources for the introduction of chemical pollutants to the Bay (Waite, 1976).

Finally, modification of coastal swamps, discussed below, and construction of new land within the Bay has produced much valuable and expensive land. Most of this land is now developed, and the result is a concentration of large urban structures at the bayshore. The wisdom of this development must be questioned in light of past hurricane events and the inevitability of future severe storms.

The change in the amount of mangrove land area is plotted on the third graph in Figure 26. Mangroves occupied less than 25% of the 1925 land area and they are found on only 6% today (Table 10). Old charts (U.S. Coast and Geodetic Survey, 1887) show that the original bayshore was predominantly mangrove lined except on portions of the mainland shore. Area V was devoid of mangroves by 1925 and by 1976 mangroves are gone from all but Areas I, VI and VII.

Mangroves have been increasing since 1925 at the Interama property (Teas et al., 1976), along the northwest shore of Virginia Key (Figures 29 and 30), and on a few spoil islands. The growth of mangroves at Interama

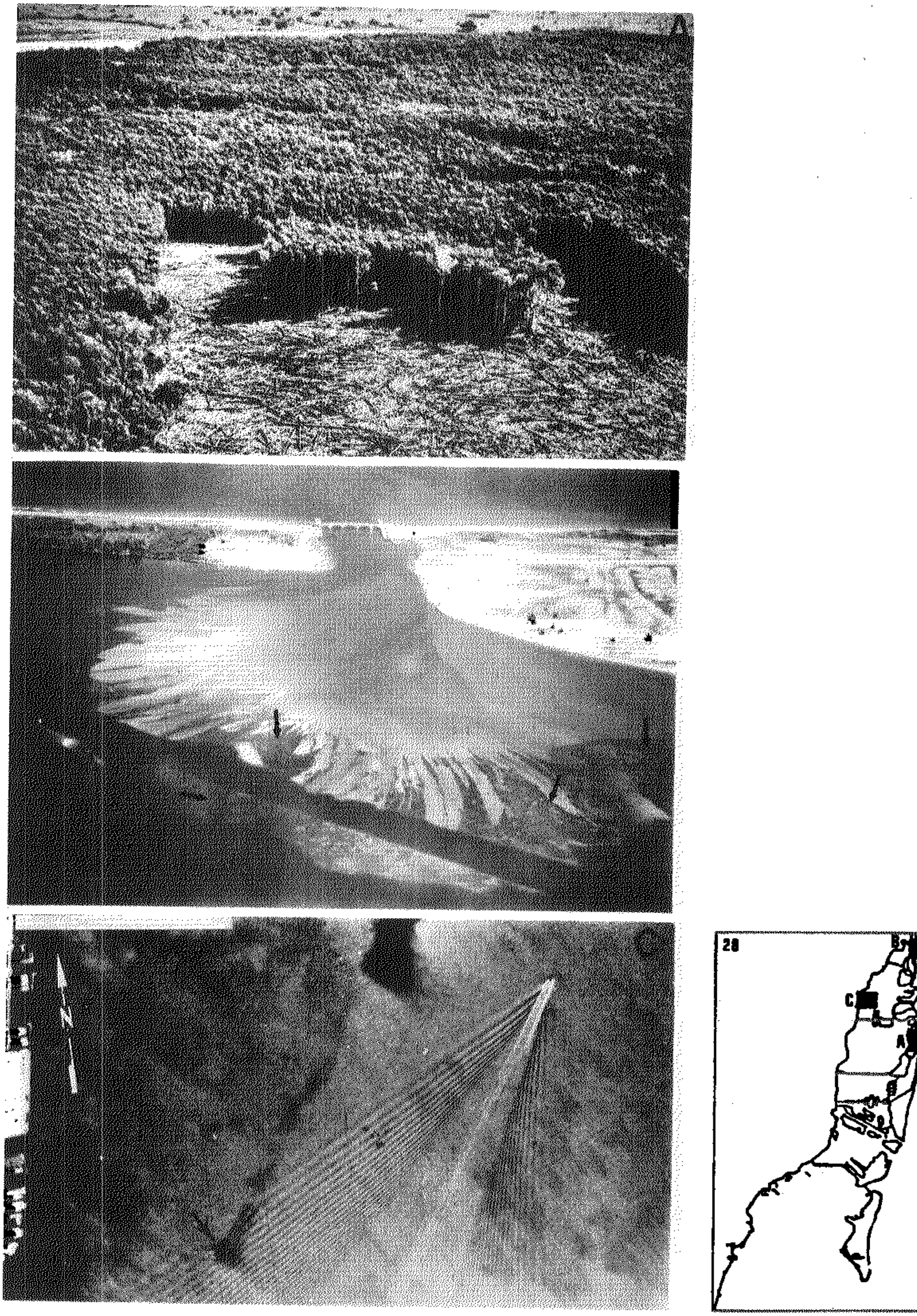
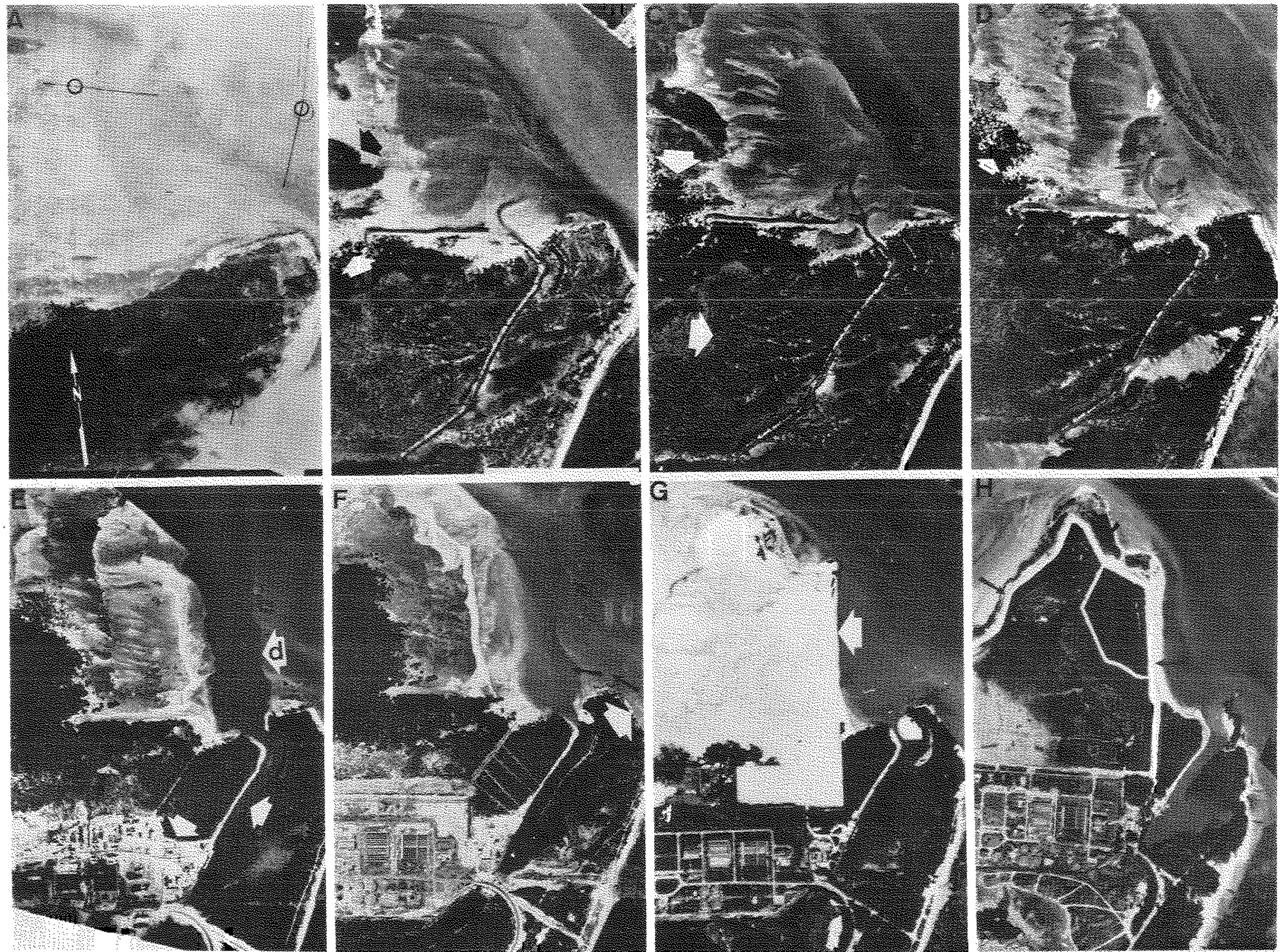


Figure 28. A: Oblique 1925 view shows the clearing of upper Miami Beach. Indian Creek is in the background. Trees are believed to be very tall black mangroves (Avicennia) (Hoyt, WP9401). B: Bakers Haulover circa August 1935 shows the fan-shaped tidal delta that formed after the cut was opened in 1925. Portions of the delta are colonized by benthic plants (arrows) (Hoyt, AT1126). C: 1976 view of boat waves acting on a spoil island (arrows). Note the pattern of wave refraction (Fla. Dept. Transportation, PD 1638-21-35).



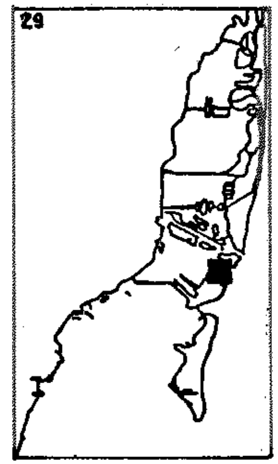


Figure 29. Sequential photographs of Virginia Key: A: 1928 view of the north end of the Key (NOAA, 687-119). B: 1940 view of same area. Mangroves and benthic vegetation have increased to the north of the island (arrows) (USGS, CJF-14-80). C: 1945 view of same area shows substantial increase in new mangroves over the shoaling bottom and in the island interior (arrows). Benthic vegetation also increases (USGS, C-1613). D: 1951 view of same area shows further rapid extension of coastal mangroves (1). Note the setback of benthic vegetation in Norris Cut (2) (USGS, 3627). E: 1954 view of same area shows more mangrove growth and initiation of significant island development (arrows). Large dredged hole (d) provided fill for the new sewage treatment plant (USGS, W-3283). F: Same area in 1958. Dredge hole is infilling with sand eroded off the adjacent ocean beach (arrows) (USGS, BC-27-11). G: 1965 view of same area shows filling of previously expnading mangrove area for use as a sanitary land fill (arrow) (USGS, L-1786). H: 1973 view of same area shows "levees" around land fill (small Arrows). Note what is left of eroding ocean beach (arrow) (Fla. Dept. Transportation, PD 1274-1307).

