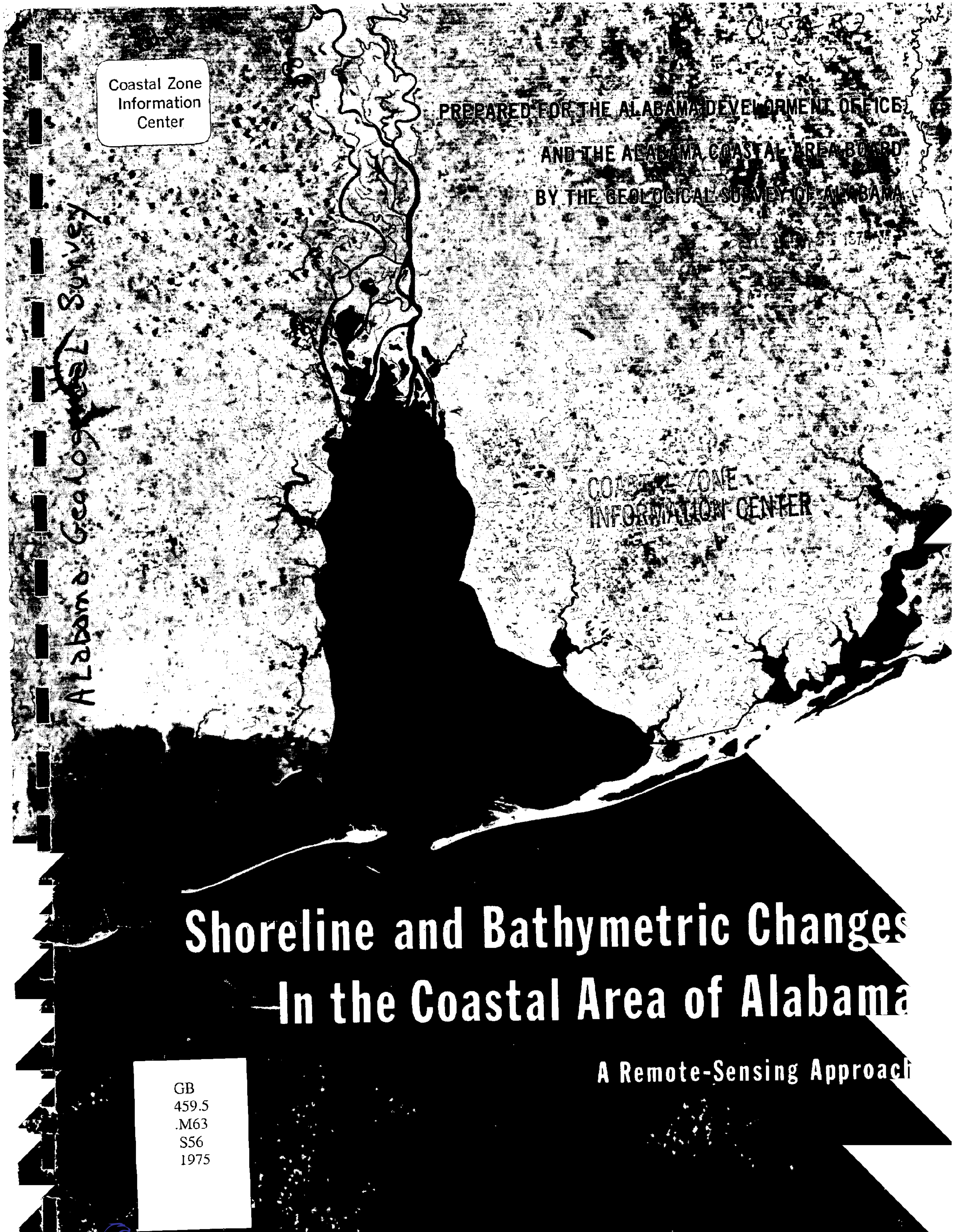

PREPARED FOR THE ALABAMA DEVELOPMENT OFFICE
AND THE ALABAMA COASTAL AREA BOARD
BY THE GEOLOGICAL SURVEY OF ALABAMA

Shoreline and Bathymetric Changes In the Coastal Area of Alabama

A Remote-Sensing Approach

COVER: Alabama Coastal Area as seen from a 912 km (566 mi.) orbit by NASA's Landsat-1 (image no. 1698-15490-7) on June 21, 1974, at approximately 9:30 a.m. The image is filtered to emphasize the land-water contrasts.

Preparation of this Document

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SHORELINE AND BATHYMETRIC CHANGES IN THE COASTAL AREA OF ALABAMA

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The Environment of Offshore and Estuarine Alabama, 1974

History of Water Supply of the Mobile Area, Alabama, 1972

SHORELINE AND BATHYMETRIC CHANGES IN THE COASTAL AREA OF ALABAMA

A Remote-Sensing Approach

Geological Survey of Alabama
University, Alabama
June 1975

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Abstract: The shorelines and near-shore bottoms of Alabama's coastal area are in a dynamic state, constantly adjusting to the combined effects of natural processes and man's intervention. Approximately 56 percent of the shoreline is eroding. Small amounts of erosion may become critical in developed areas. In general, erosion is of most concern along the western shore, at Dauphin Island, and along the north shore of Morgan Peninsula where waterfront residential areas are directly affected. Sediments derived from materials carried by the Mobile River system and by currents eroding the shorelines are gradually filling Mobile Bay. Computer analysis of bathymetry shows that the lower half of the bay is filling most rapidly, but the pattern of deposition is very complex.

A NASA computer measurement of a part of the shoreline of Alabama used Landsat images and provided the basis for a preliminary estimate of the total shoreline length. This estimate is 1,313 km (816 mi.), which is considerably higher than map measurements made by conventional means because the technique measures the intricate detail of upper estuaries and other shoreline indentations.

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Conclusions

The shorelines and near-shore bottoms of Alabama's coastal area are in a dynamic state, constantly adjusting to the combined effects of natural processes and man's intervention. Some segments of the shoreline have been armored or stabilized by seawalls and are no longer free to adjust naturally to maintain a state of dynamic equilibrium. Approximately 56 percent of the shoreline of coastal Alabama is eroding. This erosion varies from 0 - 1.5 m (0 - 5 ft) per year to more than 3.0 m (10 ft) per year. Small amounts of erosion may become critical in developed areas. In general, erosion is of most concern along the western shore, at Dauphin Island, and along the north shore of Morgan Peninsula where waterfront residential areas are directly affected. Erosion along the western shore averages 0.97 m (3.17 ft) per year. The maximum amount of erosion along the western shore occurs at Cedar Point which experiences an average of 2.60 m (8.56 ft) recession per year. At Dauphin Island there have been rapid and disatrous shoreline alterations caused by hurricanes, especially along the western spit. The northern shore of Morgan Peninsula between Seymour Bluff and Catlins Bayou has eroded an average of 52 m (170 ft) between 1917 and 1974. Although other shores show rates of erosion equal to or greater than the rates affecting these areas, in most cases, those shores are uninhabited.

Sediments derived from materials carried by the Mobile River system and by currents eroding the shorelines are gradually filling Mobile Bay. The lower half of the bay is filling more rapidly than the upper half, according to computations based on soundings from nautical charts dated 1852, 1920, and 1973. Areas of most pronounced deposition are located in the upper bay where spoils disposal is occurring, and in the lower bay north of the tidal pass. However, the sedimentation pattern is very complex, with many areal variations that deserve further analysis.

Of the many passes and inlets within the changing configurations of the coastal area, the changing configurations of Petit Bois Pass, the Mobile Bay tidal pass, Perdido Pass, and Pass Drury were analyzed historically. Two of the larger passes, the Mobile Bay tidal pass and Petit Bois Pass, appear to occupy the drowned channels of pre-Pleistocene rivers, and to be "pinned" in their positions; other smaller passes such as Perdido Pass and Pass aux Herons must be dredged constantly to keep them navigable, and former natural passes such as Pass Drury have been completely filled and have been relocated artificially.

The length of Alabama's shoreline has been measured in various ways with a wide variety of tools. As a result, the true shoreline length is unknown; it has been officially reported as anywhere from 491 km (305 mi.) to 1,313 km (816 mi.). Manual measurements using maps and charts have omitted many intricate patterns of upper estuaries which should be included as part of Alabama's shoreline. The NASA measurements included in the present study were done by computer analysis of two satellite images of different dates, and yielded an average length of 1,000.4 km (621.5 mi.) measured from the Mississippi line to 87°42' W. (south of Foley. Measurement of the entire shoreline of Alabama was not within the scope of this project. A ratio technique provides an estimate for the total shoreline if done by this computer technique of 1,313 km (816 mi.). A final measurement of Alabama's shoreline will be done by NASA's Earth Resources Laboratory in the near future and the authors recommend that the results, when reported, be adopted by the Coastal Area Board as the total length of the state's shoreline.

Recommendations

This assessment of shoreline and bathymetric changes in the coastal area of Alabama is concluded with the following recommendations:

1) A further study should be initiated which utilizes the oldest useable NOS (formerly C&GS) topographic and bathymetric data available (approximately 1847) to determine shoreline and bathymetric changes over a broader span of time to follow up this report. As complete an inventory as possible of the past and present activities

of man in the coastal area should be included. This study would include establishing a baseline framework of geologic data for the coastal region. Such work was beyond the scope of the present project, since it would involve the geologic study of the sediments accumulated in the coastal area since sea level reached its present stand.

2) A 1975 coastal zone land-use assessment should be conducted and compared with the results of this study to determine what impact shoreline erosion has on commercial, transportation and residential shore land uses in the present and in the future.

3) A series of shoreline profiles should be established at selected points showing erosion, accretion, or dynamic equilibrium. The profiles should be redone semi-annually to establish short-term and seasonal variation so this monitoring activity should become a permanent part of the Coastal Area Board program. Summary technical reports on the short-term changes detected on the profiles and updated shoreline analysis using the latest remote sensing including automatic processing of Landsat imagery for shoreline changes and land-use changes should be prepared annually.

4) The wetlands of the coastal zone should be mapped in detail, using remotely sensed data augmented by field verification. The maps would be a valuable and

necessary complement to other physical and cultural (land-use) data to be generated. This wetland study would include mapping of the inland/upland boundary and high-tide marks as indicated by plant communities.

INTRODUCTION

The shorelines and near-shore bottom areas of coastal Alabama are constantly changing. This change is a result of both natural processes and anthropogenetic actions. Changes caused by natural processes may occur almost instantly, sometimes disastrously. High winds, waves, and extremely high tides generated by tropical storms and hurricanes may cause immediate and highly visible changes in the shoreline and near-shore bathymetry. In contrast, the rise and fall of the tides, wind and wave action, and the flow of tidal currents, active over tens, hundreds, or thousands of years, make their mark on the configuration of the shoreline and near-shore bathymetry slowly and sometimes imperceptibly. Because these processes do operate so slowly, a single observer can only record a small part of the long-term changes they cause, and must rely on the existing written records of previous observers in the form of manuscripts, maps, charts, and photographs.

In Mobile Bay and coastal Alabama, there are more extensive changes than those caused by nature - these are the changes caused by man's activities. Since the first colonization of the Alabama coast by the French in the early 1700's, man has been improving the bay by deepening natural channels; constructing wharves, jetties, groins, and seawalls; and filling in the bay to produce valuable real estate from the salt marshes. The effects of these constructions and repairs on the shoreline and near-shore bathymetry are infinitely variable with location, type, and extent of construction. In some instances, construction may cause extensive changes in the shoreline and near-shore bottom configuration that are easily measurable over a short time span; in other instances, there is little or no discernible alteration.

Changes in the shoreline and near-shore bottom can have great impact upon the navigation, fisheries, recreation, and residential uses of the coastal waters. Shoaling of important passes, inlets, and ship channels increase hazards to safe navigation and incur high costs of sediment removal and disposition. The deposition of sediment over viable oyster reefs can cause the loss of a valuable fishery resource and mean loss of livelihood to many coastal fishermen. Shoreline erosion may mean increased expense for seawalls, groins, or revetments to the recreation cottage owner or permanent resident, not to mention the impairment of scenic vistas caused by such constructions. Valuable waterfront property may be lost and buildings damaged or destroyed by shoreline erosion. Many residents and the sports fisheries suffer when a tidal inlet such as Perdido Pass is partially obstructed and rendered unsafe during rough weather. Great expense is incurred on the part of local, state and federal governments to construct jetties and seawalls to control sediment deposition.

Shoreline erosion and near-shore bottom changes are not simply subjects of academic interest, but are subjects of great concern and interest to the many people of Alabama's coastal area who are directly or indirectly affected; but, the question remains, how much, how long, and for what reason do these changes occur?

Objective

The objective of this report is the documentation of the direction and magnitude of the movement of the coastal shoreline and changes of near-shore bottoms of Alabama through the use of vintage nautical charts, National Oceanic and Atmospheric Administration (N.O.A.A.) topographic sheets, U.S. Geological Survey topographic maps, air photos, and satellite imagery. Primary interest has been placed on those trends measurable since the early 1900's, but in some instances trends have been analyzed from the mid-1880's to the present.

This project is unique in that it brings new techniques to the solving of problems in a relatively small but dynamic area. Paramount among these new techniques is applied remote sensing, encompassing a group of surveillance techniques including aerial and space photography; and computer cartography using the SYMAP program.

Much of the more recent data utilized in the study represents the state of the art in remote-sensing technology. Sources such as multispectral Landsat-1 imagery, space photography, high-altitude and low-altitude color infrared photography, conventional black-and-white aerial photography, and thermal infrared imagery have all been carefully analyzed. A complete listing of the types and dates of all data used in the research is provided in appendices A and B. A general discussion of atmospheric factors precedes the shoreline and bathymetric presentation.