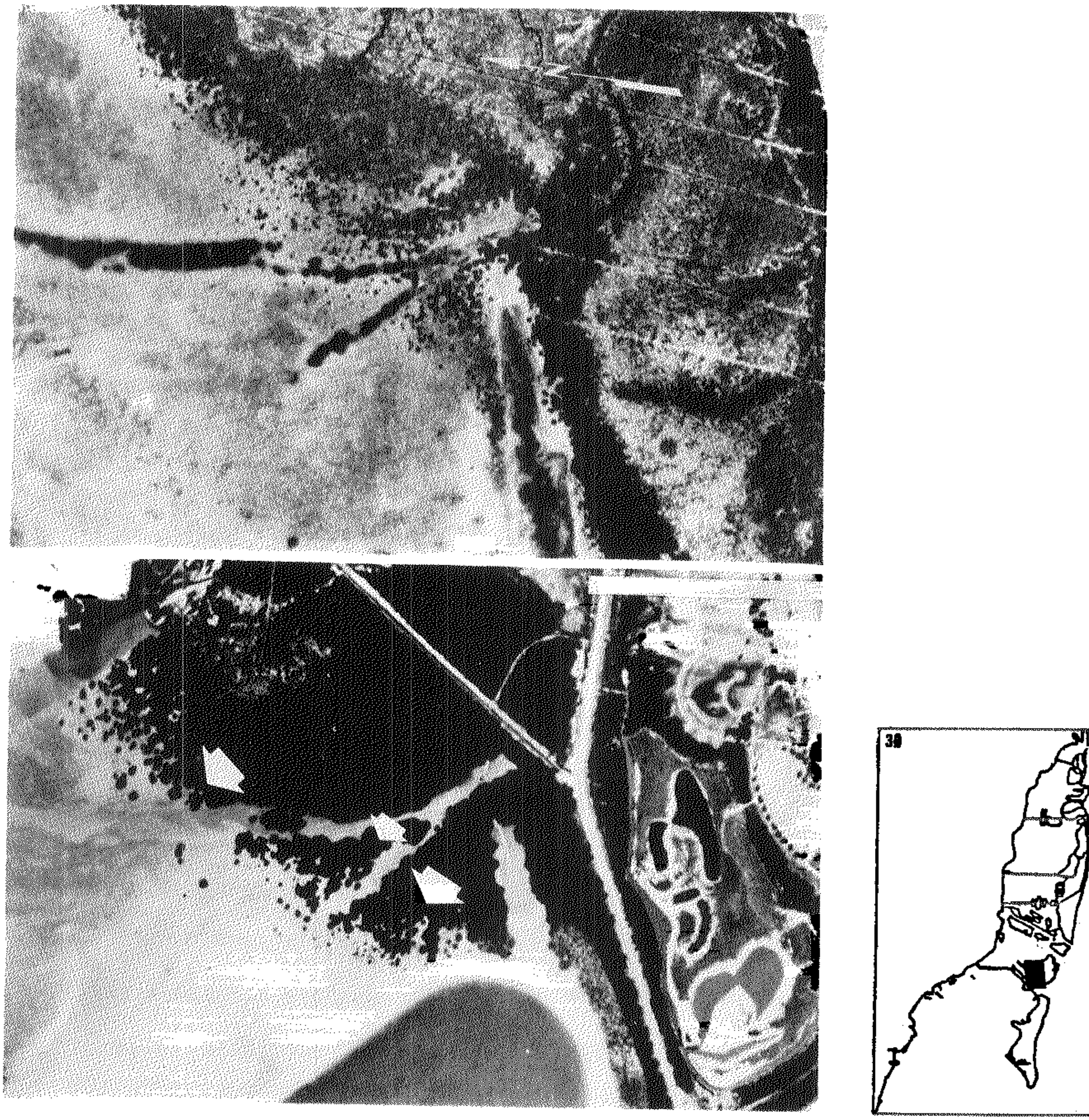


Figure 30. 1940-1976 photopair of area of increasing mangroves on Virginia Key (arrows) (USGS, CJF-14-80; Fla. Dept. Transportation PD 1638-21-36).

has been at the expense of the original freshwater marsh located there (see Teas et al., 1976) and results from salinity changes associated with the opening of Bakers Hauloever Cut and reduced freshwater flow from the west. The increase in mangroves along Virginia Key is a result of rapid colonization of shoaling bottoms. The area beneath the Virginia Key sanitary land fill (Figure 29) was shoaling during some hurricanes. The new shallow bottom land created was colonized by new mangrove trees only a few years after the shoal area was made. In addition, the mangrove swamp adjacent to the northeast corner of the Miami Marine Stadium has shown a slower, but steady increase in mangroves as shoaling occurs there (Figure 30). The shoaling is the result of decreased wave energy caused by blocking artificial structures, reduced tidal circulation and an increase in sedimentation resulting from both of these changes and nearby dredging.

The observed small increases in the amount of mangrove land area have not kept pace with the overall net decrease produced by both artificial and natural processes. Most of the decrease is related to coastal filling for urban development, prior to which, the more valuable trees were cut for their wood (Figure 28).

Comparison of aerial photographs taken before and after major hurricanes shows some of the damage produced in mangrove environments. The damage occurring during the 1926, 1929 and 1935 hurricane seasons was examined in this manner.

Simpson (1932) documents some of the hurricane damage caused by the Great Miami Hurricane of 1926. He reported the destruction of many trees on Miami Beach and around Lemon City. Wind, lightning, and, on Miami Beach storm surges, produced by this storm caused this damage. Storm winds defoliated and broke live oaks, pines, sweet bay and some of the largest mangroves growing in the United States (Simpson, 1932). After this storm Simpson could find few broken trees older than 100 years (based on counts of rings). He suggested that there was a natural cycle wherein the tall, older and therefore more exposed trees are pruned from local forests by large storms. This allows the younger trees and some opportunistic minor species to increase in size and numbers. This cycling, suggested by Simpson, is probably a characteristic of the long term dynamics of the environment so affected.

The 1926 hurricane produced changes in the terrestrial and mangrove environments on Key Biscayne and Virginia Key. The back beach palmetto scrub areas, associated with sandy beach ridge systems, were uniformly set back, probably by heavy surf and elevated tides. The mangrove swamps on both Keys had the majority of the taller trees defoliated. This included the tall black mangroves that were growing on higher swamplands such as the quartz sand "spine" of West Point on Key Biscayne (Figure 31). Mangrove areas on the mainland, at Little River and along the bayshore south of Coconut Grove show some defoliation of taller trees after this storm (Figures 31 and 25d).

The forgotten hurricane of 1929 appears to have produced more changes in some of the Bay's mangrove environments, particularly on Key Biscayne and Virginia Key. By 1932, the mangroves on both Keys are growing in a fortress-like vegetation pattern (Figure 32). The interior trees are completely gone having been succeeded by some type of lush scrub vegetation. The outer wall of red mangroves comprises both surviving trees and some that have grown since the last storm. The fortress pattern was

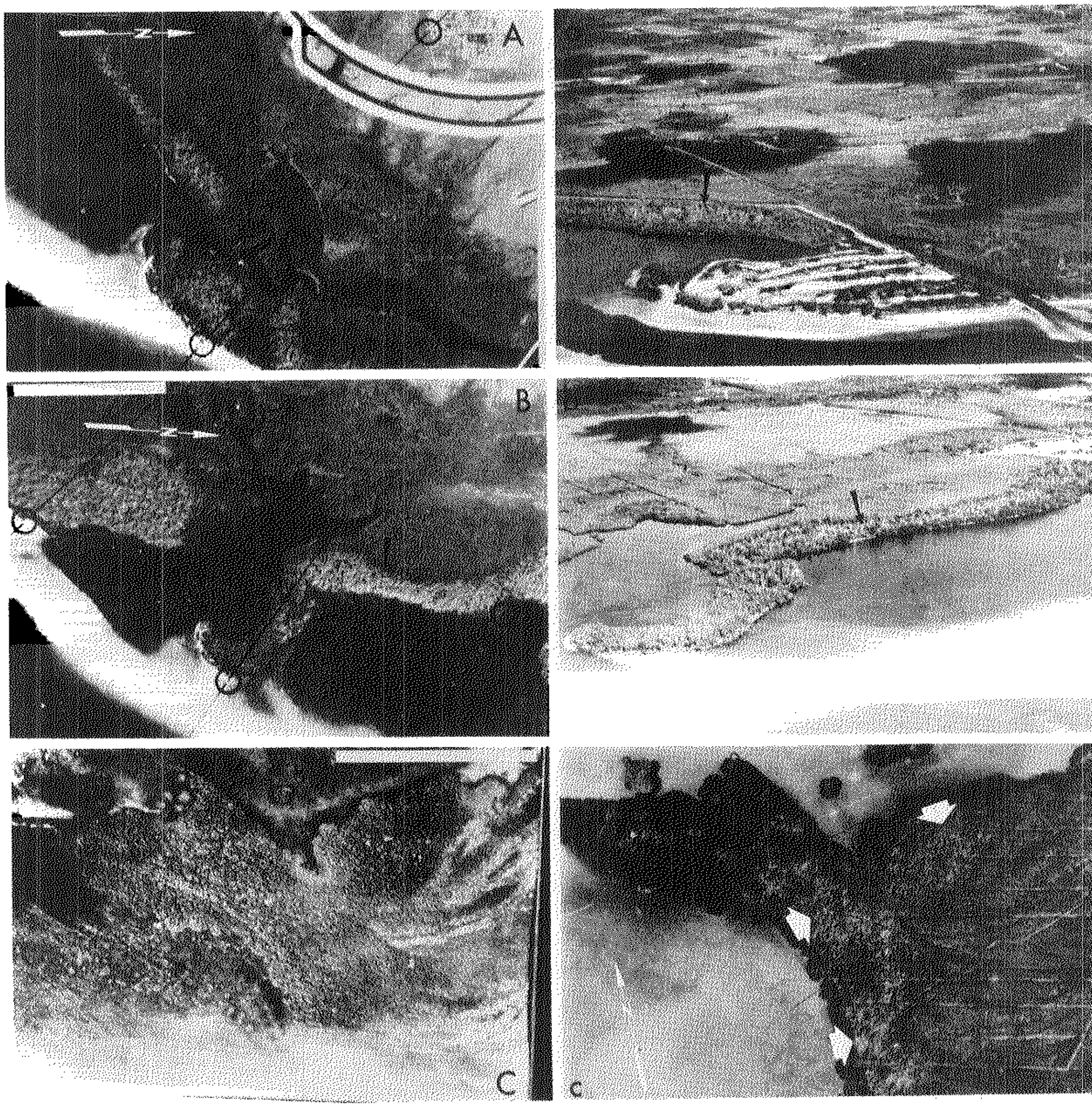


Figure 31. Changes in coastal mangroves caused by hurricanes: A: 1928 vertical and subsequent oblique views of the defoliated interior mangroves. Obliques taken June 1935 (NOAA, 697-445; Hoyt, AT1003). B: 1938 vertical and subsequent oblique views of Matheson Hammock area showing similar damage (NOAA, 697-443). C: 1925-1932 views of West Point on Key Biscayne shows loss of interior trees (Miami-Dade Library; NOAÁ, 806-102).

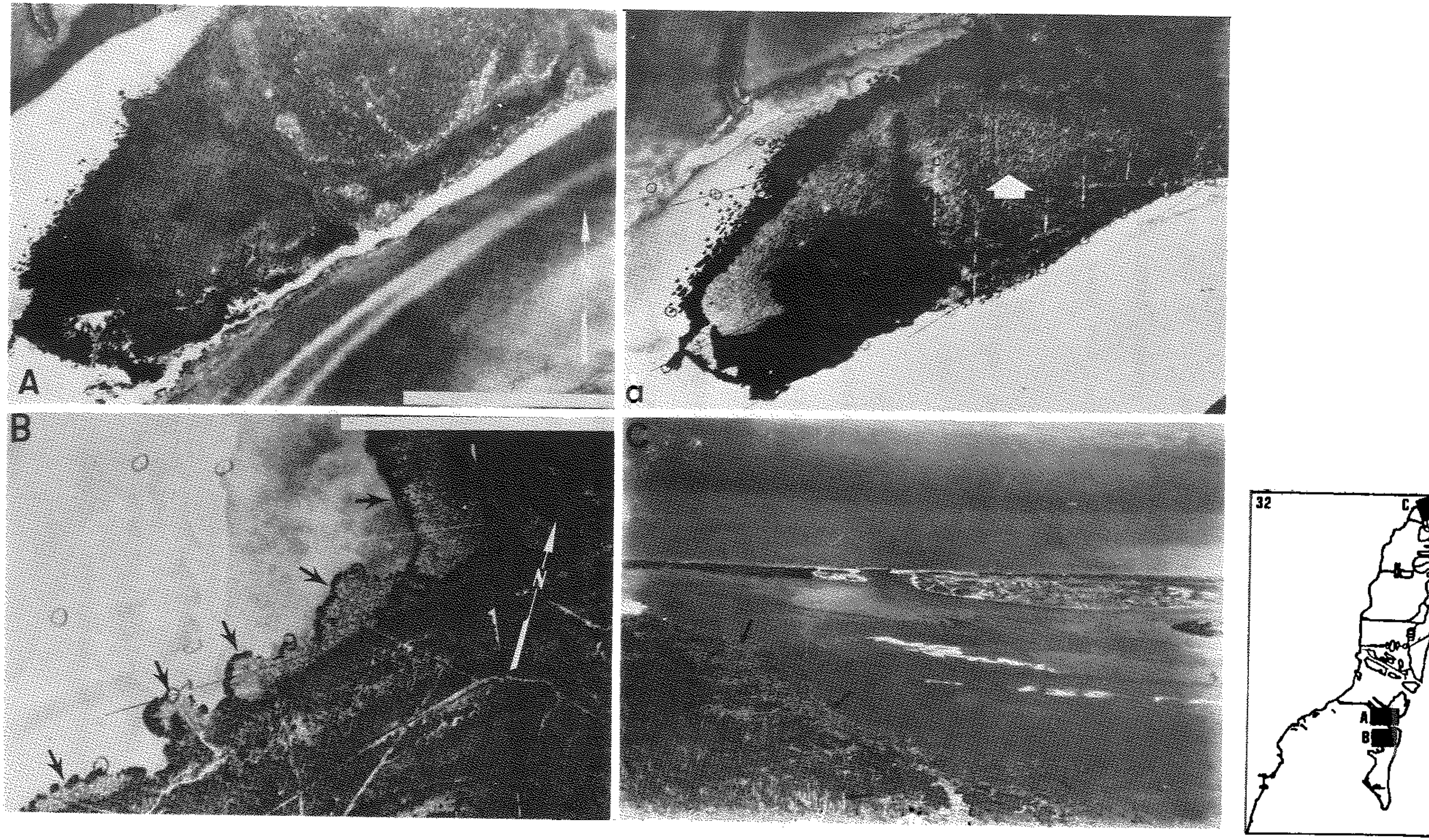


Figure 32. Mangrove swamp changes caused by hurricanes: A: 1925-1932 photopair shows fortress-like appearance of mangrove areas on Virginia Key produced by back to back severe hurricanes in 1926 and 1929. Vertical standing defoliated trees can be seen in the interior in 1932 (arrow) (Miami-Dade Library; NOAA, 806-94). B: 1932 view of fortress-like mangrove areas on Key Biscayne (arrows) (NOAA, 806-98). C: 1936 view of Interama shows dead trees in coastal swamp (arrows) (Hoyt, AT2023).

seen in Florida Bay by Craighead (1964) after Hurricane Donna (1960).

No mangrove damage was identified from the 1935 hurricane season. This is because there are few mangrove areas left by the date of the next aerial photographs (1940). The intense prewar developemnt along the bayshore has obscured any mangrove damage that may have resulted from the severe hurricanes of 1935.

Frost effects on mangroves have not been identified in this study, but Munroe and Gilpin (1930) and Simpson (1932) have observed frost damage to local coastal plants.

The loss of significant areas of coastal mangroves, regardless of cause, produces several ecological effects: (1) since mangroves can obstruct and filter surface runoff (Burns, 1976), more runoff occurs (runoff can contain nutrients and pollutants that affect Bay water quality); (2) the important food chains supported by mangroves (Burns, 1976; Fell, 1976) are reduced or lost; and (3) the habitats, nursery and breeding grounds provided in and around the mangroves is lost. The loss of habitats may explain a succession of rat, racoon and mosquito infestations reported (Lummus, 1940) during the construction of Miami Beach.

Shoreline Changes

The total length of northern Biscayne Bay's shoreline has more than doubled since 1887 (Table 10). The majority of this increase results from the construction of new land, especially fill islands, causeways and spoil islands. Hurricanes and other processes have built shoals that are later colonized by mangroves. Since mangroves define the land-water boundary in aerial photographs, mangroves expanding into the bay increase shoreline length. Hurricanes have not made substantial changes to the shorelines within the Bay, but they are extremely powerful erosive agents on the ocean beaches.

By 1925, the unmodified sections of shoreline within the Bay show no appreciable changes from the 1887 configuration. Development in Areas III, IV and especially V, however, produced significant increases in their shoreline lengths. Area VI shows the largest increase in shoreline since 1887, and Area I's shoreline has increased the least.

The effects of any change in shoreline length are dependent on the type of shoreline that is added or subtracted. Mangrove, vertical/bulkheaded, and sloping shorelines are discussed in turn.

Mangrove Shorelines

The fourth graph in Figure 26 shows the changes in mangrove shorelines. Mangrove shorelines are gone from all but Areas I, VI and VII. Area VII shows the least amount of change, while the more central heavily developed Areas show the most.

Most of the reduction in mangrove shoreline is caused by bulkheading and filling of coastal swamp land. Dumping of spoil along the shoreline of Interama has isolated most of the interior mangroves which changes the mangrove shoreline here to sloping shoreline. Mangrove shorelines can be eroded by storms and by boat waves (Teas et al., 1976, p. 135). On the other hand, shoaling can provide new space for mangrove colonization that results in slight increases in shoreline length (Figures 29 and 30).

The overall net loss of shoreline mangroves in northern Biscayne Bay effectively reduces the filtering and trapping effect of their root systems, and it reduces the reputed ability of shoreline mangroves to dissipate wave energy.

Vertical/Bulkheaded Shoreline

Since 1887, there has been a drastic increase in the amount of vertical/bulkheaded shoreline in and around the Bay. Fully 61% of the present increased shoreline is of this type (Figure 26, Table 10), while most of the increase occurs in Areas II and V. Area VII shows substantial increases in the amount of bulkheading (Table 9), but this is not apparent in the graph (Figure 26) because the total shoreline here is quite long. The short peak shown for Area VI in 1887 is produced from the Miami Oolite ridge that once outcropped at the shoreline (see photographs in Parks, 1977).

Bulkheads are used to retain dredged material during filling operations that produce new land area. Various materials have been used in their construction in the past, some of which require frequent maintenance. If not maintained the walls can be eroded or otherwise degraded to the point where fill materials behind the bulkhead can then be eroded. Most of Fisher Island and parts of MacArthur Causeway that were once bulkheaded are no longer.

The increase in vertical/bulkheaded shoreline in the Bay provides more surface area for fouling organisms such as barnacles (Moore et al., 1974). More important is the increase in reflected wave energy resulting from the more than 100 km of bulkheaded shoreline in northern Biscayne Bay.

Bruun (1959, p. 3) states that bulkheaded filled shorelines "reflect from 80% to 90% of the wave energy" that strikes them. He notes that the reflected waves can be hazardous to navigation and "often create erosion problems." Reflected waves are only slightly smaller in height and do not change in wavelength (Bruun, 1959, p. 5). The waves that are reflected may be wind waves or boat and ship wakes. Wave-induced erosion of shorelines and shallow bottoms should, therefore, be more severe in those Areas with predominantly bulkheaded coastlines, in other words, most of northern Biscayne Bay.

Sloping Shorelines

The total amount of sloping shoreline has more than doubled since 1887. The largest increase occurs in Area VI, while adjacent Area VII has less sloping shoreline because of bulkhead and canal construction. The majority of the additional sloping shoreline in the Bay results from the construction of spoil islands and spoil causeways.

Spoil beaches and natural beaches comprise the sloping shorelines of the Bay. Natural beaches are known to be unstable as they change shape and location seasonally with changes in the associated wave regime. Large waves, common in winter and during storms, produce steep beach profiles while eroding unstable sediments. Spoil beaches will react in the same manner, with some differences.

The beaches of many spoil islands are different from natural linear sand beaches. On linear beaches longshore currents move sand down the beach away from the incoming waves. When the longshore drift of sand is interrupted, the downdrift beaches tend to erode because their principal supply of new sand is lost. The construction of Government Cut has affected Fisher Island and Virginia Key in this manner (Wanless, 1976).

Since most Bay spoil islands are small and round, longshore drift does not develop or is reduced. This tends to make spoil islands errosional because sediment losses to the surrounding Bay bottom are not replaced.

The size, shape, durability and sorting of natural beach sediments are controlled by the original sediment supply and wave characteristics. Natural beaches are usually dominated by durable sediments that tend to be well sorted by size and composition. Spoil beaches, on the other hand, are composed of dredged Bay sediments that usually are poorly sorted mixes of sand, shell, rock fragments and large quantities of mud and silt. The fine grained materials are easily eroded as they become exposed to wave action (Figure 15), while coarser grained sediments remain on the beach until the wave energy increases.

Poorly sorted, fine grained spoil is currently being placed on the ocean beaches of Miami Beach, Bal Harbour, Surfside and Bakers Haulover Park. The U.S. Army Corps of Engineers is attempting to "restore" wide sand beaches to the barrier island system north of Government Cut. This 10 year project is placing 14.8 million cubic yards (11.3×10^6 m^3) of dredged offshore sediment on to the ocean shoreline. This material is pumped onto the beach as a sediment/water slurry, much of which drains immediately into the longshore transport system. The sand being retained on the beach is largely fragile mollusc and foraminifera shells that are easily abraded by the common rock fragments and large shells also dumped on the beach. As the new beach erodes, more suspendable sediment will be produced. Data from the U.S. Army Corps of Engineers (1975) shows that about 15% of the 14.8 million cubic yards ($2.5 \times 10^6 yd^3$) of the emplaced material will be lost during construction and later "stabilization of the beach profile" (read erosion). Significant amounts of this material are entering northern Biscayne Bay as suspended sediment through Bakers Haulover Cut.

The waves that modify sloping shorelines can be wind waves or boat and shipwakes. Hurricanes are extremely effective erosional agents that cause major morphological changes in affected beaches. In northern Biscayne Bay storms have been most effective on the ocean beaches of the barrier islands.

The 1926 hurricane severely eroded large sections of the barrier island beaches. On either side of Bakers Haulover the beach lost about 62 m (200 feet). This isolated the highway bridge that spanned the one year old cut (Figure 14A). A considerable amount of the lost sand was deposited inside the Bay as a large fan-shaped delta (Figure 28b). The new cut acted as a sink for sediments thereby increasing adjacent beach erosion (U.S. Army Corps of Engineers, 1946b; Purpura, 1962).

The Cape Florida beaches south of the lighthouse on Key Biscayne, lost some sand during the 1926 storm and about 16 m (50 feet) of beach was lost from the middle portion of Key Biscayne where the offshore profile is steeper. Slightly less beach was eroded from the northern end of the island. Virginia Key lost about 16 m of beach from the southeast corner of the island, and slight erosion occurred along the midsection and northeast corner.

Aerial photographs show that Miami Beach erosion from the 1926 storm varied from about 16 m near the south end to the aforementioned 62 m (200 feet) at Bakers Haulover. The beach opposite the midpoint of Indian Creek lost about 50 m (150 feet) and became the site of the first groins built locally in 1927 (Figure 14b).

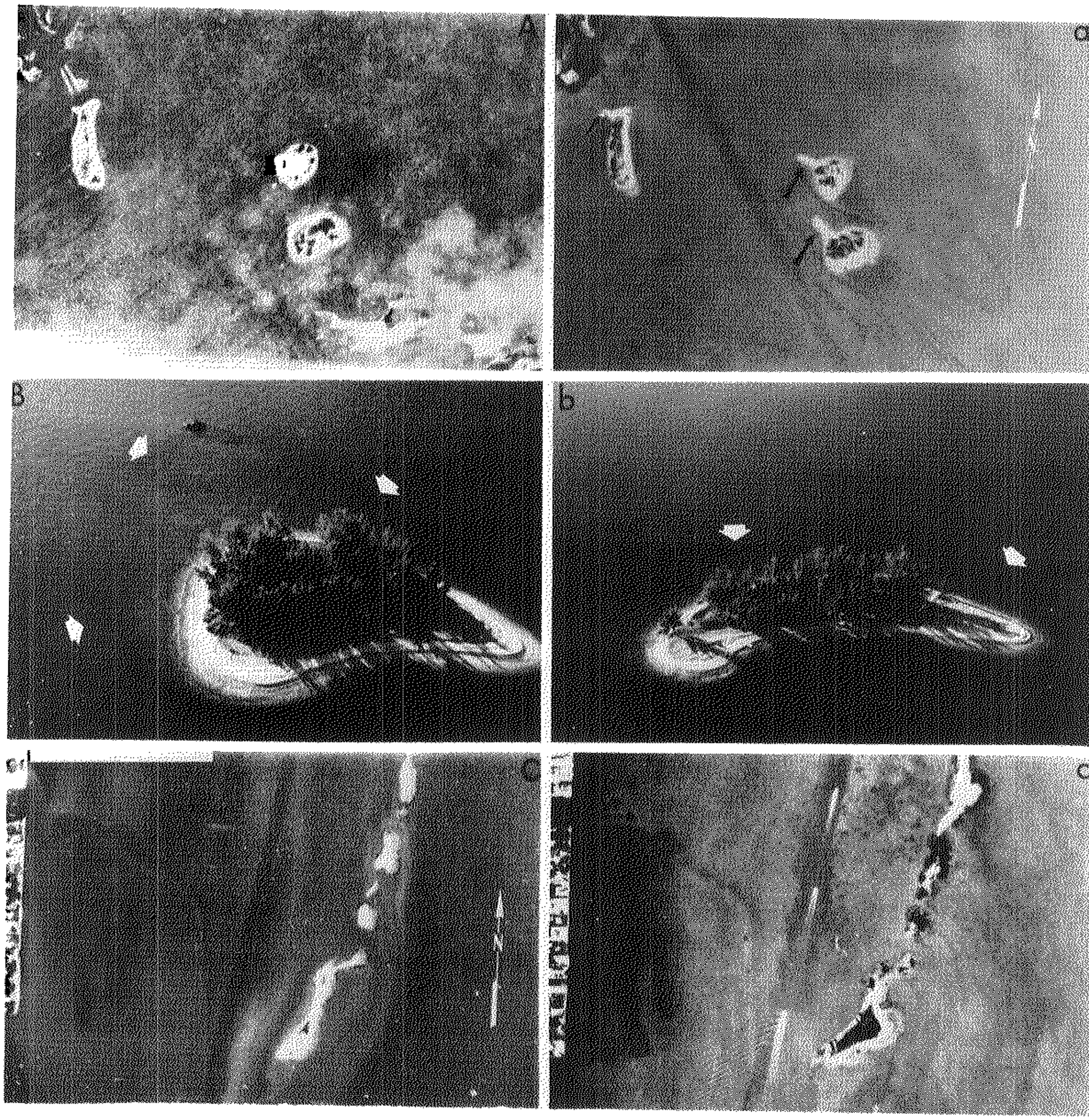
Other than slight erosion around the midpoint of Key Biscayne by the 1929 hurricane, aerial photographs show no significant changes in the ocean beach system in 1932 and 1940. Both the 1929 and 1935 hurricanes should have produced more erosion, but natural recovery may have obscured the change by the time the next aerial photographs were taken.