Methodology

General

Historic shoreline and bathymetric change assessment requires the collection of all available data concerning past shorelines and bathymetry. These data include vintage and recent nautical charts by the National Ocean Survey; vintage maps by the French colonists; topographic surveys by the U.S. Geological Survey; and all available air photos and remote-sensing imagery, including Skylab and Landsat-1 imagery.

Shoreline Changes

Understandably, the available data are of various accuracies and scales. For analysis of shoreline changes, the usable data were reduced to a common base. The base selected was the latest U.S. Geological Survey $7\frac{1}{2}$-minute topographic sheets (1:24,000) or earlier U.S. Geological Survey 15-minute topographic sheets (1:62,500) for areas where the former were unavailable.

Whenever possible, opaque prints were converted to positive transparencies at a scale suitable for use in the K & E Kargl photo-rectifier. This machine was used to reduce or enlarge data to the scales of the base maps while simultaneously allowing for the correction of small distortions inherent in the original data. Where prints could not be converted to transparencies, a Focalmatic desk projector (opaque projector) was used to transfer the shorelines to the base map. Once the selected data were compiled at the base scales, segments of the resulting shoreline configurations were quantitatively analyzed to provide information concerning the linear extent of shoreline erosion or accretion and, where appropriate, the area of land lost or gained. All areas were measured with a polar planimeter. At selected locations identifiable on the base maps (U.S. Geological Survey topographic sheets), the total change of the shoreline was determined and the rates of change for various intervals of time were calculated. In some areas the average erosional rates were determined by planimetering the area of erosional or accretional change for a particular shoreline segment and dividing this figure by the length of the shoreline segment.

Bathymetric Changes

National Ocean Survey charts of Mobile Bay containing hydrographic surveys for the years 1852 (Coast Chart no. 188, published in 1856), 1920 (U.S. Coast and Geodetic Survey no. 1266, published in 1921), and 1973 (U.S. Army Corps of Engineers Navigation Maps of Gulf Intercoastal Waterway, New Orleans, LA, to Apalachee Bay, FL, map 6, 7, and 8) were used to conduct an analysis of bathymetric changes in Mobile Bay and vicinity. A 0.5° latitude by 0.5° longitude grid was superimposed on each of the three charts. The depth of water at each grid intersection on each chart was interpolated and stored on punch cards. A computer program called SYMAP, developed by the Laboratory for Computer Graphics and Spatial Analysis, Harvard Center for Environmental Design Studies, Graduate School of Design, Harvard University, Cambridge, MA, was used to produce 12 maps showing the bathymetry, the areas of deposition, and the areas of washout between 1852 and 1920, 1920 and 1973, and 1852 and 1973.

Factors Determining Accuracy of Results

General

Assessing long-term shoreline changes by comparison of vintage National Ocean Survey (formerly U.S. Coast and Geodetic Survey) topographic sheets, U.S. Geological Survey topographic sheets, and remotely sensed data, all at differing scales, mapping detail, and accuracies, must obviously introduce some question as to the accuracy of results derived from these data. Aside from the accuracy of the original data, there may be problems in interpreting shorelines from aerial photography or other remotely-sensed imagery, and there certainly are cartographic difficulties in compiling data using different datums or lacking horizontal control, and in transferring shorelines to a common base. Once all data are compiled on a common base, there are limits to the accuracy of measurements of shoreline changes and determinations of average changes and rates of change.

Accuracy of Original Data

U.S. Coast and Geodetic Survey Topographic Surveys

The degree of accuracy of the early surveys depended upon the purpose of the survey, its scale and date, the standards for survey work then in use, the relative importance of the area surveyed, and the ability and care that the individual surveyor exercised in his work (Shalowitz, 1964). However, a high degree of accuracy does not necessarily mean a high degree of detail; this depended upon the importance of a shoreline area to the purposes of the survey, as seen by the surveyor. Thus, in many shoreline areas, shoreline segments were sketched in between surveyed control. This is especially true of marshy areas where, of necessity, the outer edge of the marsh and not the actual high water line was mapped, as in cases where details of minor tidal creeks were omitted. In general, the horizontal accuracy of the mean high water line on the early surveys is within a maximum error of 10 m (33 ft) and may possibly be much more accurate (Shalowitz, 1964). After World War II, photogrammetric mapping techniques further increased the accuracy of the survey. In summation, Shalowitz (1964), states:

> There is probably little doubt but that the earliest records of changes in our coastline that are on a large enough scale and in sufficient detail to justify their use for quantitative study are those made by the Coast Survey. These surveys were executed by competent and careful engineers and were practically all based on a geodetic network which minimized the possibility of large errors being introduced. They therefore represent the best evidence available of the condition of our coastline a hundred or more years ago, and the courts have repeatedly recognized their competency in this respect ....

U.S. Geological Survey Topographic Maps

The U.S. Geological Survey publishes 7.5-minute (1:24,000 scale) and 15-minute (1:62,500 scale) topographic maps, which were used in this study.

Under the U.S. National Map Accuracy Standards for maps at scales smaller than 1:20,000 (which includes both the 7.5-minute and 15-minute maps), 90 percent of all well-defined features, with the exception of those unavoidably displaced by exaggerated symbolism, will be depicted within 0.50 mm (1/50 in) of their geographic positions as referred to the map projection (Defense Intelligence Agency, 1967). On a 7.5-minute topographic sheet, 0.50 mm (1/50 in) is equivalent to 12 m (40 ft) on the ground. For a 15-minute map, this accuracy is equivalent to 31.7 m (104 ft) on the ground. The preceding accuracies are minimum standards and are greatly exceeded in most cases.

Remotely Sensed Data

Actual photographs, such as the prints and transparencies used in this study (app. B), are subject to various sources of distortion or image displacement. Objects on aerial photographs may not be registered in their current horizontal position because of optical or photographic distortions, tilting of the camera lens axis at the instant of exposure, or variations in local relief (Avery, 1970).

Errors due to optical aberrations or photographic deficiencies were small and needed no special corrective measures for the purpose of this study other than normal care to use only the central area of the photographs. Tilting of the camera lens axis was corrected by making the appropriate scale adjustments along the axis perpendicular to the tilt axis of the photograph with a K&E Kargl photo-rectifier while transferring shoreline data to the base maps. Because the study area is of low relief, the effects of relief displacement were negligible.

Aerial photographs at scales ranging from 1:20,000 to 1:130,000 were used in the study (app. B). The smaller scale photographs (1:130,000) presented some problems in the interpretation of the land/water interface, and at this scale determination of the salt marsh/water interface was somewhat arbitrary. There was no problem in differentiating sandy beach from water, because the contrast between the two was always great.

Cartographic Procedure

Topographic Charts

Original plane-table surveys used by the Coast and Geodetic Survey to compile navigation charts included shoreline data overlayed on a 1-minute grid. Positive prints of these data were converted to positive transparencies or autopositives at scales near those of the $7\frac{1}{2}$- or 15-minute topographic maps, on which a 1-minute grid had been drawn to facilitate transfer of shoreline data. The photorectifier was then used to project the data onto the bases, while simultaneously allowing for corrections and "fitting" of data necessary because of minor distortions generated in the various photographic and duplication processes.

Aerial Photographs

The geometric inaccuracies of aerial photographs required some corrective photogrammetric triangulation to determine shoreline locations where ground control was available. The lack of ground control or identifiable cultural control in many areas (notably Mississippi Sound and the Mobile delta) precluded the use of aerial photography in determining shorelines in these areas.

Although the cartographic procedures used in this study may have introduced some errors in the transfer of shoreline data from the topographic charts and aerial photographs to the topographic map base and then to the final illustration, the major emphasis of the procedures used was the correction or diminution of errors inherent to the original maps and photos.

Accuracy of Measurements and Rate-of-Change Determinations

Measurements of linear distances on maps were made to an accuracy of 0.25 mm (0.01 in), which is equivalent to 6.0 m (20 ft) on the ground for a map at 1:24,000 scale or 15.8 m (52 ft) for a 1:62,500-scale map. An optical comparator with a 0.5-mm reticle was used for all shoreline changes and most rate-of-change determinations. This type of measurement often produces a higher order of accuracy than the original data warrants.

The determination of rate-of-change is subject to certain limitations. The intervals between surveys and remote-sensing coverage are erratic, rates of erosion or accretion must be assumed to be linear between the dates of shoreline measurement, and multiple rates can be obtained at any one shoreline segment using various combinations of lines (Brown and others, 1974), or by fractionally shifting the location of the line of measurement.

Despite these limitations, the method of assessment of long-term change and rates-of-change in the shoreline using charts, maps, and remotely sensed data represent the most practical method now available. The user of this study's results should realize that the limitations of the methods of measurement used require that emphasis be placed on the general trend of shoreline change, with the measured change and rate of change being of secondary concern; in other words, is shoreline erosion occurring at a low rate or a relatively high rate in a given area, or is there apparent equilibrium in a given area?

An appreciation, by the user, of the limitations of the methods used in this assessment will ensure that the results of this study will be both significant and useful to the proper management and development of the resources of the coastal area.

Acknowledgements

The authors appreciate the assistance and cooperation of several individuals in various organizations. The shoreline computer measurement work was done by Kenneth Faller at the Earth Resources Laboratory, NASA Johnson Space Center. The authors would also like to thank John Cammack of the Geological Survey of Alabama and Edmund German of the U.S. Geological Survey for their help in the coordination of the SYMAP computer program. Some of the information dealing with suspended sediment in Mobile Bay was kindly provided by Allen Kerr and

Dewayne Imsand in the Hydrology and Hydraulics Branch of the U. S. Army Corps of Engineers in Mobile. Read Stowe, professor of anthropology at the University of South Alabama, provided ancient maps of Dauphin Island.

THE MILIEU

Atmospheric

Located between 30° and 31° N. latitude at the northern end of the Gulf of Mexico (fig. 1), Mobile Bay is characterized by a warm humid subtropical climate, with somewhat high temperatures from April through October and mild winter months. This type of climate mainly results from 1) the latitudinal position of Mobile Bay and its eastern location in relation to the North American landmass; and 2) the effects of two dominant air masses, the warm moist tropical air mass originating from the gulf and the cool dry continental polar air from central Canada. Of importance to the coast are the amounts of precipitation, seasonal trends, and hurricanes.

Precipitation totals at the Mobile station average 173 centimeters (cm) or 68.1 inches (in) per year. Monthly characteristics are illustrated in figure 2. There is no well-defined seasonal trend such as a dry winter or summer period; however, there is a noticeable difference in that the precipitation decreases during the fall. Monthly or seasonal differences in precipitation affect the discharge of the Alabama River into the bay and consequently affect the depositional/erosional rate at the same time.

Hurricanes have played a pronounced but infrequent role in altering or shaping the shoreline. Table 1 lists the dates of hurricanes that have affected Alabama

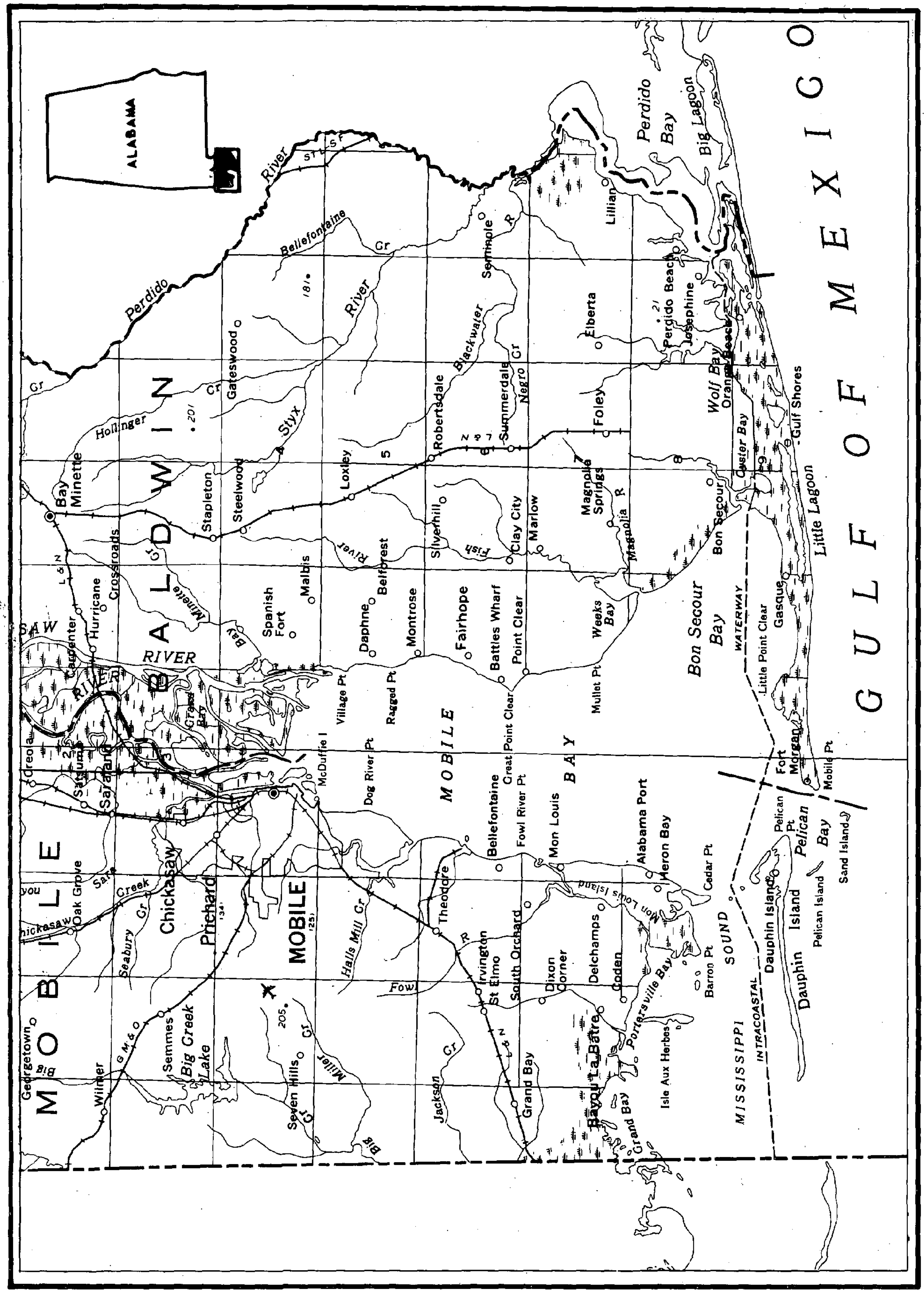

Figure 1.--Location of study area.