Spoil islands are not permanent features, they both move and erode completely away (Figures 24 and 33). Movement is controlled by the wave regime which affects erosion rates and the movement direction. Movement is produced by accretion of the low energy side of the island at the expense of the side attacked by the strongest waves.

Two spoil islands in Area I have migrated away from the Intracoastal Waterway apparently because of boat wave erosion (Figure 33). The erosional side of the islands is close to the western Bay Harbour Isle which should block formation of large wind waves from this direction. Frequent boat traffic in the adjacent Intracoastal Waterway is considered responsible.

These two islands are boomerang-shaped, unlike the rest of the spoil islands in the Bay, and have steep coarse grained beaches on all sides. The steepest sides face the waterway. The islands appear to have eroded to the west about 50 m since they were built about 40 years ago. An elevated spoil platform was left behind as they moved that has since been colonized with benthic plants.

In summary, increasing the amount of spoil shoreline increases the number of potential sources for suspended sediments (turbidity), buries the previous bottom community, changes bottom topography and modifies



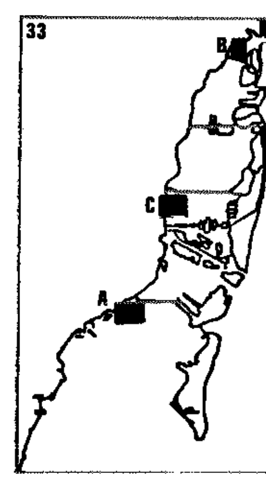


Figure 33. Spoil island changes: A: 1925-1940 sequence shows spit formation (arrows) on Viscaya spoil islands. At present, these islands are awash at highest tide levels and the island vegetation is essentially gone (see Figure 35D) (Miami-Dade Library; USGS, CJF-14-82). B: Two 1978 oblique views of small spoil islands in Area I (see Figure 24 for vertical views). They are migrating away from the Intracoastal Waterway which is just out of picture at top. Note steep beaches, boomerang shape, and vegetated erosional platforms (arrows) (photos by author). C: 1940-1976 photopair shows spoil islands along the Intracoastal Waterway. These islands are in an exposed location with waves attacking them from both the waterway and the relatively open bay to the east. The island shapes have changed, but their relative position has remained the same (USGS, CJF-10-03; Fla. Dept. Transportation, PD 1638-21-29).

water movement.

Water Area Changes

The amount of open water area in northern Biscayne Bay has been reduced by 11 sq km since 1925 (Table 10). This value is slightly higher than the 8 sq km land increase because it does not include any increase in water area within the canals bordering the bay. Open water area has increased slightly in Area VII, remained essentially the same in Areas I and V, and decreased throughout the remaining Areas. The largest decrease (4.4 km^2) occurred in Area VI as a result of dredge and fill operations there. The proposed future expansion of Dodge Island to include Lummus Island will further increase this value.

Open water decreases within the Bay are the direct result of filling and spoil dumping. The construction of fill islands appears to be the single largest contribution to this change. Decreases are at the expense of existing biological habitats that are buried or removed by dredging. The amount of plant and animal species that the Bay can support decreases accordingly. In addition, the tidal prism will decrease when the water area is decreased (Michel, 1976, p. 226), the effect of which remains to be determined.

Dredged Bottom Changes

Seventeen percent of the submerged bottoms studied have been dredged (Table 10, Figure 26). North of Rickenbacker Causeway, 40% of the Bay bottom is modified by dredging. The dredged 17% for the total study area corresponds well with Chardon's figure of 20% calculated from less detailed maps of much smaller scale (Chardon, 1976, p. 240). Fully 93% of the present bottom of <u>Area V</u> is dredged, most of which occurred prior to 1925 (Figures 20 and 26). <u>Area I</u> has the second most dredged bottom in the study area.

When bottom lands are dredged, the surficial sediments and their associated fauna and flora are removed (Wanless, 1976a). Older sediments are exposed and the deeper dredgings (for example, the Miami Ship Channel) can penetrate into bedrock. The resulting bottom is quite different from the pre-dredging substrate for several reasons.

The deeper new substrate does not receive light of the same intensity or color as these both change with depth. Benthic plant and animal species that are light dependent will be less likely to recolonize bottoms that are dredged especially in areas where turbidity levels are high.

Dredging of navigational channels produces large amounts of spoil that is usually dumped away from the channel (Figures 15, 24 and 25). The effects of intertidal spoil and spoil islands were discussed previously and subtidal spoil is examined in the discussion of disturbed bottom that follows. Spoil is a significant source of turbidity (Wanless, 1976b).

Current patterns within the Bay are altered by the change in bathymetry by dredging (Michel, 1976). Tides, especially flow more easily through the interconnected dredge holes (Figure 34) with resulting decreases elsewhere. Blocking causeways further channelize tidal currents into the waterways that bisect the causeway. Turbid water masses are transported between <u>Areas</u> in dredged channels (Figure 34) where currents are focused in this manner.

Dredging operations cause significant turbidity. Sediment laden water is produced by the dredge, leaks out of transport pipes, and runs off

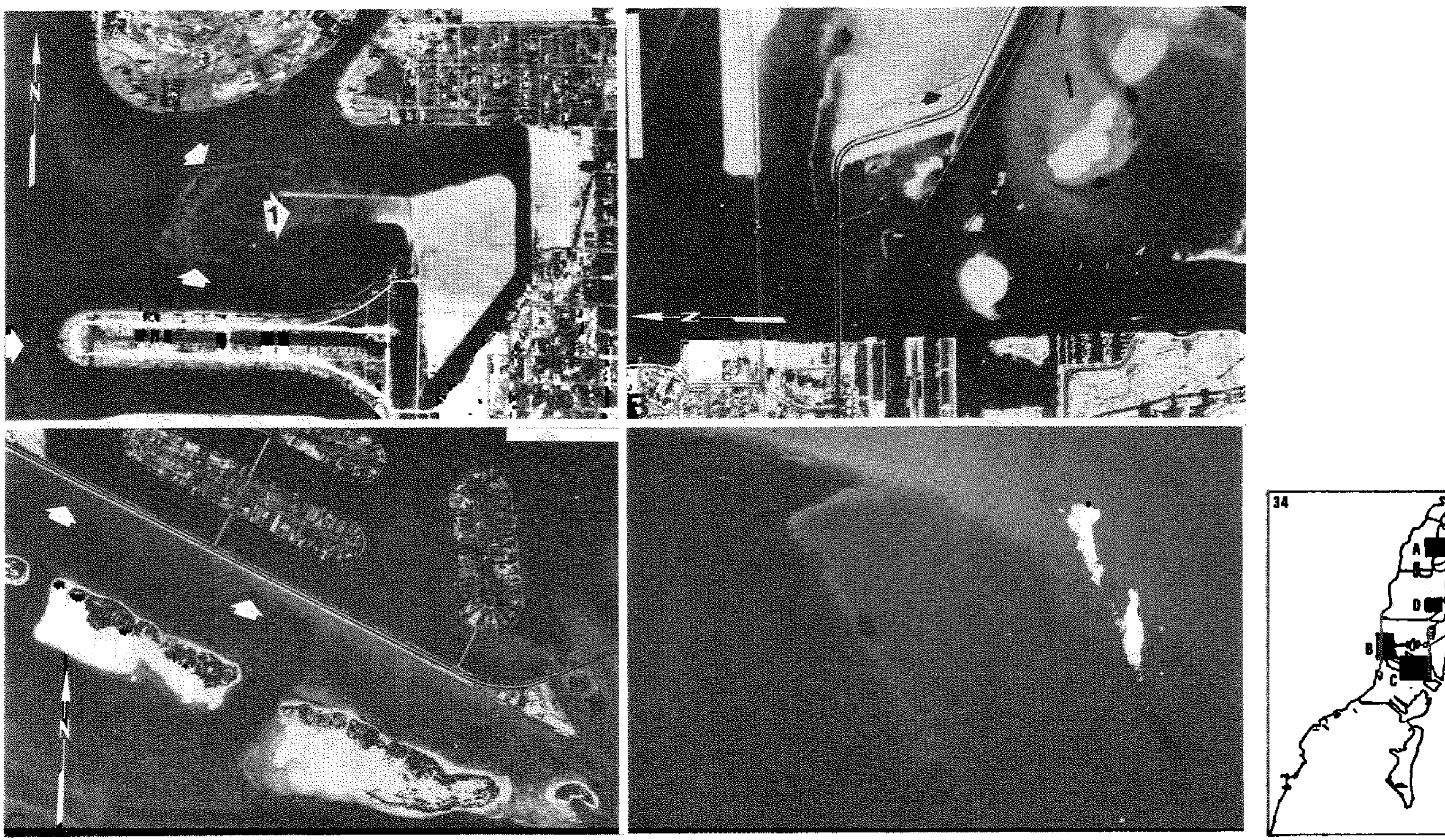


Figure 34. Examples of turbidity: A: 1940 view of turbid runoff from the filling of Stillwater Point (1). Note the remnants of the shallow bottom shown in Figure 13 (arrows) (USGS, CJF-14-72). B: 1928 view of turbidity originating from the original Dodge and Watson Islands (wide arrows). Turbid plumes from the former are moving into the Ship Channel and then east (small arrows) (NOAA, 697-457). C: 1940 view of turbid water moving along MacArthur Causeway (arrows) (USGS, CJF-10-03). D: 1978 oblique view of channelized turbid water moving south (upper right to left) in Melloy Channel. Note the lush benthic vegetation growing at the sharply defined channel edge (arrow) (photo by author).

the fill or spoil site (Figure 15). Dredging exposes unstabilized sediments that can be eroded subsequently, which adds significantly to turbidity levels. Resuspension of fine grained sediments from the bottom of dredged holes may be especially important in those dredged features that are used frequently by boats.

Boat traffic is largely concentrated over the dredged bottoms where more depth is available. A review of boat wave effects is found in Appendix B. Boat induced currents from movement, propellor wash (Figure 27) and boat waves (Figure 28) all combine to elevate erosive energy levels in dredged areas. Turbidity levels may be greater and are more likley to be sustained in very active channels and marinas where boat traffic is abundant.

The majority of the dredged holes in the Bay have not filled in since they were constructed, however, filling in is possible in some cases (Figure 29f). Wanless (1976b) has documented changes in sediment texture and a loss of seagrass beds adjacent to a borrow pit located off the northeast shore of Key Biscayne. He noted increased substrate erosion next to the pit and smothering of their seagrass beds by subsequently mobilized sediments. Infilling has also occurred in a borrow pit dug in Norris Cut (Wanless, 1976b; Figure 29). Some of the beach erosion at the northeast corner of Virginia Key and south of the Cape Florida lighthouse is directly related to a net flux of sediment into adjacent borrow pits. Chemical pollutants can become trapped in stagnant dredge holes. Previous pollution studies, however, failed to recognize the abundance of dredged bottom being studied, and may therefore have overemphasized the role of chemical pollutants in the Bay.

Disturbed Bottom Changes

The graph of disturbed bottom (Figure 26) is nearly identical to the dredged bottom graph. Since disturbed bottom is comprised of both dredged and spoil bottoms, the similarity shows that dredging is more significant. The 1976 plots on both graphs are slightly different for Areas II and VI where spoil is now more abundant. Spoil covers less than 3 sq km of the present bottom of northern Biscayne Bay (Table 10, Figure 19).

Submerged spoil is dumped along the edges of dredged holes, adjacent to waterways, and next to spoil islands. Dumped spoil smothers the previous habitat and is subject to erosion by waves and currents (Wanless, 1976b).

Dumping of spoil decreases water depth at the site which can cause circulation changes. It also provides a new shallow bottom that may be more suited to plant growth because of better light conditions. The shallow spoil platform left behind migrating spoil features are commonly colonized by marine plants (Figures 24 and 33).

Coarse grained spoil colonized by rooted plants (such as the top of core 615-9, Appendix A) may resist erosion by strong currents. The west edges of Melloy Channel in Areas III and IV, and both edges of the Intracoastal Waterway are thinly covered by patches of rocky spoil. This spoil is colonized by plants and the Melloy Channel example has survived erosion by hurricane produced currents (Figure 25).

Benthic Vegetation Changes

The two graphs at the bottom of Figure 26 relate the changes in benthic plant cover. The amount of the bottom colonized by benthic plants has decreased substantially since 1925, except in Areas I and II where it has increased (Tables 3 through 10, Figure 20 and 21).

The majority of the macro vegetation seen in 1925 is growing on bottoms less than 2 m deep. Benthic vegetation is not detectable in the 1925 aerial photographs of Areas I and II, and the vegetative cover is sparse and patchy in Area III. Because of extensive pre-1925 dredging and uncolonized deeper bottom near the mainland, Areas IV and VI show very little benthic cover.

Areas I and II have marked increases in benthic vegetation by 1928 (Figure 25) when the shallow bottoms along the east side are colonized by moderately lush plant communities (Figure 25). The sparse beds seen on the shoal that crosses Area III increase in vegetative density as well (Figure 25).

The shallow banks of the Safety Valve tidal mudbar belt are covered by a diverse assemblage of benthic organisms (Voss and Voss, 1955). The patterns produced by these communities have changed frequently in the past as seen in Figure 25. The shallow bottoms adjacent to the mainland shore south of Brickell Point, are quite dynamic as well. After some hurricanes vegetation patterns here mimic bedrock topography with more plant growth over presumed karst features (Kohout and Kolipinksi, 1967; Zieman, 1972).

Significant benthic macro-vegetation has not been detected in the 1976 aerial photographs on bottoms deeper than 2 m except in Area VII. With the exception of some surficial algal mats, few plants were observed below 2 m when snorkeling in natural or artificial deep areas north of Rickenbacker Causeway.

Increases in benthic vegetation can be offset by other decreases. The shallow east side of Areas I, II and III show substantial increases in plant cover between 1925 and 1928 (Figure 25). By 1976 most of this new vegetation was destroyed by dredge and fill operations that consumed most of the shallow bottom. The overall vegetation increase in the northernmost Areas is the result of water quality changes occurring between the 1925 and 1928 photographic dates. The only significant change in this period was the opening of Bakers Haulover Cut in 1925, which resulted in an improvement in circulation (Michel, 1976) that also decreased salinity (Teas *et al*., 1976) and temperature fluctuations that stress marine plants.

Newly created shallow bottoms are capitalized upon by seagrasses and algae. Both spoil substrates and natural shoal areas can have been rapidly (1 to 3 years) colonized by some plant species (Figures 29b and 35).

Large decreases in benthic vegetation have occurred as the direct result of dredging and burial by fill and spoil. Decreases caused by pollution, smothering with mobilized spoil, and direct boat scour are insignificant at the scale of this study. Linear scour marks in the seagrass beds in the center of Area VII are probably the result of trawling with fishing nets as the water is too deep for them to be caused by boats directly. This area has been a shrimping ground in the past.

Hurricanes produce many changes in the Bay's benthic floral beds. The 1926 hurricane eroded benthic plants along the Cape Florida shoreline, on one channel bottom in the Safety Valve, in Bear Cut (Figure 25), offshore of Virginia Key, from the Bay side of Norris Cut, from Melloy Channel just north of MacArthur Causeway, and in the vicnity of Lummus Island. Other vegetated bottoms appear intact in 1928, except in the bedrock depressions along the south mainland shore of Area VII where a decrease in width of

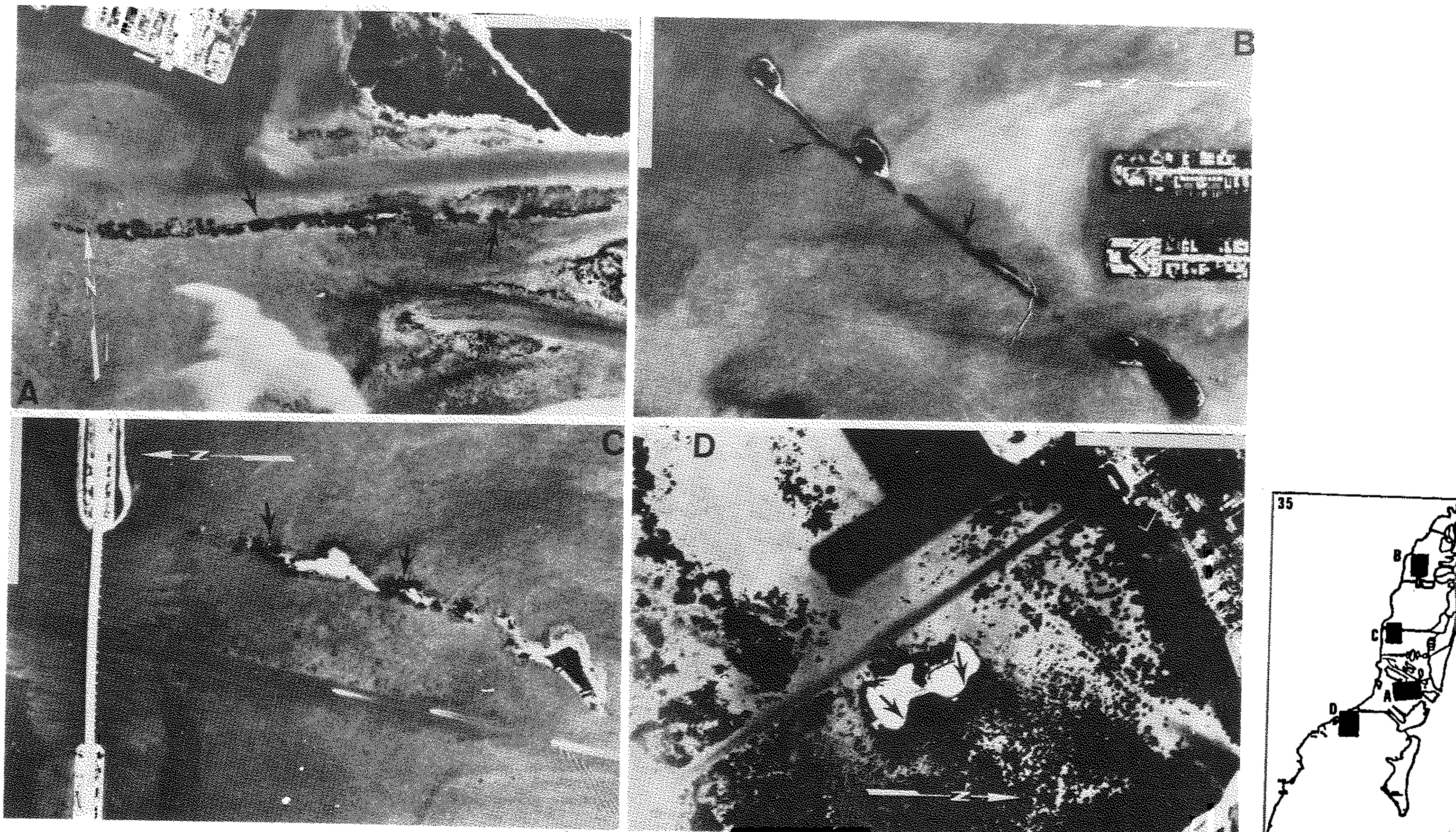


Figure 35. Examples of benthic vegetation growing on spoil (arrows): A: 1976 view from Area VI. (Fla. Dept. Transportation, PD 1638-20-22). B: 1976 view from Area II. (Fla. Dept. Transportation, PD 1638-21-33). C: 1976 view from Area IV. (Fla. Dept. Transportation, PD 1638-21-29). D: 1976 view from Area VII. (Fla. Dept. Transportation, PD 1638-21-26).

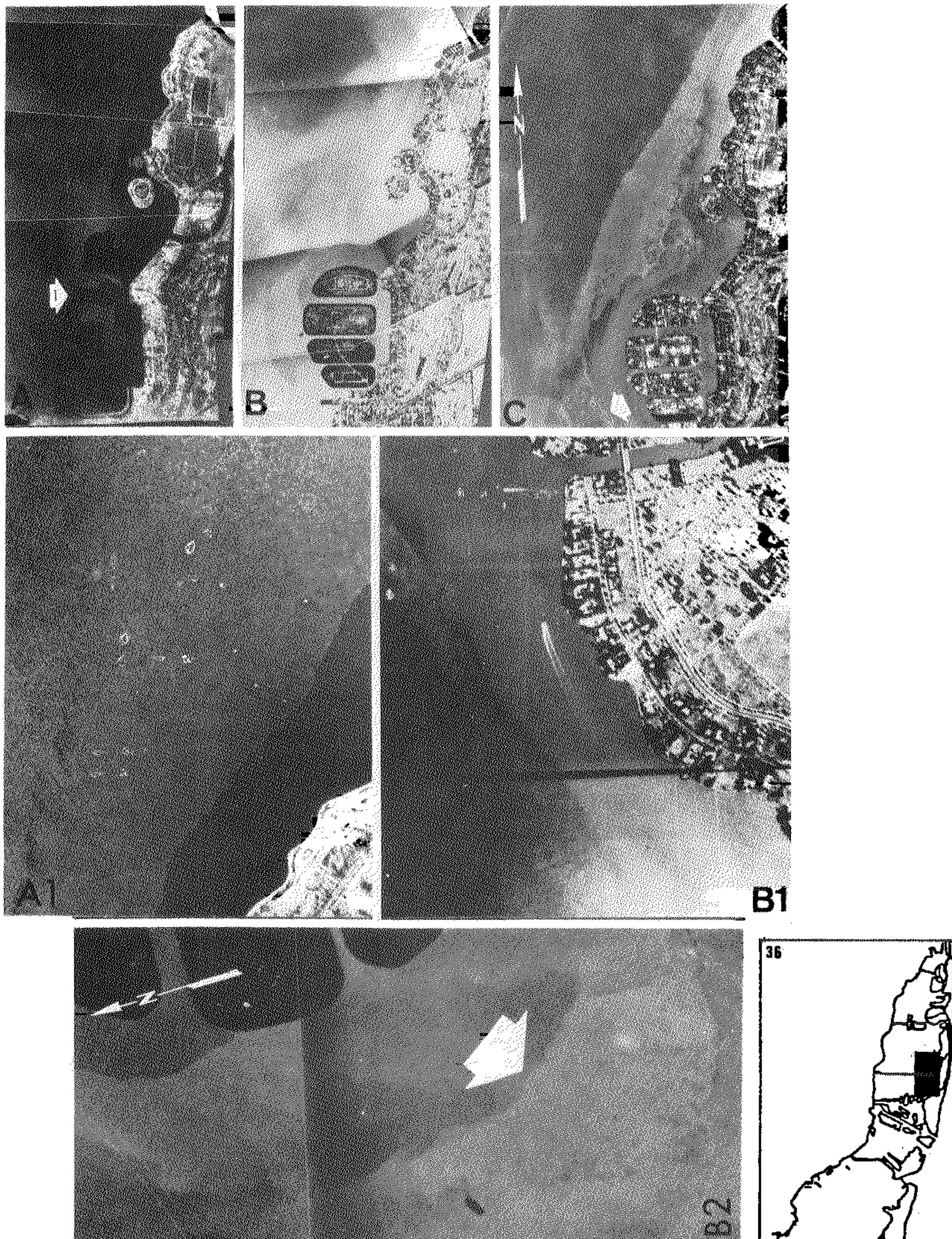


Figure 36. Benthic vegetation changes along Melloy Channel produced by hurricanes: A: 1925 photomosaic shows original mangrove Sunset Islands (1), well defined dredged areas, and even, but sparse vegetation on undredged bottoms west of Melloy Channel (see enlargement A1) (Miami-Dade Library). B: Same area in 1932. Turbidity obscures some detail but bottom vegetation is now lush (B1) except at the tip of the "boot" that was eroded by 1929 hurricane (B2, arrow) (NOAA, 806-68, -70, -72, -74). C: Same area in 1940. Severe erosion of benthic vegetation by 1935 hurricane over a large portion of channel margin. The "boot:", recolonized after 1929, is not eroded however (arrow) (USGS, CJF-10-03).

pre-storm grass patches is evident. Part of this decrease could be related to ground water discharge changes (Kohout and Kolipinski, 1967). The 1926 hurricane had minimal effect on the Safety Valve banks. Lack of photographic coverage of the more southerly banks prevent a complete analysis of this area however.