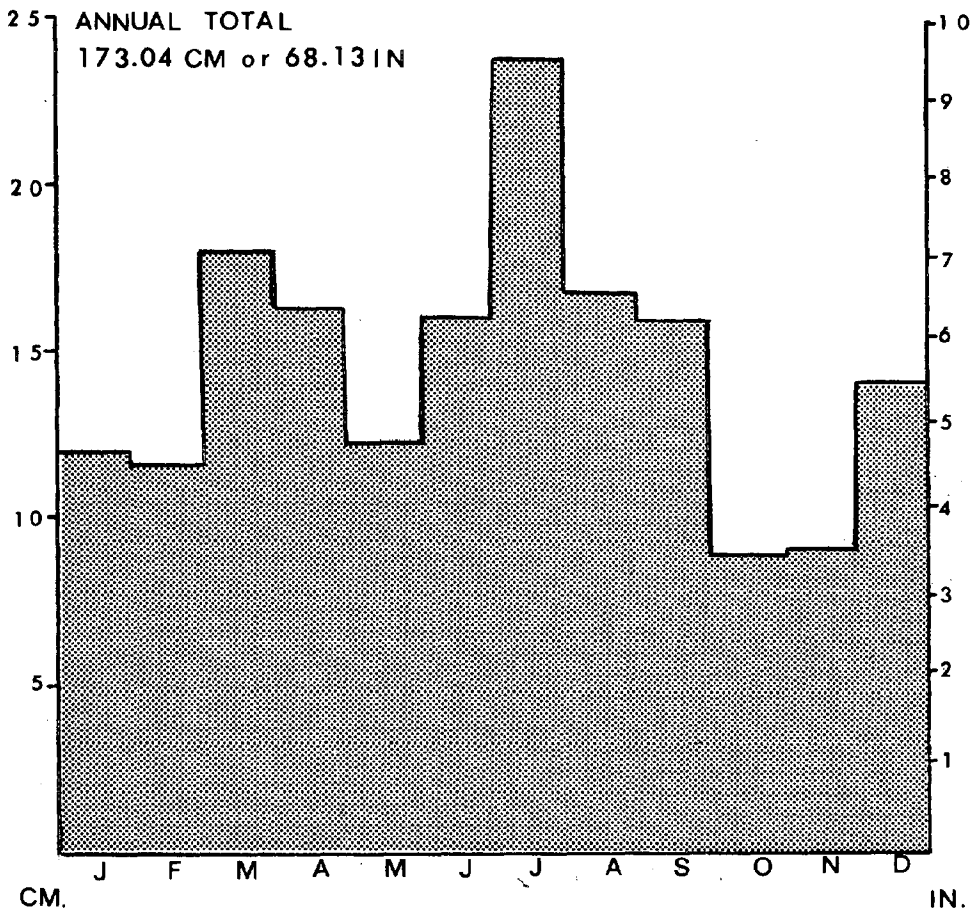

Figure 2.--Monthly precipitation characteristics for Mobile station, 1941-1971 (Brower, Meserve, and Quayle, 1972).

in the past 75 years. Note that these storms all occurred in August, September, or October, except for the July hurricane of 1916. Sixty-five percent of the hurricanes occurred during September. A hurricane affects Alabama's coast every 52 months, on the average. The specific effects of these storms upon the shoreline and bathymetry will be discussed later, as appropriate.

Table 1.--Hurricanes that have affected Alabama*

Date	Remarks
15 August 1901	Landfall, Grand Isle, La.
27 Sept. 1906	Very destructive - wind intensity of 150 kph (94 mph) at Fort Morgan. Landfall, Pascagoula, Miss.
20 Sept. 1909	Landfall, Grand Isle, La.
14 Sept. 1912	Landfall, Mobile, Ala.
29 Sept. 1915	One of the most intense. Landfall, Grand Isle, La.
5 July 1916	3.25 m (10.8 ft) tide above mean sea level at Mobile (2.3 m (7.5 ft) at Dauphin Island and 3.4 m (11.2 ft) at Gulf Shores). Landfall, Gulfport, Miss.
18 Oct. 1916	Landfall, Pensacola, Fla.
28 Sept. 1917	Waves overtopped the seawall at Fort Morgan. Landfall, Pensacola, Fla.
20 Sept. 1926	One of the most destructive - 48.2 cm (19 in) of precipitation recorded at Bay Minette. Landfall, Perdido Beach, Ala.

1 Sept. 1932	Landfall, Mobile, Ala.
19 Sept. 1947	Very destructive - considerable damage near the mouth of the Dog River. Landfall, New Orleans, La.
4 Sept. 1948	Landfall, Grand Isle, La.
30 August 1950	Mainly affected the Fort Morgan-Gulf Shores area (Hurricane Baker). Landfall, Mobile, Ala.
24 Sept. 1956	Hurricane "Flossy" mainly affected Dauphin Island. Landfall, Ft. Walton Beach, Fla.
15 Sept. 1960	Hurricane "Ethel" - no serious damage. Landfall, Pascagoula, Miss.
3 Oct. 1964	Hurricane "Hilda" caused beach erosion from Point Clear to Mullet Point and along the Fort Morgan peninsula. Considerable damage reported at Dauphin Island. Landfall, Franklin, La.
17-18 August 1969	Hurricane "Camille" - very destructive storm. Tide at Pass Christian rose to 6.8 m (22.6 ft) above mean sea level. Landfall, Waveland, Miss.

* Source: Report on Hurricane Survey of Alabama of Alabama Coast, U.S. Army Corps of Engineers (USACE) 1965 and 1970; and Chermock, Boone, and Lipp, 1974.

Hydrospheric

Mobile Bay receives the waters from the fourth largest river system in the United States. The Mobile River system (fig. 3) drains approximately 112,966 square kilometers (km^2) or 43,650 square miles ($mi.^2$) and discharges a mean annual 1,764.8 cubic meters per second (m^3/s) or 62,316.8 cubic feet per second (ft^3/s). Another mean annual discharge of 3.55 m^3/s (125.6 ft^3/s) enters Mobile Bay below the Battleship Parkway from Montlimer Creek and Fish River (Crance, 1971).

The movement of the outgoing water through the bay has been examined (Austin, 1954) and shows that during a 6-day period in October 1952 (period of low river discharge) the river discharge moved primarily on the western side of the ship channel. Moreover, Austin states that 85 percent of that discharge passed through the Mobile Point inlet directly into the Gulf of Mexico, while the remaining 15 percent flowed through the Mississippi Sound outlets. A more recent study (Lamb, 1972) indicates an increase in salinity in the Mississippi Sound area which would probably change the percentages for movement of the discharge. It is probable that the building of the bridge system from Cedar Point to Dauphin Island (plus the subsequent sedimentation) has diverted some fresh water from the Mississippi Sound, thereby increasing the salinity (Lamb, 1972). However, some of the Landsat-1 imagery (for example, November 17, 1973, pass in appendix A) seems to confirm

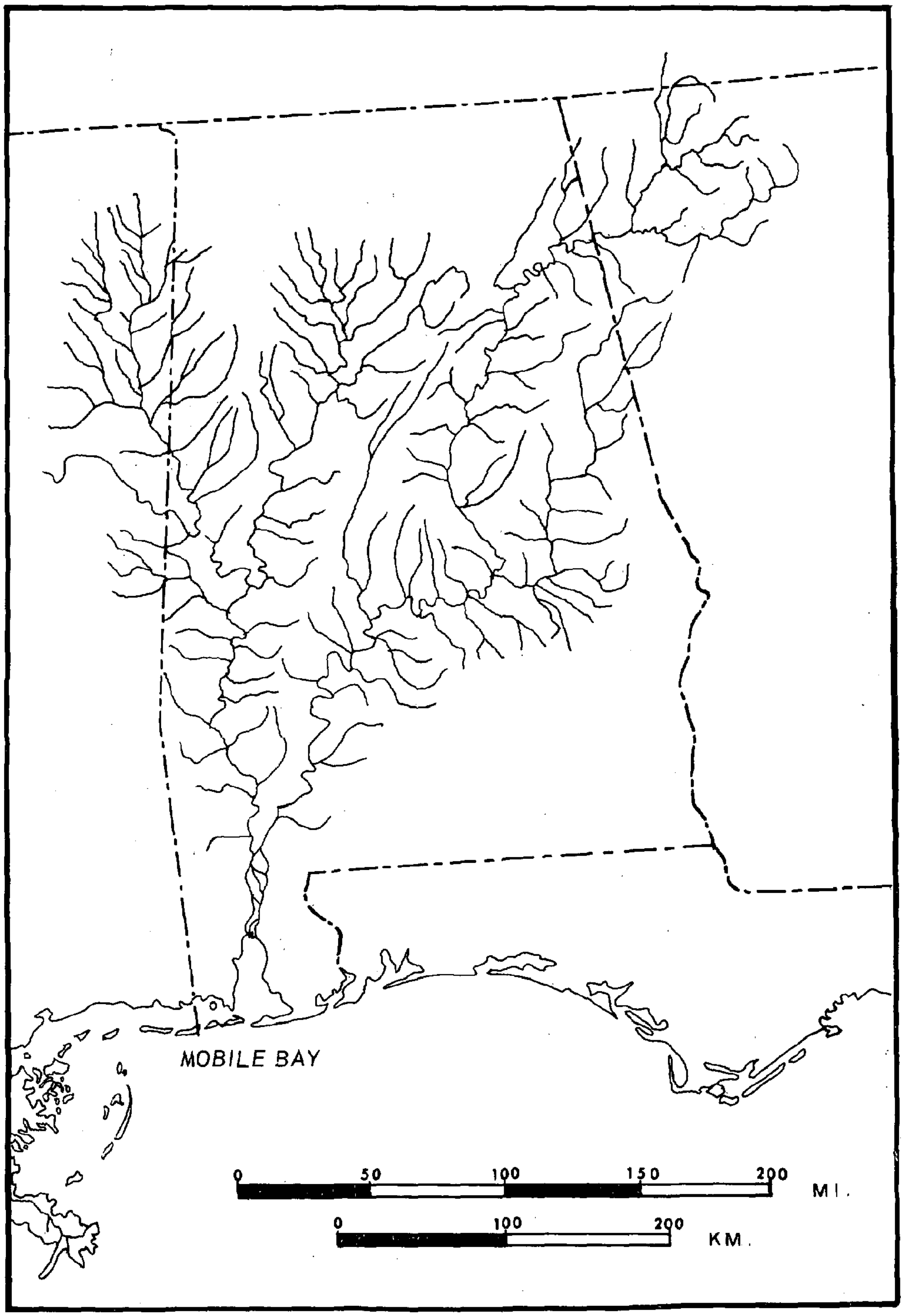

Figure 3.--Mobile River drainage basin.

Austin's results. Thus, it is apparent that the circulation pattern within the bay warrants further field investigations.

Figure 4 illustrates the flow pattern of discharge through the bay. This Skylab photograph was taken on January 21, 1974, at about 3:00 p.m. local time. The light tones (as opposed to the darker tones) show the suspended sediment being carried out of the bay and illustrate the direction of flow very well. January 1974 experienced an unusually high monthly discharge with a mean of 5,869.6 m^3/s (207,259 ft^3/s). Only three other months of January have exceeded this mean discharge since 1929. The January 1974 discharge represents about a 222 percent increase over the mean for that month (app. B).

Mobile Bay has diurnal tides that vary from 36 cm (1.2 ft) at Mobile Point to 45 cm (1.5 ft) at the mouth of the Mobile River. An extreme high tide of 3.24 m (10.8 ft) above mean sea level was recorded during the July 1916 hurricane and an extreme low tide of 3.15 m (10.5 ft) below mean sea level was measured during the 1926 hurricane (Crance, 1971).

Tides, river discharges, the bottom configuration of the bay, and water movement deflected due to the coriolis effect all contribute to the circulation patterns within the bay. Average current velocities associated with the flood and ebb tides vary between 15 cm per second during flood tide at the Mobile River entrance to 77 cm per second at Mobile Point during ebb tide (see table 2 for the velocities in different parts of the bay).

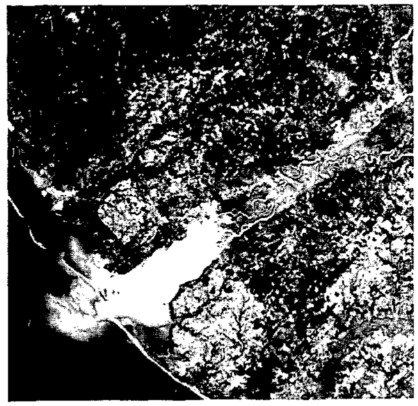

Figure 4.--Skylab 4 photograph (SL4-63-392) taken with the S190A camera over Mobile Bay on January 21, 1974, at 3:00 p.m. local time or 2 hours before high tide. The light tones within and south of the bay indicate suspended sediment discharging into the Gulf of Mexico.

Table 2.--Average tidal current velocities (diurnal) in centimeters per second*

Location	Flood tide	Ebb tide
Main ship channel entrance	36	52
Mobile Bay (off Mobile Point)	72	77
Channel, 10 km (6 mi.) N. of Mobile Point	31	26
Mobile River entrance	15	36
Tensaw River entrance	21	36
Pass aux Herons	67	67

*From U.S. Coast and Geodetic Survey, Tidal current tables, 1969, <u>in</u> Ryan and Goodell, 1972.