The 1929 hurricane, based on the availability of information, might seem unimportant because terrestrial damage was light and few people were injured in Miami. However, this storm is proposed as the cause of severe erosion of seagrass beds (principally Thalassia) from the banks in the Safety Valve (Figure 36). The shoal west of southwest point (Key Biscayne) also showed new bare spots in the attached vegetation after this storm. Benthic vegetation was again eroded from the bottom west of Norris Cut and floral beds are reduced between Lummus and Dodge Islands and the FEC Railway Channel (Fisherman's Channel). The latter change could also be caused by smothering related to spoil island construction. This storm also eroded plants from the "toe of the boot" outlined by dredged holes just north of Belle Island (Area IV); see Figure 36. Further north the western margin of Melloy Channel was slightly affected as was the undredged bottom at the northeast corner of Area III.

The most striking bare bottom area in the 1940 photographs is a large swath that runs north from Venetian Causeway along the edge of Melloy Channel (Figure 36c). The benthic vegetation there has been completely lost from the bottom. Evidence for erosion is found in core 615-8 which contains a zone of coarse grained layers 15 to 30 cm below the surface. There are three distinct layers in this zone that could represent three different storm events, each producing an erosional lag. A 1935 date is interpreted for the top of these layers because the erosion shown in 1940 (Figure 36c) most likely resulted from the 1935 "Yankee Hurricane". Storm surges from north to south could have been "aimed" by the easternmost Venetian Causeway islands, forced out of the channel, and flowed over the adjacent undredged bottom where it eroded the substrate.

The extreme southeast corner of the undredged bottom in Area IV was eroded in the 1929 storm but not in the 1935 hurricane (Figure 36b). This area might have been protected by a coarse grained (shelly or rocky) lag produced by 1929 storm erosion, and later recolonized by seagrasses. The resulting root bound coarse substrate should have protected the substrate from subsequent erosion. This physical-biological "armor" could provide a mechanism for the protection of substrates from erosion in periods when one storm is closely followed by another. Spoil areas along Melloy Channel (Figure 36) that are colonized by seagrasses have also resisted erosion when adjacent natural bottoms have not.

Other damage to the Bay's benthic vegetation between 1929 and 1940 is probably storm related. Benthic cover was lost from shallow bottoms west of northern Key Biscayne, and there is a noticeable decrease in vegetation density in the vicinity of Fair Isle (Grove Isle). Finally, some of the small seagrass beds on the tidal delta west of Bakers Haulover appear to be buried by new sand lobes, and the small floral beds west of Biscayne Point (Area II) are less dense.

Frosts are responsible for some fish kills within northern Biscayne Bay (Munroe and Gilpin, 1930; Simpson, 1932) and they may exert an influence on benthic vegetation. The relative importance of killing frosts and extended cold weather on the Bay's benthic communities is unknown.

The "grass" index is used to show approximately how much of the original bottom is stabilized by benthic plants. Since undisturbed bottoms in the Bay tend to be shallower than dredged bottoms (Figures 18 and 19), any Area with a low "grass" index has significant amounts of unvegetated shallow bottom. Areas II and IV have the lowest "grass" indices. The low value in Area II is attributable to the areas original (1925) lack of benthic vegetation and slightly deeper natural bottoms (U.S. Coast and Geodetic Survey, 1887). The low value in Area IV is probably the result of high turbidity levels south of Julia Tuttle Causeway, however, this cannot be proven. The highest "grass" index is Area III's which has large shallow cross-bay shoal that is extensively colonized by algae and seagrasses.

Seagrass beds and many algal communities can produce prodigious quantities of new sediment. Sediment is produced by some plants and other organisms that live in the substrate or grow epiphytically on the plant (Ginsburg and Lowenstam, 1958; Wanless, 1967; Scoffin, 1973). Additional sediment can be transported into the plant community where it may become trapped (Ginsburg and Lowenstam, 1958). The plant and sediment accumulation can be eroded by various processes which release the fine sediments to the water column. An increase in benthic cover should increase the rate of sediment production by epiphytic organisms, some of which is fine grained enough to be released during erosion of the substrate. This effect should raise turbidity levels in the water for some time after the erosion occurs.

The overall decrease in benthic vegetation (Figure 26) has affected the biological productivity of the Bay (Thorhaug, 1976). Less sediment production by benthic organisms is expected but more of the bottom is unstabilized by plants. An increase in bare bottom increases the potential sources for easily suspended sediments that can affect turbidity levels (Wanless, 1976b).

Cores

Short cores were taken throughout northern Biscayne Bay at sites (Figure 9) selected both to check preliminary interpretations and to clarify confusing aerial photography. Core sequences were used to determine sedimentation rates for various parts of the bay. Descriptions for the eleven cores taken can be found in Appendix A. Five cores are especially important and are discussed below. Additional core data can be found in Wanless (1967, 1969) and the U.S. Army Corps of Engineers (1943). Wanless (1967,1969, 1976a) also provides cross sections based on coring and probing transects which show the general packages of Holocene sediment in northern Biscayne Bay (Figure 10).

Core 614-1 penetrated to bedrock in an abandoned dredge channel that trends north-south in Area I (Figure 24). This channel was part of the original Intracoastal Waterway dug between 1925 and 1928 and later abandoned for the present Intracoastal Waterway in Area I. The old channel is outlined by sparse seagrass beds dominated by *Syringodium* but with minor *Thalassia*. The channel outline can still be seen in air photographs (Figure 24). At the core site the channel bottom is 45-50 cm lower than the surrounding substrate.

Core 614-1 is divisible into three parts: an upper grey carbonate sand, a 2 cm thick coarse-grained shelly sand at 13-16 cm below the surface, and a lower grey shelly sandy mud with many plant fibers and balls of mangrove detritus. The upper surface of the core is bound by an algal mat, and the upper part contains minor amounts of quartz sand and plant detritus with rare shell. Internal laminae are not apparent. The coarse shell sand layer is made up of blackened whole shells (mostly bivalves), shell fragments and quartz sand grains. The lower part of the core, faintly laminated by alterations of mud and sand, shows a fining upward sequence with mud more abundant towards the top. A small (0.5 cm) oolitic limestone fragment (Pleistocene) was found at the coarse sandy bottom of the core of 28 cm. There are no seagrass rootlets visible in any part of this core.

The coarse shell sand layer in the middle of core 614-1 may have been produced by natural storm winnowing. It is however more likely the product of dredging the old channel as suggested by the reworked blackened shell material and its position between two distinct sediment types. If this interpretation is correct then the upper 17 cm of sediment has accumulated since 1925-1928. The sedimentation rate in Area I is then calculated at approximately 2.9 mm per year (using 1927 as the date of the coarse shell sand layer). This corresponds well with rates from two other areas, discussed below.

The sediments in Core 614-1 are different above and below the coarse shell sand layer. This is evidence that the style of sedimentation in Area I has changed significantly since the 1920's. This change can be related to destruction of coastal swamps, changes in shoreline character, and changes in circulation and water chemistry. Circulation and water chemistry in Area I were strongly affected by the opening of Bakers Haulover Cut in 1925 (Michel, 1976; Teas *et al*., 1976).

Four cores were taken from sites in the middle of Area III. Two of these sites are in and two are adjacent to the 1896 Florida Coastline Canal and Transportation Company channel that trends north-south in mid-bay. Cores 614-5 and 614-6 are from the channel and were taken about 25 m apart (-5 north of -6). Cores 614-7 and 614-8 were taken from the bottom adjacent to the channel. The channel is still visible in air photos because of benthic vegetation patterns, and it retains a relief of about one meter below the surrounding substrate. In June, 1978 a few sparse patches of seagrass (Syringodium) were growing in the channel proper. The channel margins were lushly colonized by a red algal community with Laurencia dominant and lesser amounts of Dictyota. In places, this algal community is one meter in thickness and extends over much of the adjacent undredged bottom. Portions of the undredged bottom adjacent to the channel are colonized by circular patches of dense Halimeda as much as 2 m in diameter. Bare patches of bottom in this area are predominantly a coarse sand of whole Halimeda plates with little fine sand or mud (see top of cores 614-7 and 614-8 in Appendix A).

Both cores 614-5 and 614-6 show a distinct change in sediment attributes occurring between 20 and 25 centimeters depth. Below this depth, both cores contain alternating layers of shelly sand and mud. This layering is typical of the lower portions of all the intra-bay cores. Above 20-25 cm, the sediments are rarely laminated and coarser grained overall. Small, broken plates of the calcareous green algae Halimeda occur only in the top 5 cm of each core. In cores 614-7 and 614-8, a less distinct change in sedimentation occurs between 15 and 22 cm. Halimeda was found in them as deep as 15 cm and whole Halimeda plates dominate the present surficial sediments.

The change in sediment attributes at 20 to 23 cm in cores 614-5 and 614-6 is interpreted to record the lower limit of dredging in the canal in 1895-1896. The project depth of 1.7 m, if adhered to, would have left some sediment overlying the bedrock which is about 2.5 m below mean low water. Therefore, the upper sediment package accumulated since 1896 yields a sedimentation rate of about 3.0 mm per year in the center of Area III. If this is correct, the occurrence of Halimeda plates only in the upper 5 cm of 614-5 and 614-6 predicts that Halimeda first made its appearance to Area III about 15 years ago. This would be right after construction of Julia Tuttle Causeway in 1960. Completion of this causeway to the south modified Area III by: (1) focusing tidal flow into the bay margin channels (Melloy and the Intracoastal Waterway) which should have reduced turbidity levels in the center of Area III; and (2) isolating the area from potentially more polluted waters to the south. Halimeda plates may be accumulating at a faster rate on the shallower bottoms adjacent to the channel as suggested by the lower depth limit of Halimeda plates found in cores 614-7 and 614-8 or this could be evidence for an earlier introduction of Halimeda to Area III.

Core 615-8 was taken from a shallow bottom sparsely covered with the seagrass Syringodium, adjacent to Melloy Channel below Julia Tuttle Causeway (Area IV). The area is characterized by abundant boat wave and natural current activity and by high turbidity levels. This core can be divided into four sedimentological zones: (1) an essentially featureless muddy carbonate sand in the top 13 cm; (2) three distinctly different coarse grained, shelly quartz sands between 13 and 31 cm; (3) a varied sequence of shell sands that show bioturbation (burrowing) between 31 and 38 cm; and (4) the lower 28 cm of alternating shell sand and mud layers.

The core site was vegetated prior to the 1935 hurricane as seen in Figure 36. In the 1940 vertical photography the site is bare. As discussed in the hurricane section, one or more storms are responsible for this damage. The three layers of coarse grained, shelly quartz sand at 15 to 29 cm are interpreted as storm lag deposits caused by bottom erosion, winnowing of fine sediments and concentration of the coarser grained shells. The upper coarse layer (13 to 22 cm) can be correlated to the 1935 hurricane season and can then be used to calculate a sedimentation rate. The topmost 13-15 cm in this core give a calculated sedimentation rate for this part of Area IV of 3.4 mm per year.

In summary, sedimentation rates calculated from cores taken in northern Biscayne Bay range from 2.9 to 3.4 mm per year. The increase in rate from north to south is probably not meaningful as each Area can have its own hydrological and sedimentological attributes. In all the cores discussed (and several others), a distinct change in the character of sediments occurs near the top. The uppermost sediments are generally coarser grained and poorly laminated, if at all. The coarser surface sediments are interpreted to date since the onset of urbanization in the Biscayne Bay region. Finally, the lack of abundant mud and silt in the surface sediments of a highly turbid area suggests that suspended sediments produced and transported in northern Biscayne Bay are not accumulating in the shallower areas cored. The suspended sediments may be accumulating in southern Biscayne Bay, in the deepest dredged holes, or transported offshore by way of the inlets and cuts. Elevated wave energy levels, related to a predominantly bulkheaded shoreline and abundant boats, could be the important reason for the observed change in the character of northern Biscayne Bay sediments.

CONCLUSIONS

The stated purpose of this study is to document the historical changes in the terrestrial, shoreline and submerged environments of northern Biscayne Bay. To accomplish this purpose I have discussed the pre-development and present setting, and I have provided a scenario of the important historical events that have combined to produce the present distribution of Bay environments.

Historical vertical aerial photographs are a unique resource. They provide a window to the later stages of the Bay's development from "a parcel of pitiful flats" (Romans, 1775) to its present distribution of urbanized and modified environments. Because of the limited amount of previous study of northern Biscayne Bay, historical aerial photographs are the only available source of new information about past events. Historical, vertical aerial photographs are therefore an extremely valuable tool for environmental analysis, yet most prior studies have failed to recognize and capitalize upon this tool.

The before and after maps presented herein (Figures 16 through 21) show dramatically the major changes in the Bay's environments occurring between 1925 and 1976. Measurement of the mapped environments has yielded the following major trends:

1) The amount of land area has increased.
2) The amount of developed land area has increased substantially. Some areas were extensively developed prior to 1925. Most of the terrestrial area studied is now developed.
3) The amount of mangrove land area has decreased substantially. The only significant stands of mangroves remaining are located

in the northernmost and southern sections of the study area.

4) Shoreline length has doubled since development began.

5) Mangrove shorelines were once common but they are essentially non-existent in northern Biscayne Bay today.

6) Vertical/bulkheaded shorelines are now the most common shoreline types. Most of the increased shoreline length results from the creation of new bulkheaded shorelines.

7) Sloping shorelines, principally constructed with dredge spoil, have increased in abundance. This is especially true north of Rickenbacker Causeway.

8) The amount of open water area has decreased.

9) The amount of dredged bottom has increased. Much of the dredging occurred prior to 1925.

10) The overall amount of benthic vegetation has decreased substantially since 1925. However, plant abundances have increased on the bottoms north of 79th Street Causeway. This increase is significant.

11) The "grass" index has decreased except north of 79th Street Causeway. Overall there is less vegetation growing on undisturbed bottoms today than there was in 1925.

12) Turbidity is persistent around the 79th Street Causeway and the Miami Harbor complex of islands and channels. Turbidity is generally more common in the more recent photographs.

The terrestrial and shoreline environments of northern Biscayne Bay are the province of man. The natural changes resulting from physical and biological processes acting on these environments are insignificant when compared to the effect of urban development. The land areas studied are drastically modified, and the few remaining natural areas are heavily stressed. The present shoreline has retained very little of its former character. The abundant bulkheaded shoreline, resulting from dredge and fill operations, is capable of maintaining wave energy within the Bay.

In contrast, over half of the submerged Bay bottoms are not modified to any appreciable extent. Dredge holes have produced a "strip mine topography" which is imprsssive, but much of the original bottom area remains intact, and much of this is vegetated.

The Bay proper is not dead. It is not an open cesspool and I doubt that is has ever been that way. Indeed, plant abundance has increased in a few areas since 1925, and the shallow bottom north of Julia Tuttle Causeway has recently seen the introduction of a geologically important calcareous green algae, Halimeda.

For too long now, the submerged portions of the Bay have been written-off by both developers and some environmental scientists as being beyond saving. Restoration is the present operative word when discussing the future. Restoration will be important, but the future of northern Biscayne Bay will depend on saving, studying and understanding the environments that have survived over eighty years of urban development and natural stress.

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Appendix A

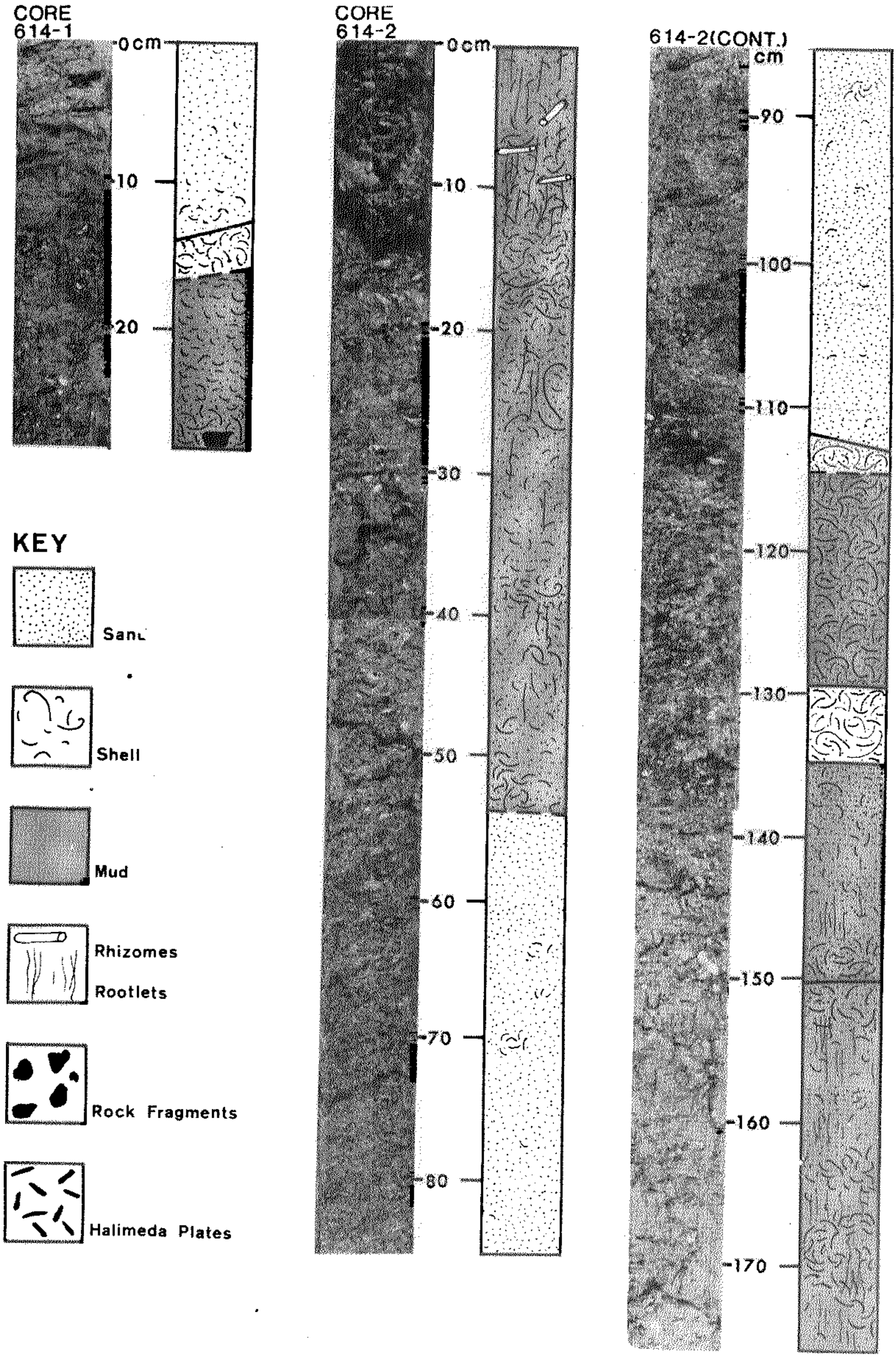
Core Descriptions

The following set of figures is a photographic documentation and description of the sediment cores taken in northern Biscayne Bay. Figures are organized by sample numbers running from 614-1 through 614-8 and 615-7 through 615-9. Sample 614-2 is presented in two adjacent rows because of its length.

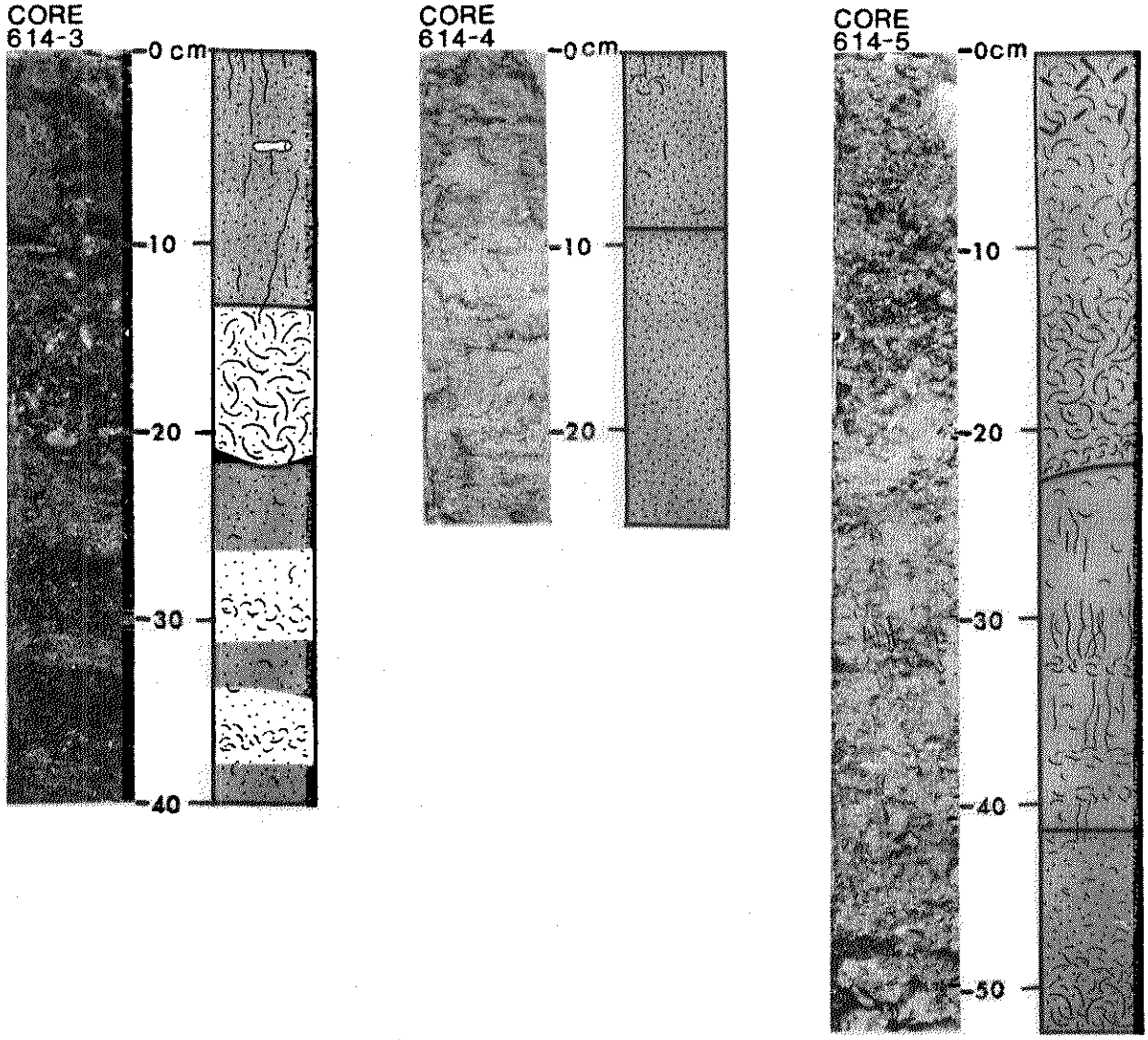
Core locations are shown in Figure 9 and the sample numbers are organized by Area as follows:

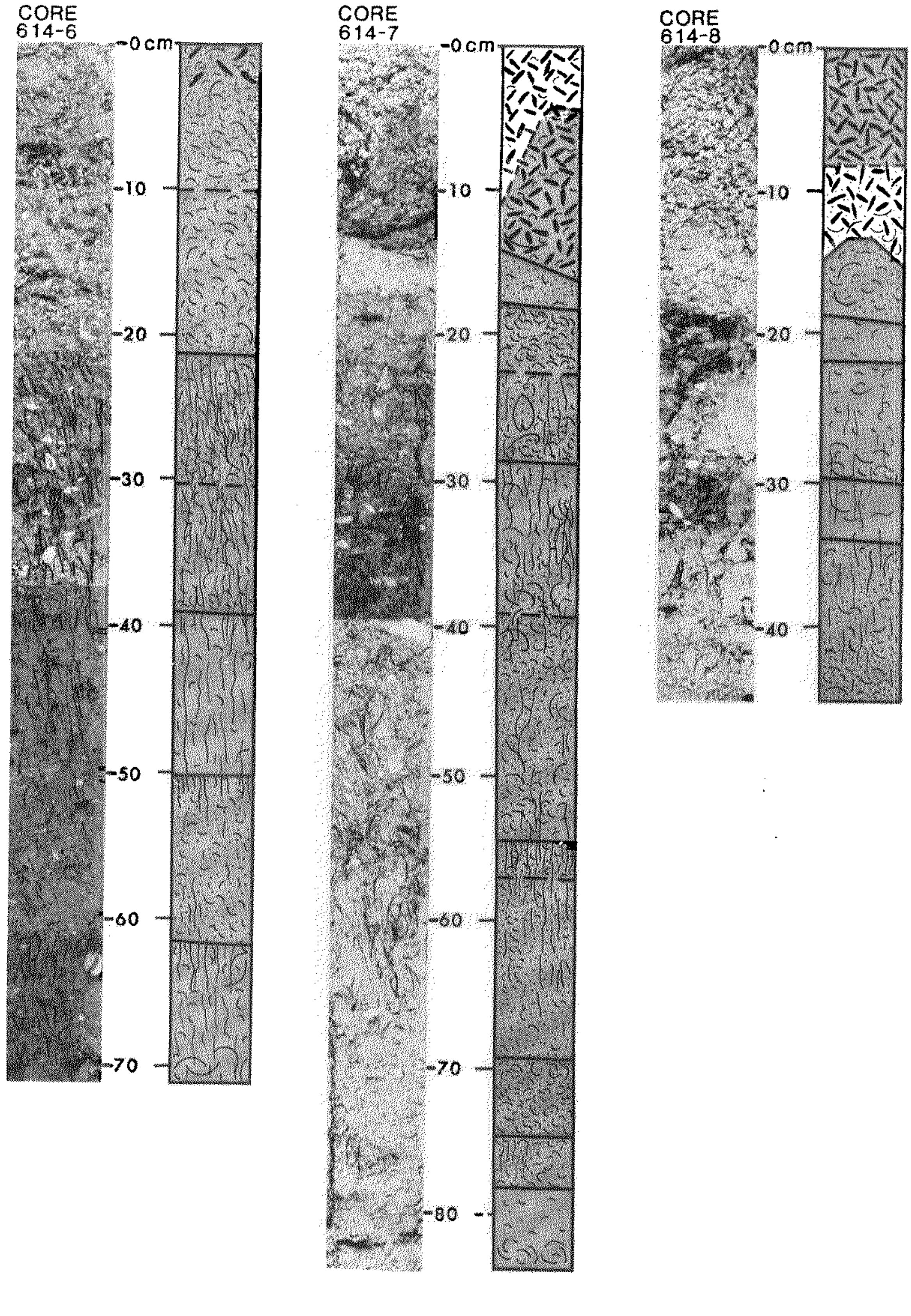
Area	Sample No(s).	Bottom Type	Approx. Water Depth (meters)
I	614-1	Dredged	2.0
II	614-2	Undisturbed	0.5
	614-3	Dredged channel margin	1.0
	614-4	Dredged	2.5
III	614-5	Dredged	2.5
	614-6	Dredged	2.5
	614-7	Dredged channel margin	1.0
	614-8	Dredged channel margin	1.0
	615-9	Dredged channel margin	0.5
IV	615-8	Undisturbed	1.5
VII	615-7	Undisturbed	1.5

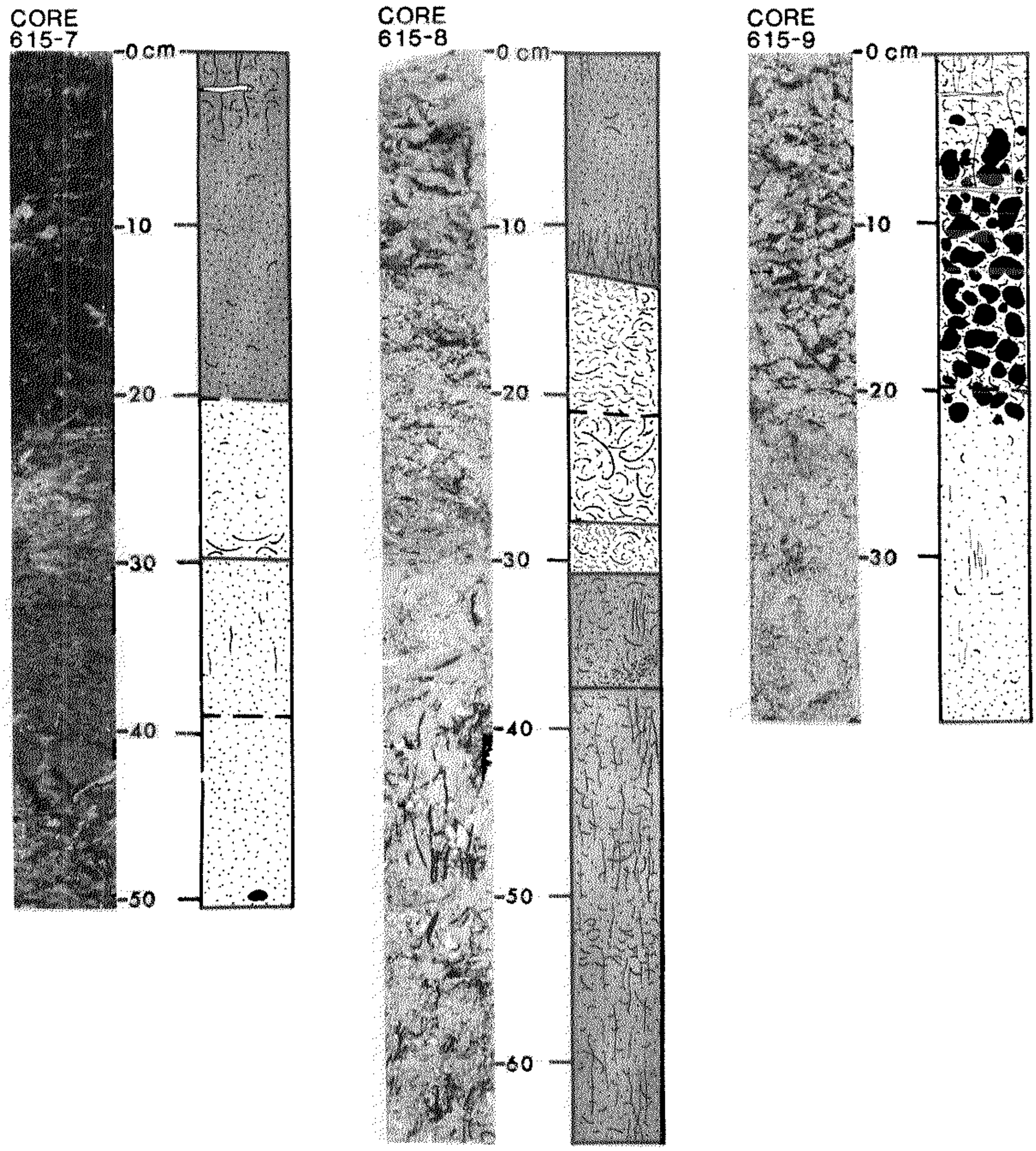
A photograph of the total core sequence is on the left side and a schematic description of the major sediment types is on the right, separated by the depth below substrate surface scale. The last is in centimeters. A key to the patterns shown in the schematics can be found at the bottom of the first figure. Solid horizontal lines show sharp contacts between sediment units and dashed lines represent gradational contacts.



CORE
614-1
0 cm
10
20
CORE
614-2
0 cm
10
20
30
40
50
60
70
80
614-2(CONT.)
cm
90
100
110
120
130
140
150
160
170
KEY
Sand
Shell
Mud
Rhizomes
Rootlets
Rock Fragments
Halimeda Plates


CORE 614-3
0 cm
10
20
30
40
CORE 614-4
0 cm
10
20
CORE 614-5
0cm
10
20
30
40
50


CORE
614-6
0 cm
10
20
30
40
50
60
70
CORE
614-7
0 cm
10
20
30
40
50
60
70
80
CORE
614-8
0 cm
10
20
30
40


CORE
615-7
0 cm
10
20
30
40
50
CORE
615-8
0 cm
10
20
30
40
50
60
CORE
615-9
0 cm
10
20
30

APPENDIX B: Boat and Ship Processes

A moving vessel is a source of energy in the form of surface waves generated as the vessel moves through water (Johnson, 1958). This is important in northern Biscayne Bay because there were at least 5,000 boats wet berthed in Dade County as of 1976 (Austin, 1976).

Two distinct types of waves are produced behind a moving boat: transverse and diverging waves. Where these two wave types intersect (crest to crest) a larger wave is produced (called a "cusp"). Both types of waves have curved crests whose form is controlled by ship speed and the behavior of the wave in shallow water.

The wave height is a function of the boats hull characteristics, and wavelength is directly proportional to the ship speed. As speed increases wavelength increases (Johnson, 1968; Bascom, 1958). Width of the wake increases as boat speed increases. When vessel speed becomes equal to the theoretical shallow water wave velocity of the wake waves the wake pattern changes and the transverse waves disappear. The wake narrows and wave height reduces to a lower speed wake pattern. Most displacement hull vessels never reach the transition speed because of hull and power limitations. Planeing hull boats decrease displacement as they begin to plane on the water surface which may reduce the size of their wake waves.

Johnson (1958) found that wave period was independent of the distance away from the producing vessel. Vessels with better "lines" tend to produce smaller waves although potential speed and the potential shoaling wave height may be greater. The speed that produces the largest wave is different in each type of hull design. Data presented by Das and Johnson

(1970) suggests that recreational boats on occasion produce more wave energy than big ships.

Water depth strongly influences wave parameters. Boat and ship waves produced in shallow water differ from those that are produced in deep water and then move across a shoaling bottom (Johnson, 1968). The important factor that controls wave size is the ratio of boat draft to water depth. In shoaling water, some small boats can produce breaking waves of greater height than those produced by a larger vessel, even when the small boat is moving at a lower speed (Hay, 1968).

Artificial boat produced waves are important because they can erode shallow bottoms, spoil shorelines, submerged or exposed channel banks (Das and Johnson, 1970), and they are capable of causing property damage.

In northern Biscayne Bay wind waves are limited in size because of the short fetches available (except south of Rickenbacker Causeway); boat waves are not. In northern Biscayne Bay boats are abundant and active on a regular basis. Many boat waves originate in waterways over dredged bottoms, and are subsequently reflected off of the abundant vertical bulkheads lining the bayshore. This suggests that boat waves are a major source of the energy needed to resuspend fine grained bottom sediments. A thorough study of boat wave phenomenon in northern Biscayne Bay is needed.

Boats also produce waves and currents within the water body they pass through. Turbulent eddies (propeller wash) can erode bottom surfaces. Figure 27 shows two examples of turbidity produced by side thrusters or tugboat propellors alongside of Dodge Island. The oil barge making daily trips to Turkey Point in south Biscayne Bay has been observed to produce turbid plumes in the Intracoastal Waterway. Elevated turbidity levels are certainly in part maintained by erosion from boat and ship produced currents.

Power boat propellers can erode bottom sediments and benthic plants directly. Propeller scour marks are common on most shoals in the bay (see Craighead, 1964; U.S. Department of the Interior, 1973). This erosion can produce small amounts of suspended sediment and the scour marks persist as bare scars for long periods of time (Jones, 1968). Since scour marks in plant beds recover slowly they are important erosive agents in shallow floral communities.