According to Ryan (1969), during flood tide the incoming water that passes through the Mobile Bay tidal pass first deflected to the east, and then northward in a counterclockwise direction (fig. 5). However, a recent study of a hydrodynamic and salinity model for Mobile Bay (Hill and April, 1974) indicates different results. Taking in consideration that the wind velocity is zero, the inflow and outflow profiles are shown in figures 6 and 7.

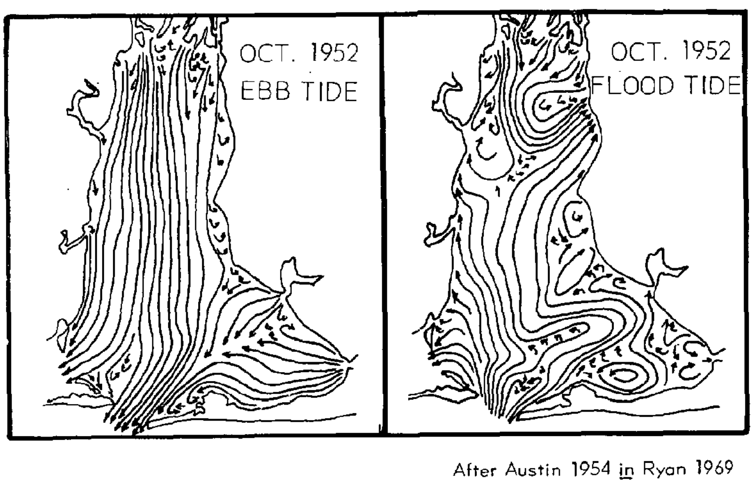

Figure 5.--Surface currents in Mobile Bay.

The ship channel has altered the natural circulation pattern by introducing a salt-water wedge up the entire length of the bay. Both the Tombigbee and Alabama Rivers discharge about the same quantity of sediment into the bay. Certain variations exist between the two rivers during certain periods of low and high discharges. Appendix B, table 4, indicates the amount of suspended sediment for a period of 12 years.

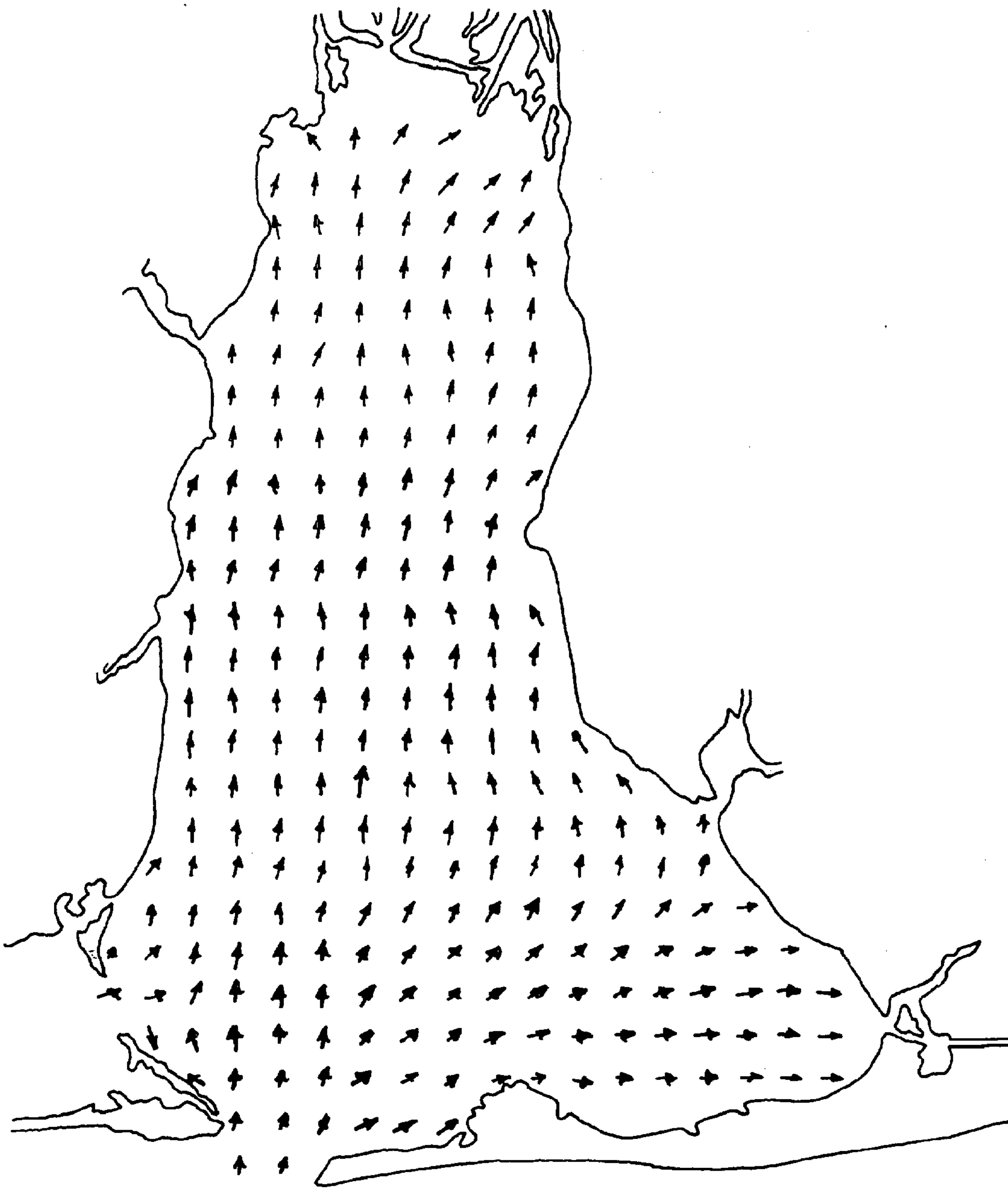

Figure 6.--Velocity directions for flood-tide flow predicted by a hydrodynamic model (after Hill and April, 1974).

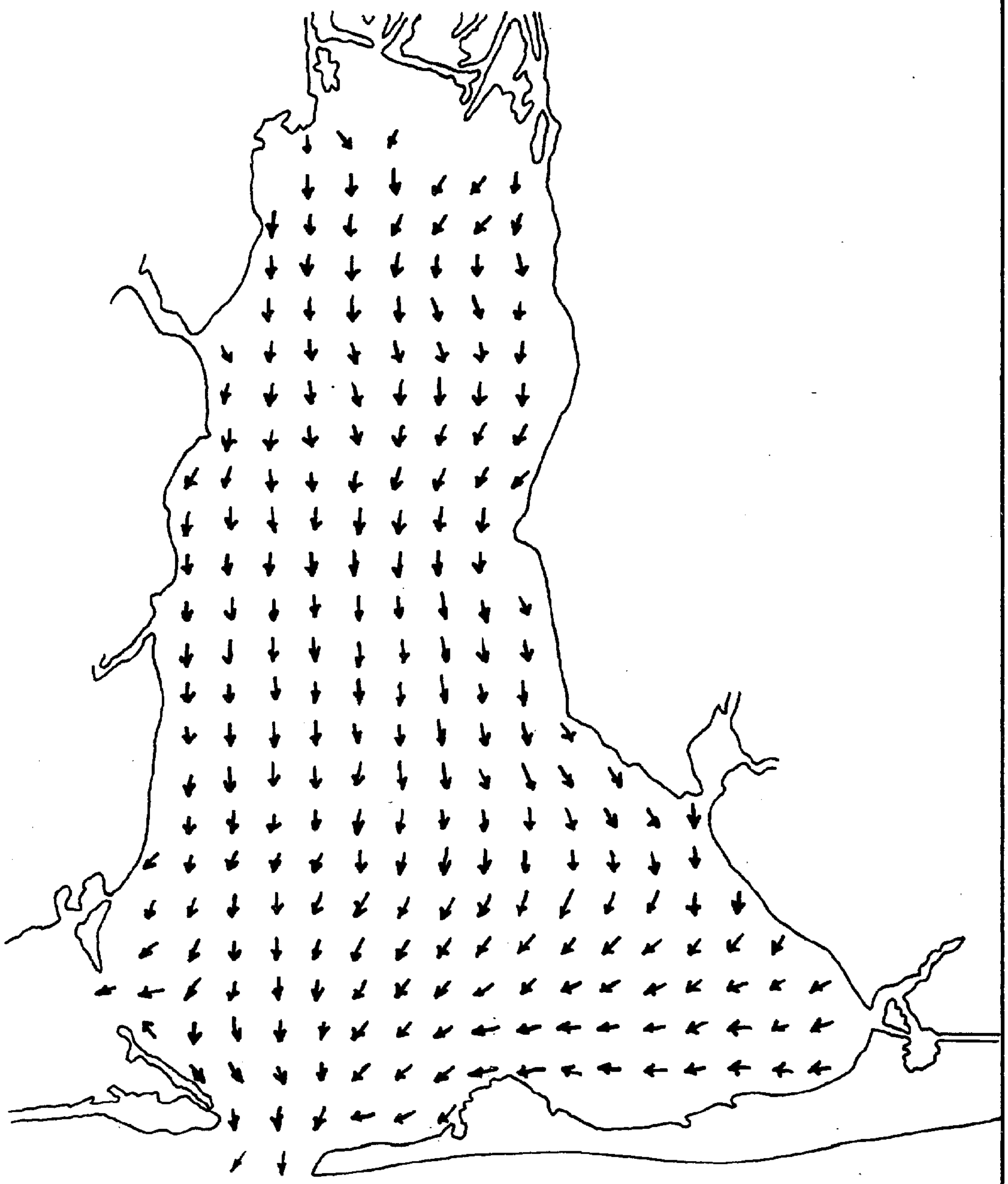

Figure 7.--Velocity directions for ebb-tide flow predicted by a hydrodynamic model (after Hill and April,1974).

Satellite imagery has proven to be a very useful tool for the study of sediment patterns. In July 1972, NASA launched its first Landsat-1 satellite (formerly ERTS-1) into a near-polar orbit. This was the first satellite dedicated entirely to the study of the earth, and its track passes over Alabama every 18 days. The multispectral scanner (MSS) subsystem on the platform images the earth's surface in four different bands of the electromagnetic spectrum. These four bands are as follows:

Band 4	0.5 to 0.6	micrometers	wavelength	(green)
Band 5	0.6 to 0.7	"	"	(red)
Band 6	0.7 to 0.8	"	"	(near infrared)
Band 7	0.8 to 1.1	"	"	(near infrared)

Suspended sediment transported by streams and rivers is quite visible on Landsat imagery and can be easily traced in the sea. For example, the Landsat-1 band 5 image of November 12, 1974 (fig. 8), illustrates very nicely the sediment plume extending approximately 20 km (12 mi.) into the Gulf of Mexico. This image is of particular interest because the ship channel forms a boundary between the heavily sedimented eastern part of the bay and the less sedimented western part of the bay. Such a pattern is contrary to the findings of previous studies on circulation patterns within the bay; however, it probably resulted from unusual conditions because patterns on most other Landsat-1 images seem to follow the earlier findings. Noted also on this November 12 image is a large amount of sediment off the Mississippi

Figure 8.--Landsat-1 band 5 scene taken on November 12, 1974, over Mobile Bay. Unusual sediment patterns appear higher on the eastern side of the bay instead of the western part. High amounts of sediment transported by the Mississippi River appear off the west side of Chandeleur Island. Also well outlined is the concentration of suspended sediment on the northern side of the Mississippi Sound Islands, which supports Austin's results on the circulation pattern.

River delta. Low tide in this case occurred approximately an hour and a half after the image was recorded.

A December 5, 1973 (fig. 9), image shows unusual patterns not only within and off Mobile Bay, but as far as 60 km (40 mi.) southeast of the Mississippi delta. Again, in this case, low tide was about two and a half hours before the multispectral scanner recorded the image.

A series of Landsat-1 band 5 images, along with tidal graphs, current velocities, and river discharge, is provided in appendix A. The seasonal trend of the amount of suspended sediment (which is actually a function of river discharge) going out of the bay can be observed on the imagery dated 1972 to 1974.

Throughout this 2-year time sequence tidal stages varied widely, and it is very apparent that tidal circulation dictates the transportation pattern of the sediment. In case of unusually high discharge, the tidal mechanism seems to be overridden, as illustrated in the case of the January 20, 1974, Skylab photograph.

From the Skylab and Landsat-1 scenes, several observations concerning suspended sediment can be made: 1) suspended sediment is clearly visible on the imagery; 2) the amount of sediment is usually associated with the discharge characteristics of the Alabama - Tombigbee Rivers; 3) the boundaries between sedimented and less-sedimented waters can be drawn as far as 100 km (64 mi.) out into the Gulf of Mexico; 4) there is a definite sedimentation concentration on the

Figure 9.--Landsat-1 band 5 scene taken on December 5, 1973. The image displays large amount of suspended sediment detectable as far as 100 km (60 mi.) southeast of the Mississippi River delta.

northern side of the Mississippi Sound Islands. This represents not only discharge of sediment by other streams, but also confirms Austin's study stating that about 15 percent of the sediment from Mobile Bay flows through the Mississippi Sound outlets; 5) general patterns in the current directions can be inferred; 6) the longshore westward current is detectable on most of the imagery. For sediment studies, band 5 (red) Landsat-1 imagery is found to be the best for the detection of sediment distribution patterns.

BATHYMETRY

Mobile Bay is about 50 km (31 mi.) long, 13 km (8 mi.) wide in the north, and as much as 38 km wide (24 mi.) wide in the south. It is nearly blocked from the Gulf of Mexico at the south by the Mobile Point barrier and Dauphin Island. A second outlet (and inlet) is Pass aux Herons, between Dauphin Island and Cedar Point. The bay measures approximately 1,015 km^2 (392 mi^2) in area.

Mobile Bay is a geologically young estuary. In fact, most estuaries are young, ephemeral features, having been formed by the last eustatic rise in sea level. Mobile Bay has probably held its present outline and shape from the time of its formation several thousand years ago; however, the bay is filling with sediment. The characteristic pattern of estuaries is to fill most rapidly near the head (delta) and progressively fill up in the more distant reaches. This pattern can be altered by changing rates of sediment influx from rivers and streams, relative changes in sea level, tidal circulation, and climatic changes. Man's influence, also, is an important factor. Within the next thousand years, Mobile Bay will probably become an alluvial-deltaic plain similar to the present delta.

The contemporary configuration of the bottom of the bay is essentially flat and sloping southward. The dredging of the 12x122 m(40x400 ft) ship channel has increased the relief down the center of the bay, and the dredging of the east-west intracoastal waterway has had a similar effect in an east-west direction across the widest part of the bay (fig. 10 and table 3). These changes are confined to narrow corridors, but there are also other changes in configuration due to more or less natural causes. These "natural" causes may ultimately be man-induced rather than otherwise, and they involve differential sedimentation and erosion rates.

The bay was deeper in 1852 than in 1920 or 1973, as table 4 indicates. The rate of filling between 1852 and 1920 was 0.49 m (1.63 ft) per 100 years. This rate decreased to 0.52 m (1.68 ft) per 100 years between 1920 and 1973. These figures are for the entire bay and were obtained by taking the mean of a systematic sample consisting of 1,720 soundings taken from National Ocean Survey charts.

It is illuminating to divide the bay into two equal parts, the northern half and southern half, and compute the mean depths for the same three dates. Table 4 shows the results. The filling of the upper bay is decreasing, whereas the filling of the lower bay is increasing (fig. 11). The rate of filling of the upper bay was 0.58 m (1.91 ft) per 100 years between 1852 and 1920, but this rate decreased to 0.30 m (1.00 ft) per 100 years between 1920 and 1973. This decrease is significant but its cause is unknown. The construction of dams on the Alabama River and other tributaries in the Mobile River drainage basin may have trapped sediments that would

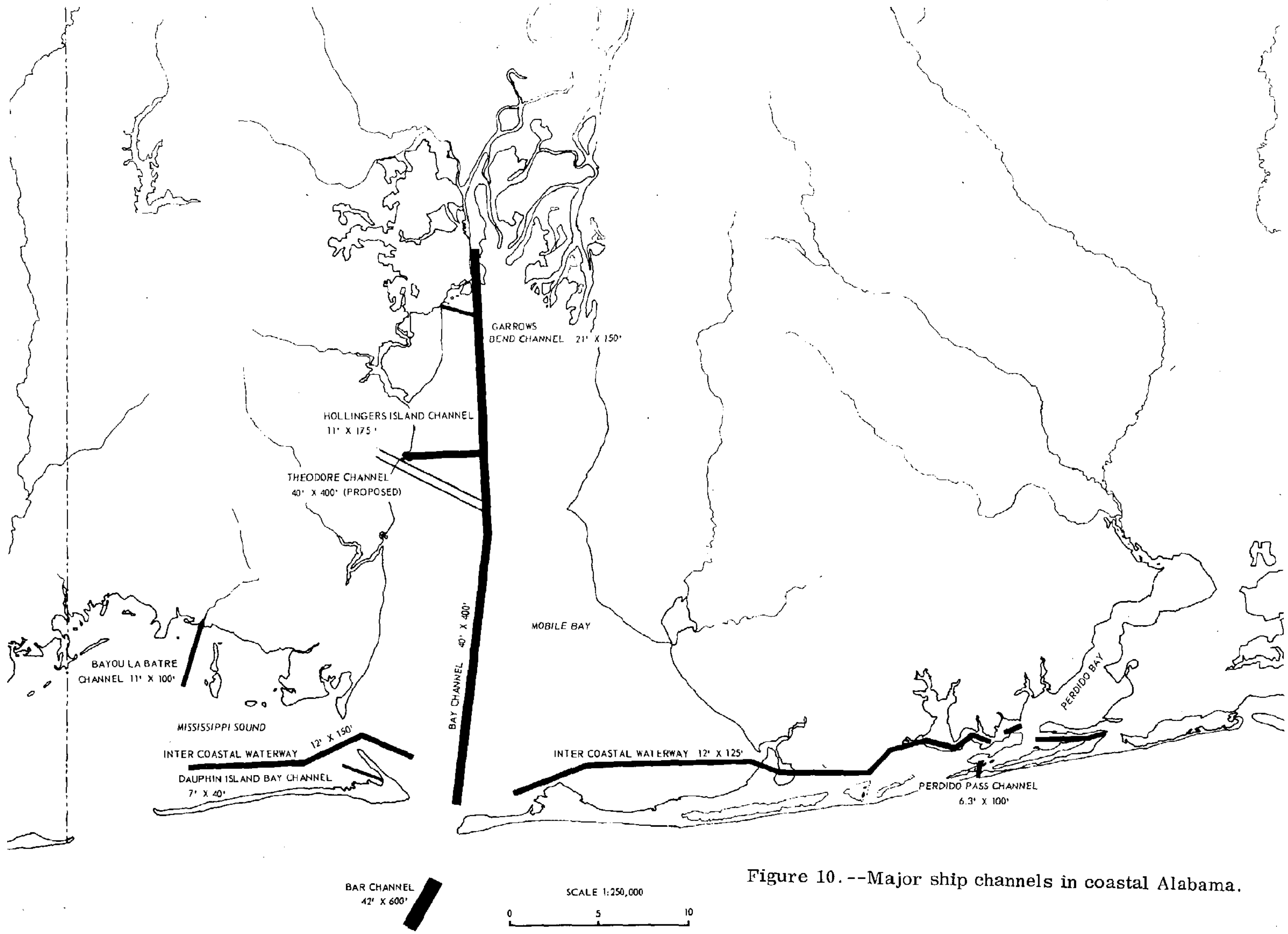

Figure 10.--Major ship channels in coastal Alabama.

Table 3.--Dredging in coastal Alabama

AREA	DATE	VOLUME	
		Gross cubic meters	Gross cubic yards
Mobile Outer Bar	March 1975	215,813	(283,965)
	June 1974	185,683	(244,320)
	July 1972	199,482	(262,476)
Perdido Pass	July 1974	303,616	(399,495)
	Sept. 1972	289,122	(380,424)
	July 1971	183,888	(241,958)
Fort Gaines (Mobile Bay tidal pass)	Aug. 1974	12,261	(16,133)
	Nov. 1972	54,098	(71,182)
	Nov. 1974	34,023	(44,767)
Pass Heron (Pass aux Herons)	March 1969	1,141,319	(1,501,735)
Bon Secour (Bay)	July 1974	303,616	(399,495)
	Oct. 1966	45,203	(59,478)
	Oct. 1964	590,713	(777,254)

NOTE: All dredging jobs do not start and finish at the same point year after year; therefore, the volumes dredged vary greatly.

Source: U.S. Army Corps of Engineers, 1975 (written communication).

Table 4.--Mean depths (MLW) and rates of filling of Mobile Bay

MEAN DEPTHS			RATES OF FILLING		
1852	1920	1973	Change 1852-1920	Change 1920-1973	Change 1852-1973
			TOTAL BAY		
10.71 ft (3.26 m)	9.60 ft (2.92 m)	8.71 ft (2.65 m)	Filled 1.11 ft (0.33 m)	Filled 0.89 ft (0.27 m)	Filled 2.00 ft (0.60 m)
			Rate 1.63 ft/100 years (0.49 m/100 years)	Rate 1.68 ft/100 years (0.51 m/100 years)	Rate 1.65 ft/100 years (0.50 m/100 years)
			UPPER BAY		
8.90 ft (2.71 m)	7.60 ft (2.31 m)	7.07 ft (2.15 m)	Filled 1.30 ft (0.39 m)	Filled 0.53 ft (0.16 m)	Filled 1.83 ft (0.55 m)
			Rate 1.91 ft/100 years (0.58 m/100 years)	Rate 1.00 ft/100 years (0.30 m/100 years)	Rate 1.51 ft/100 years (0.46 m/100 years)
			LOWER BAY		
12.52 ft (3.81 m)	11.59 ft (3.53 m)	10.35 ft (3.15 m)	Filled 0.93 ft (0.28 m)	Filled 1.24 ft (0.37 m)	Filled 2.17 ft (0.66 m)
			Rate 1.36 ft/100 years (0.41 m/100 years)	Rate 2.34 ft/100 years (0.71 m/100 years)	Rate 1.79 ft/100 years (0.54/100 years)

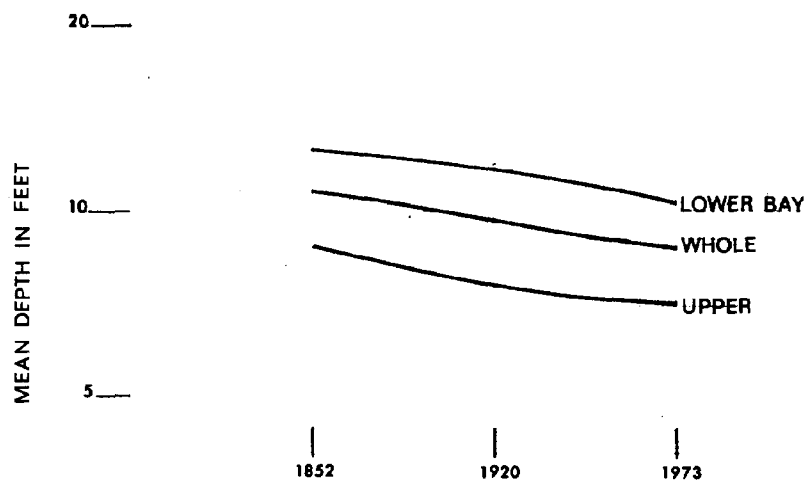

Figure 11.--Rates of filling of Mobile Bay, 1852-1973.

have otherwise reached Mobile Bay. One can also speculate that there has been a decrease in land under cultivation, a resulting decrease in erosion, and therefore a decrease in suspended sediment load carried by the rivers

The lower bay shows an increase in the rate of filling from 1852 to 1973. Between 1852 and 1920, it filled at the rate of 0.41 m (1.36 ft) per 100 years. Between 1920 and 1973, this rate increased substantially to 0.71 m (2.34 ft) per 100 years. As with the upper bay, the initial causes of the rate change during these periods is not known but is subject to speculation. The increase in sedimentation in the lower bay might be attributed to dredging of the east-west intracoastal waterway, the widening and deepening of the ship channel*, or the relatively recent construction of the Dauphin Island causeway** across one of the bay's two outlets. In any event, as table 4 shows, the lower bay was only 3.15 m (10.35 ft) (mean) deep in 1852.

Ryan (1969) compiled isopachs of the bay and cites sedimentation rates in excess of 1.2 m (4 ft) per 110 years in the delta area. In Bon Secour Bay he shows rates of 0.6 to 0.9 m (2 to 3 ft) per 110 years. His results are consistent with the

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* The ship channel was constructed between 1826 and 1857 to a depth of 3 m (10 ft). Between 1870 and 1934, the channel was deepened and widened periodically and reached its present dimensions between 1955 and 1957 (Ryan, 1969, p. 38-39).

** Construction of the causeway was completed in the mid-1950's.

findings of this study. Ryan (1969, p. 68) states that Bon Secour Bay appears to have the highest natural sediment accumulation rate. The findings of this study differ: the bottom north of the bay entrance, east of Dauphin Island, has the highest sediment accretion rate; whether this deposition is natural or is man-induced spoil is debatable. In any event, the highest rate of deposition is not in Bon Secour Bay. The distribution characteristics are discussed later, along with the SYMAP computer maps of bathymetry. Ryan does write that the entire bay has an average accumulation rate of 0.5 m (1.7 ft) per century, a finding confirmed by this study.

Ryan (1969) does not report a decreasing erosion rate for the upper bay, however. He emphasizes man's role in increasing the sedimentation rate in the upper bay, and cites rates of greater than 0.9 m (3 ft) per 100 years in the area immediately south of the delta. This may be the case in isolated areas, but this study finds a lower, decreasing rate 0.46 (1.51 ft) per 100 years for the upper bay during the 1852-1973 period.

To summarize the bathymetric findings of this phase of the study, the rate of filling of the upper bay is decreasing, while the rate of filling of the lower bay is increasing. Overall, the bay is filling at the rate of 0.5 m (1.65 ft) per century. There is no reason to expect any change in this trend in the near future. As a result of the filling, Mobile Bay will shrink in size and the delta will prograde southward.

A discussion of the statistical means of bay depths provides only a general picture. For details, computer plots of bathymetry were generated using the Harvard University SYMAP program. These maps originated from soundings tabulated from National Ocean Survey charts . A grid having a 0.8 km (0.5 mi.) spacing was used for systematic sampling of bathymetry for the three dates 1852, 1920, and 1973. These maps, each having 1,720 sample points, were interim steps for synthesis of a derivitive set of maps showing change between the dates 1852-1920 and 1920-1973, as well as 1852-1973. For each date and period, the bathymetry of the bay will be discussed, the salient changes will be described, and the changes will be divided into depositional and erosional components.

Figure 12, entitled "Mobile Bay Bathymetry, 1852," depicts a flat, rather featureless estuary before the effects of man had become evident. The greatest bay depths were at the tidal pass between Dauphin Island and Mobile Point. The central area of the bay measured 3-6 m (10-20 ft) in depth, and the mean depth for the entire bay measures 3.3 m (10.7 ft).

Figure 13 shows the bay in 1920. Its character is considerably different, and the effects of dredging (spoil) are evident. Much of the west-central part of the bay is now only 1.5-3.0 m (5-10 ft) deep, which is only half as deep as in 1852. The western part of Bon Secour Bay has also become considerably shallower during

Figure 12. Mobile Bay bathymetry 1852

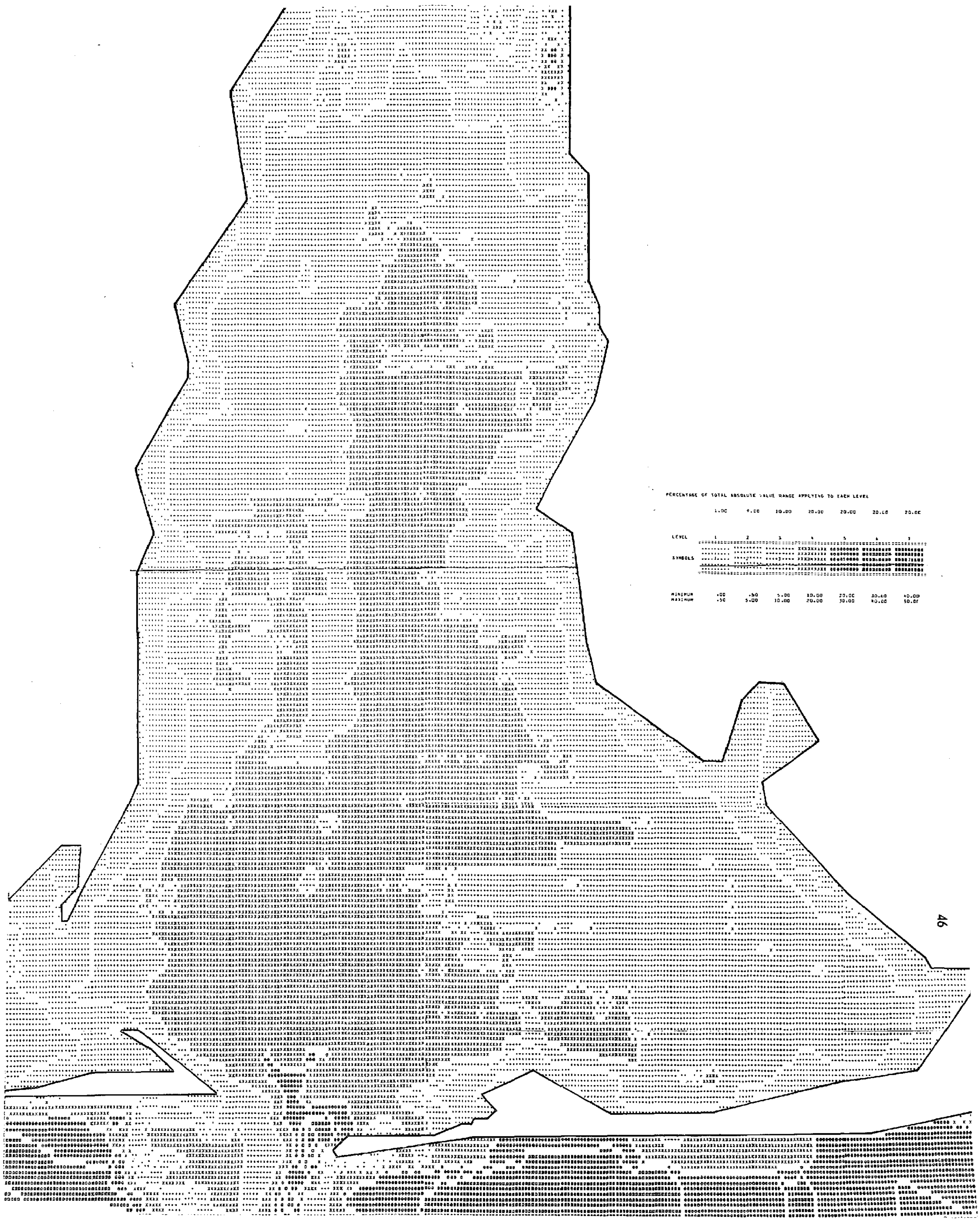

Figure 13. Mobile Bay bathymetry 1920

this 68-year period. The tidal pass to Mobile Bay remains, however, the deepest water. Figure 14 is a computer-derived comparison of the two bathymetric maps, and shows filling as well as washout (erosion) of the bottom. The "difference map" reveals filling in the main entrance (outer bar), as well as in small isolated location east of Dauphin Island, in the center of the bay, and generally east of Mobile city. The south-central part of Mobile Bay experienced 0.3-1.0 m (1-3 ft) of filling during this period. Figure 15 shows only the filling (positive values) and thus simplifies the patterns considerably. The areas of washout, 1852-1920, which are represented as negative values, are illustrated in figure 16. This map reveals that there existed few areas of washout, submarine erosion, or scouring in the bay.

Figure 17 shows the present (1973) Mobile Bay bottom configuration. The bathymetry is now complex, quite unlike the patterns of 1852 and earlier. The effects of dredging show as a more or less continuous north-south trending ridge 1.5-3.0 m (5-10 ft) deep at mean low water (MLW). This ridge widens at the latitude of Cedar Point but tapers in again and deepens quickly to more than 12 m (40 ft) at the main entrance. The upper bay immediately south of the delta is now shallow, averaging only 1.5 m (5 ft) deep or less. Much of the bay off the city of Mobile has been filled, and there is little bay area left deeper than 3 m (10 ft) now. Figure 18 shows the computer analysis of differences. The greatest deposition

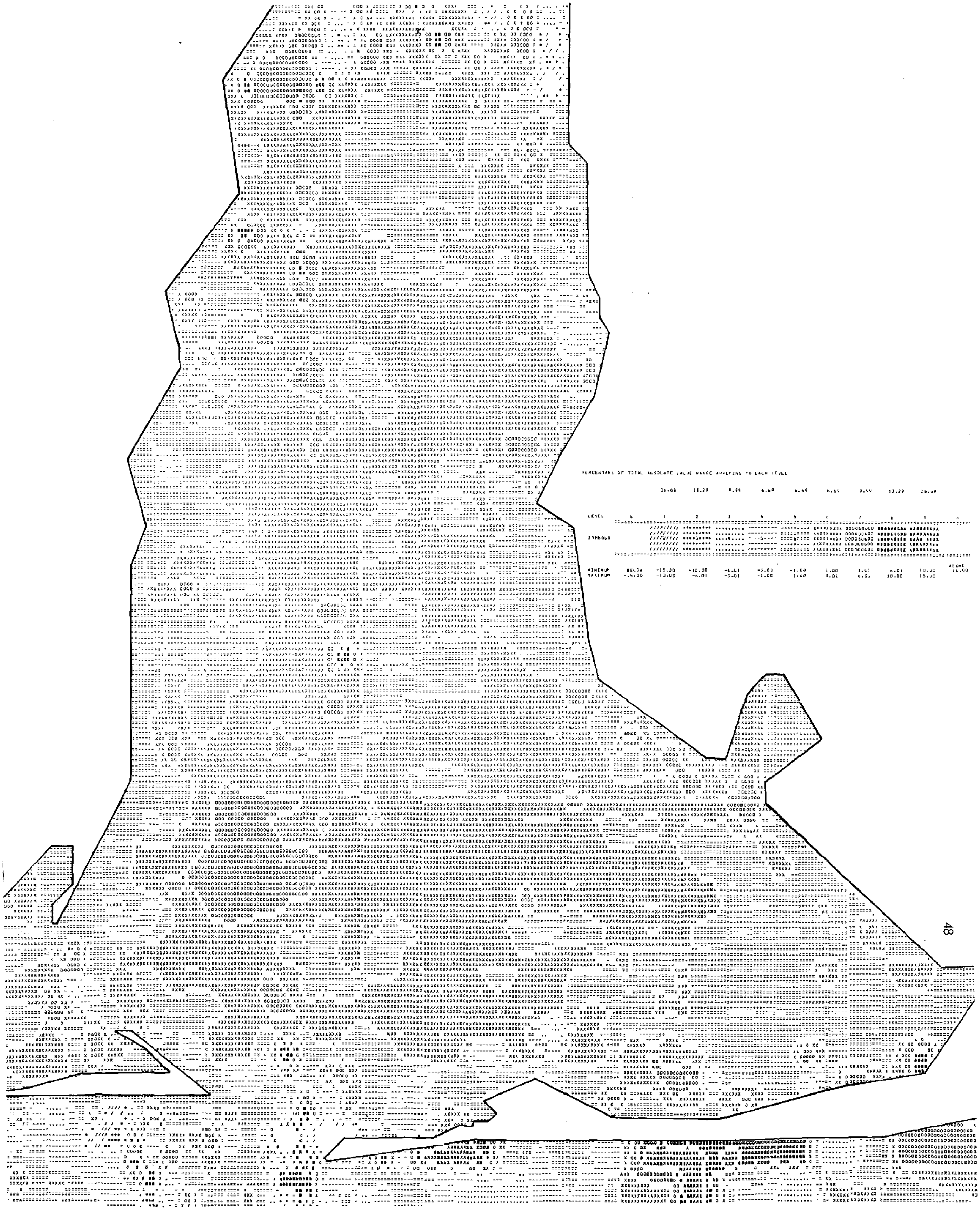

Figure 14. Changes in bathymetry in Mobile Bay 1852-1920

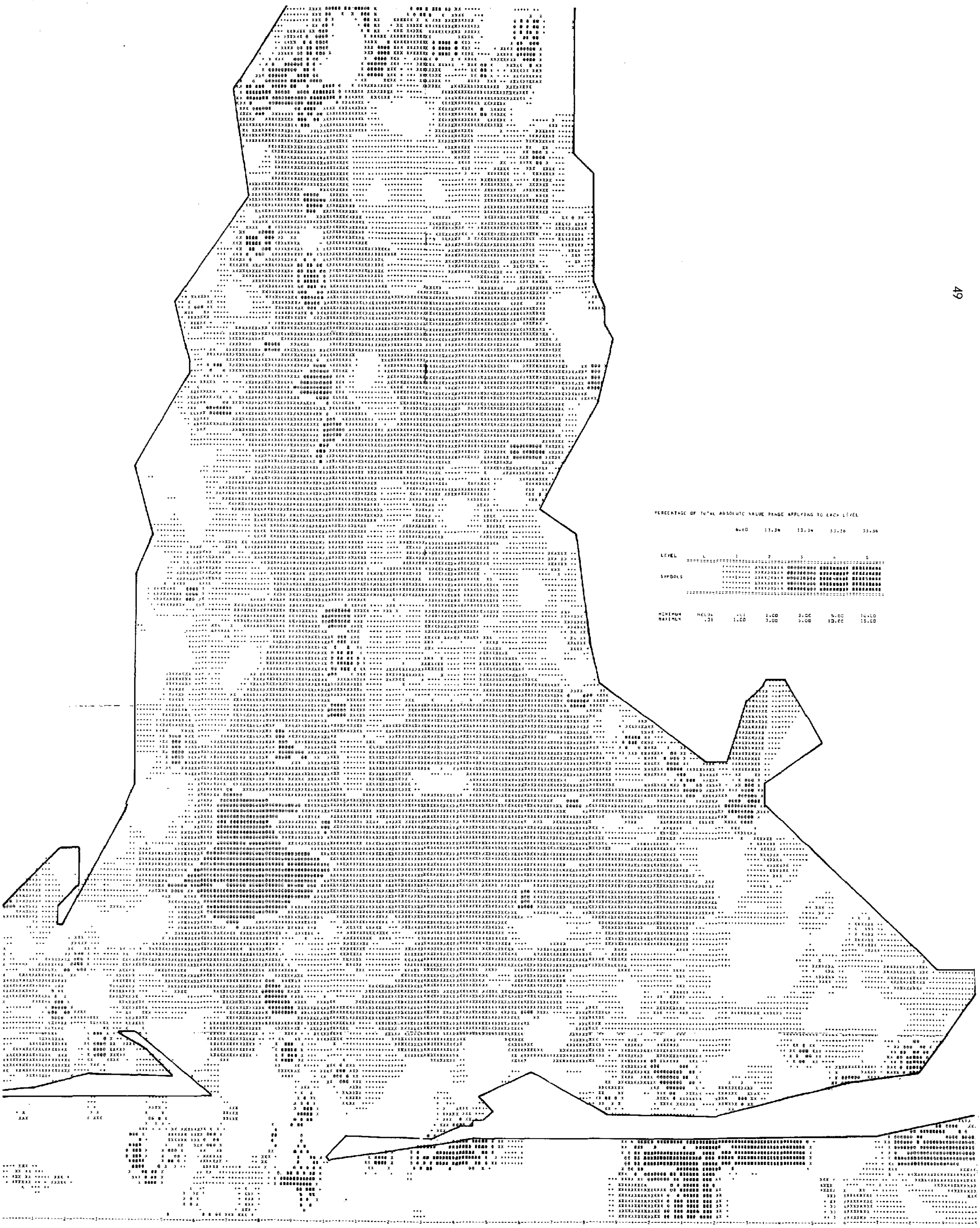

Figure 15. Areas of deposition in Mobile Bay 1852-1920

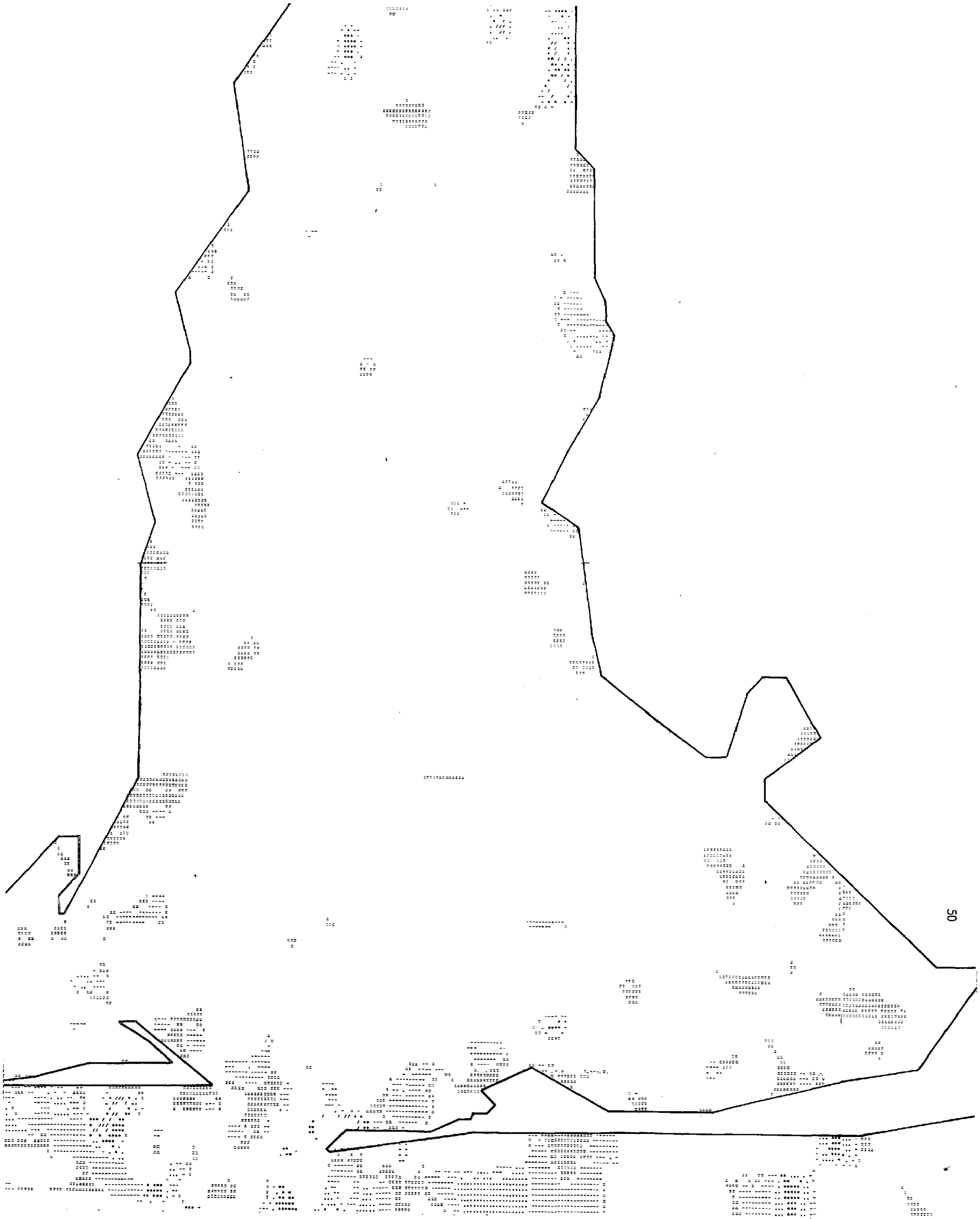

Figure 16. Areas of washout in Mobile Bay 1852-1920

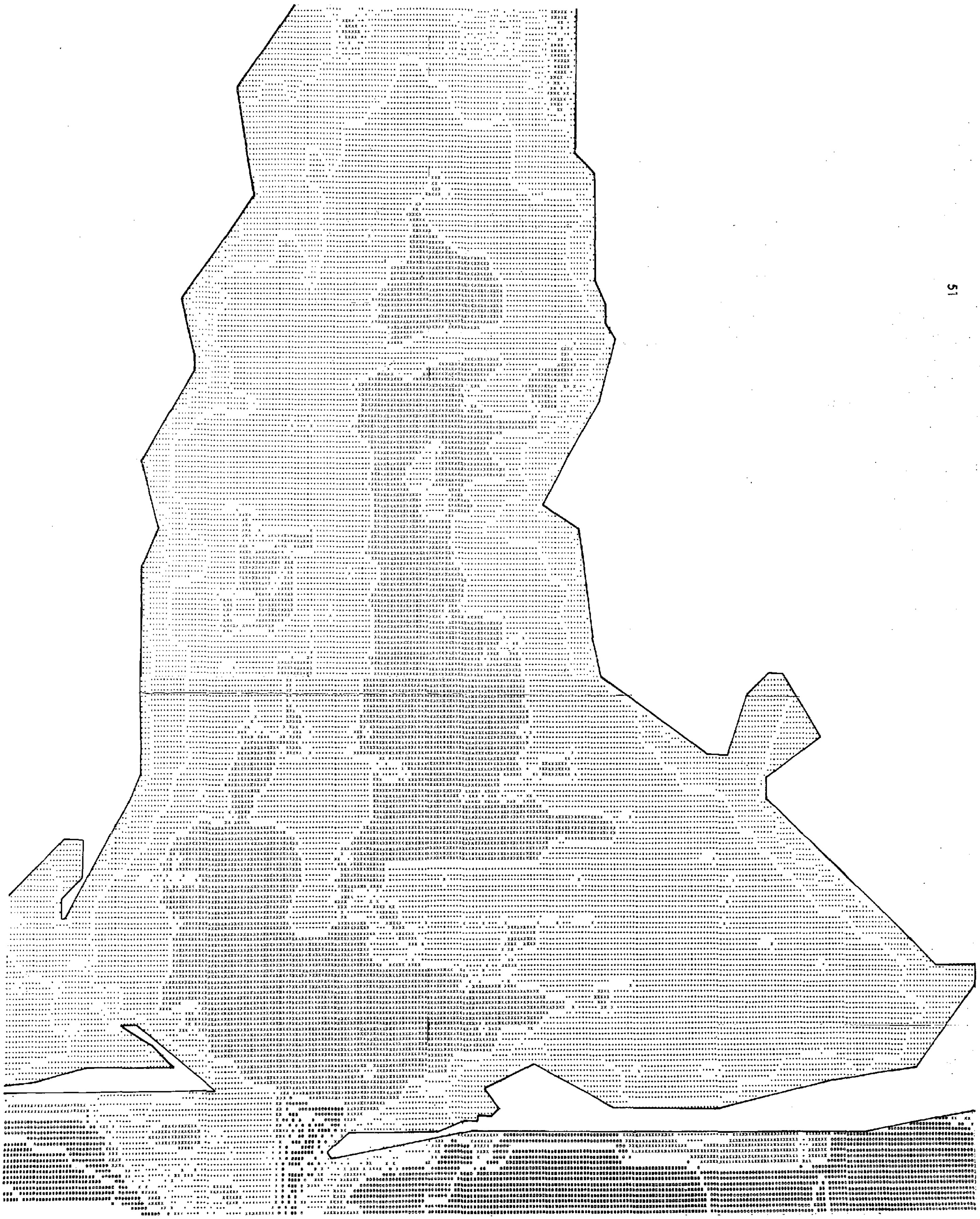

Figure 17. Mobile Bay bathymetry 1973

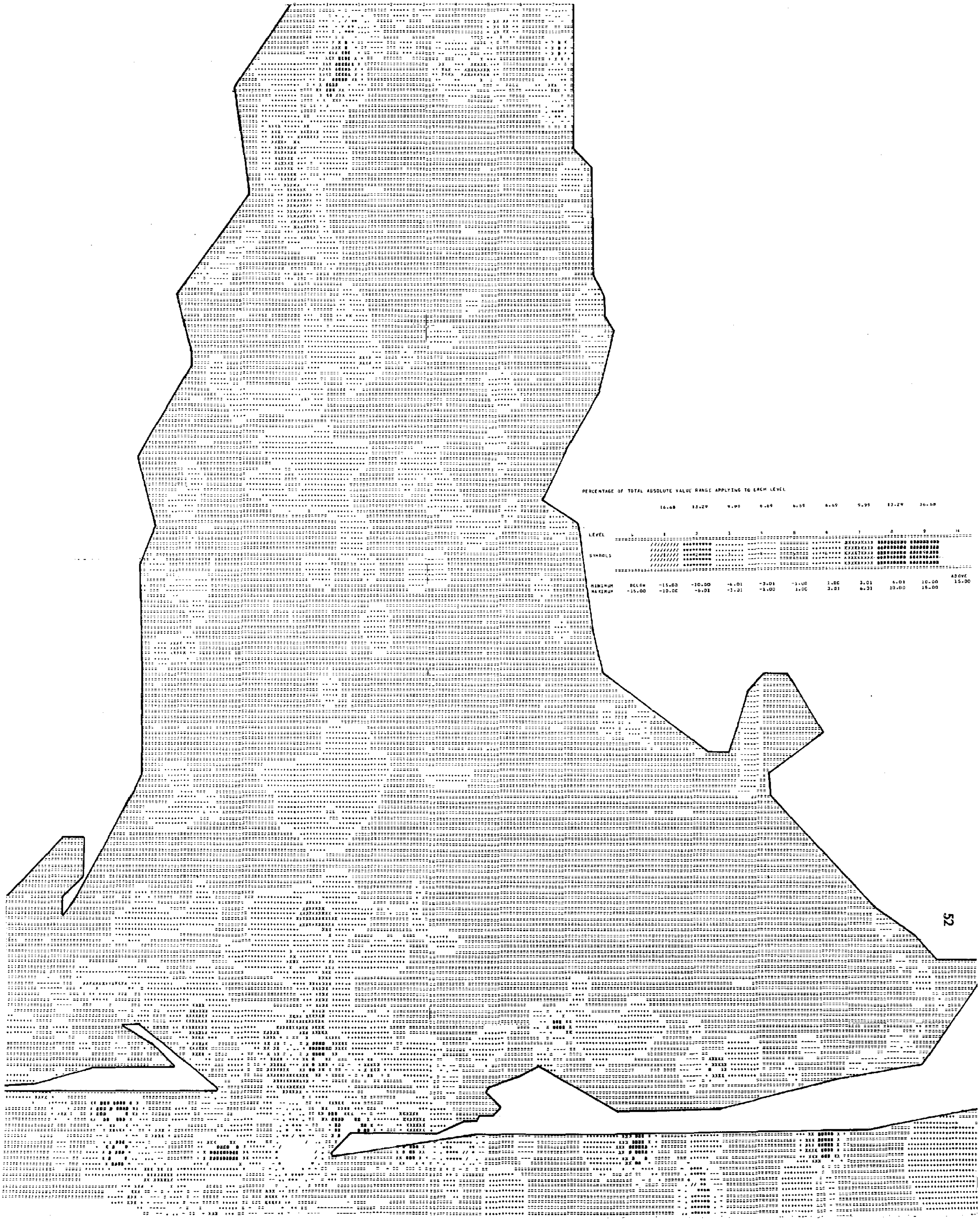

Figure 18. Changes in bathymetry in Mobile Bay 1920-1973

occurred in four areas: 1) off Mobile city, 2) east of Dauphin Island, north of the main entrance to the bay, 3) south of Dauphin Island, and 4) north of Little Point Clear. Each of these areas is of limited extent, but the filling is significant, on the order of 3 m (10 ft) addition to the bottom during the 53-year period. Figure 19 shows only the areas of deposition (1920-1973), and figure 20 shows only the areas of washout during the period. The latter map reveals three areas of erosion of 1.5-3.0 m (5-10 ft) magnitude: 1) off Mobile, 2) in the tidal pass, and 3) in the gulf bordering Mobile Point.

Three additional computer maps illustrate the overall change in bathymetry from 1852 to 1973. Figure 21 shows both deposition and washout. This map is divided into positive and negative components (figs. 22, and 23). The positive pattern (fig. 22) is dominant, and the salient difference is the dredging along the ship channel. This ridge of spoil is evident from the main entrance all the way to Mobile. Each end of this ridge is raised even more, so that about 3 m (10 ft) of filling has occurred in these two locations. Figure 23 shows the overall negative pattern (washout) during the 121-year period. Most of the scouring has occurred in the main entrance of Mobile Point, but other significant areas of washout are in the upper bay off Daphne (Ragged Point) and the Blakeley River bar. Eastern Bon Secour Bay shows as much washout as it does deposition; in other words, little overall change is evident in this area.

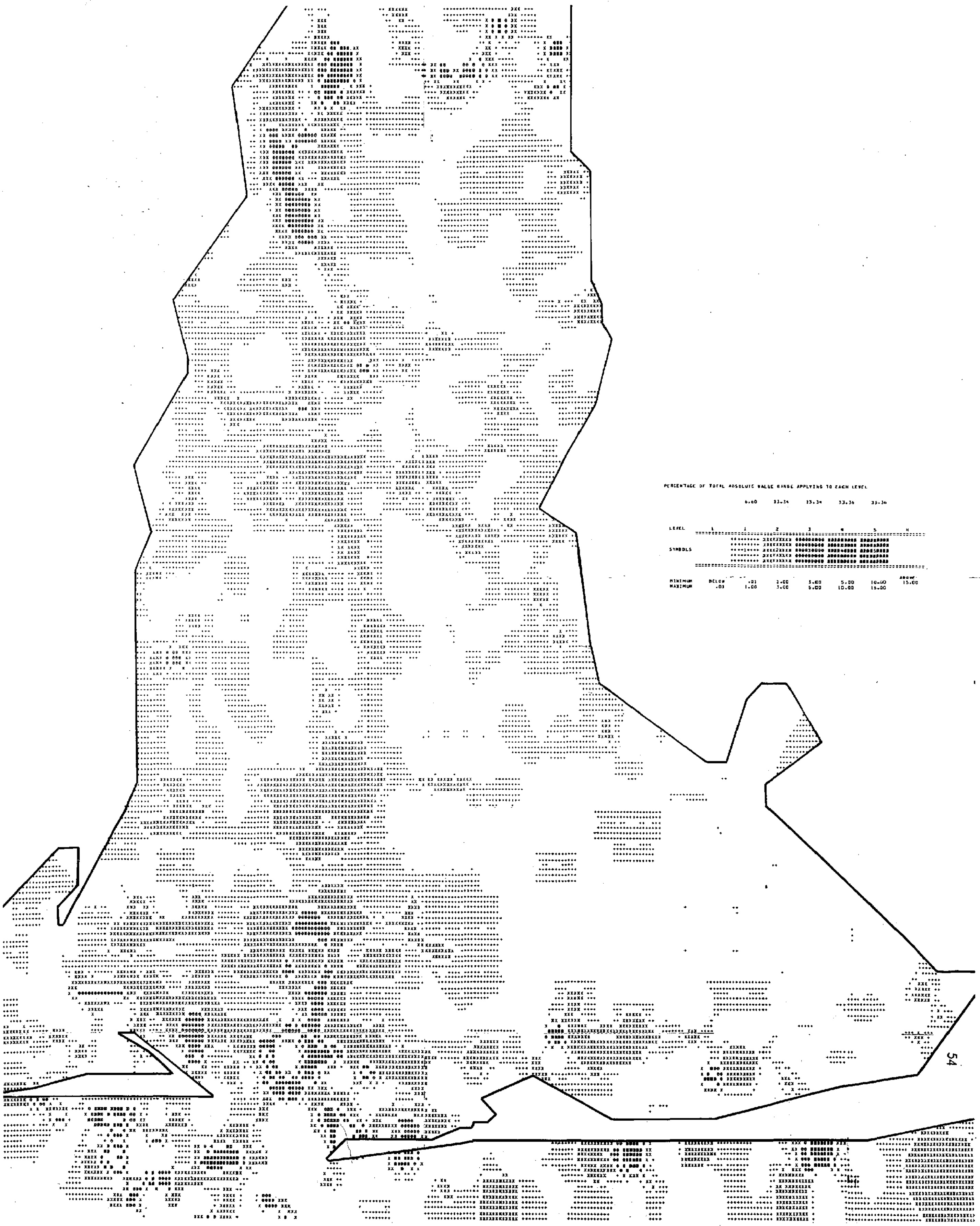

Figure 19. Areas of deposition in Mobile Bay 1920-1973

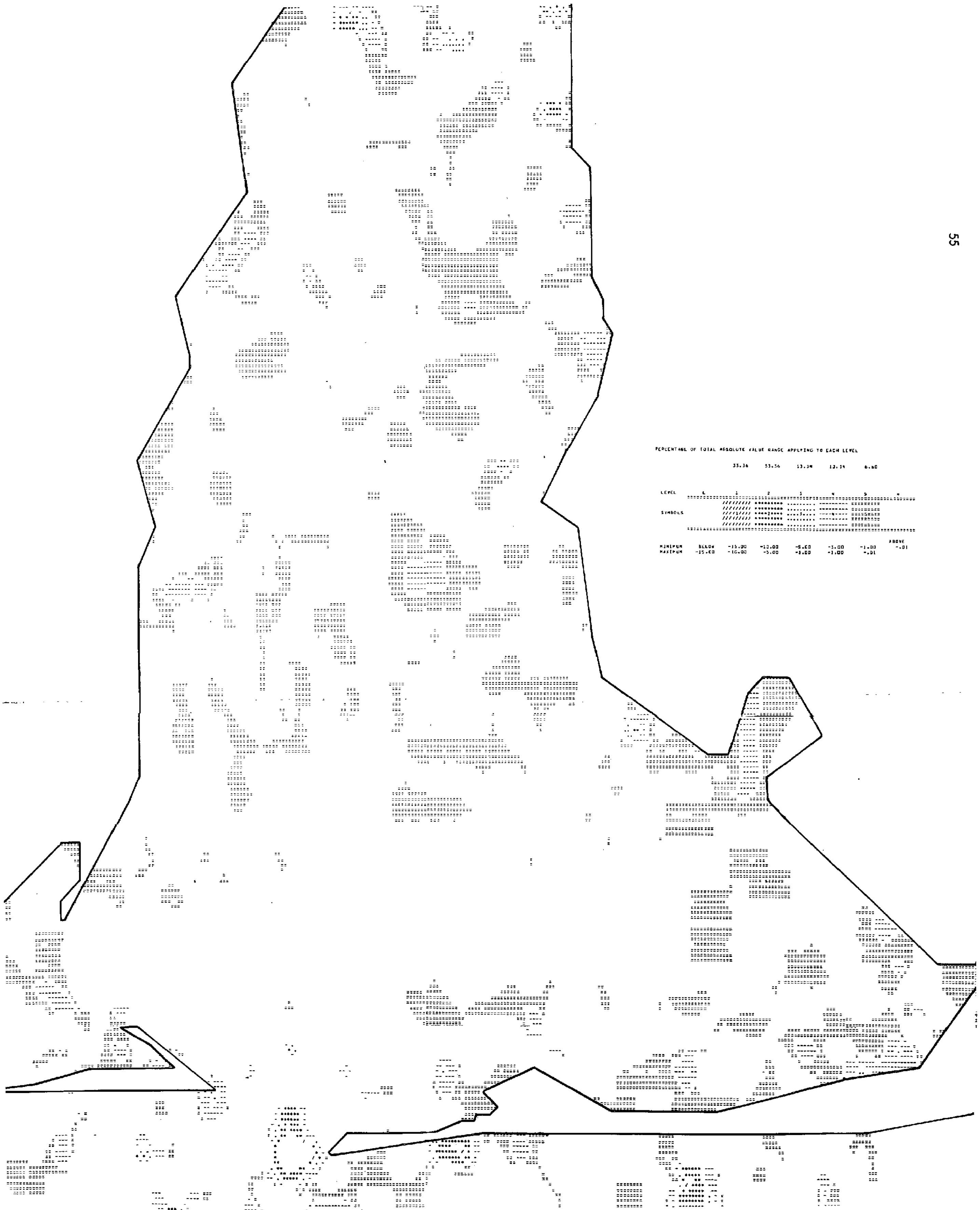

Figure 20. Areas of washout in Mobile Bay 1920-1973

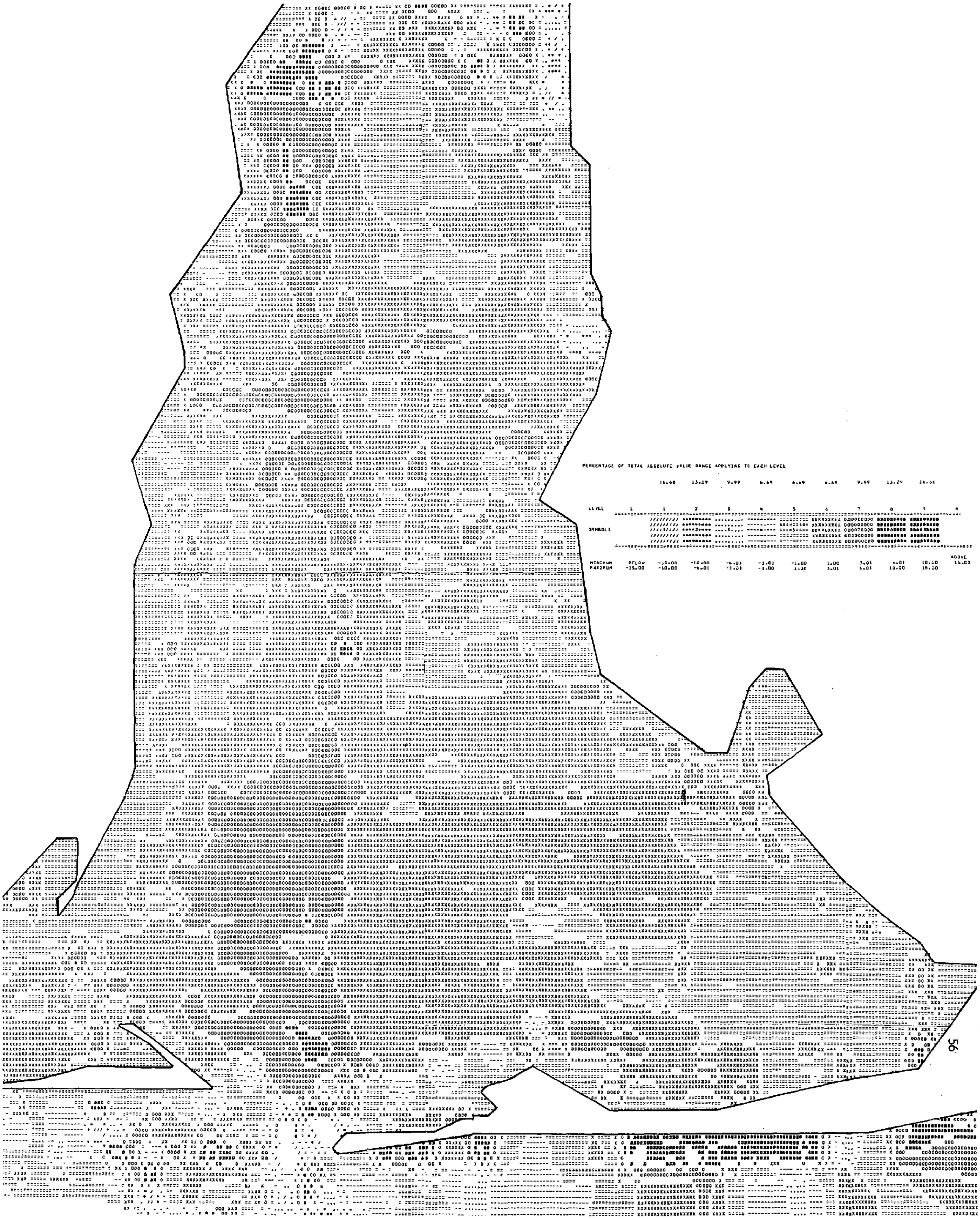

Figure 21. Changes in bathymetry in Mobile Bay 1852-1973

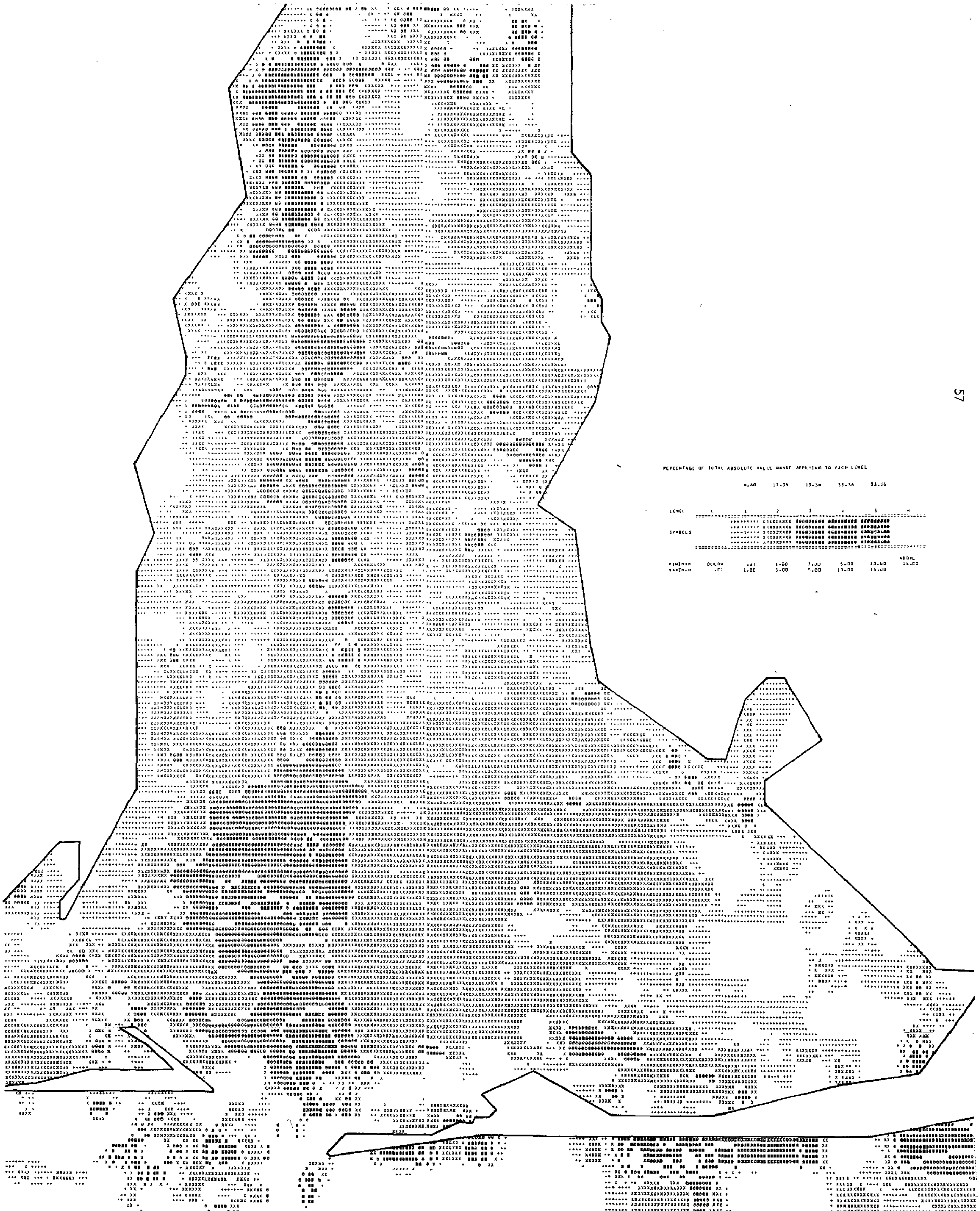

Figure 22. Areas of deposition in Mobile Bay 1852-1973

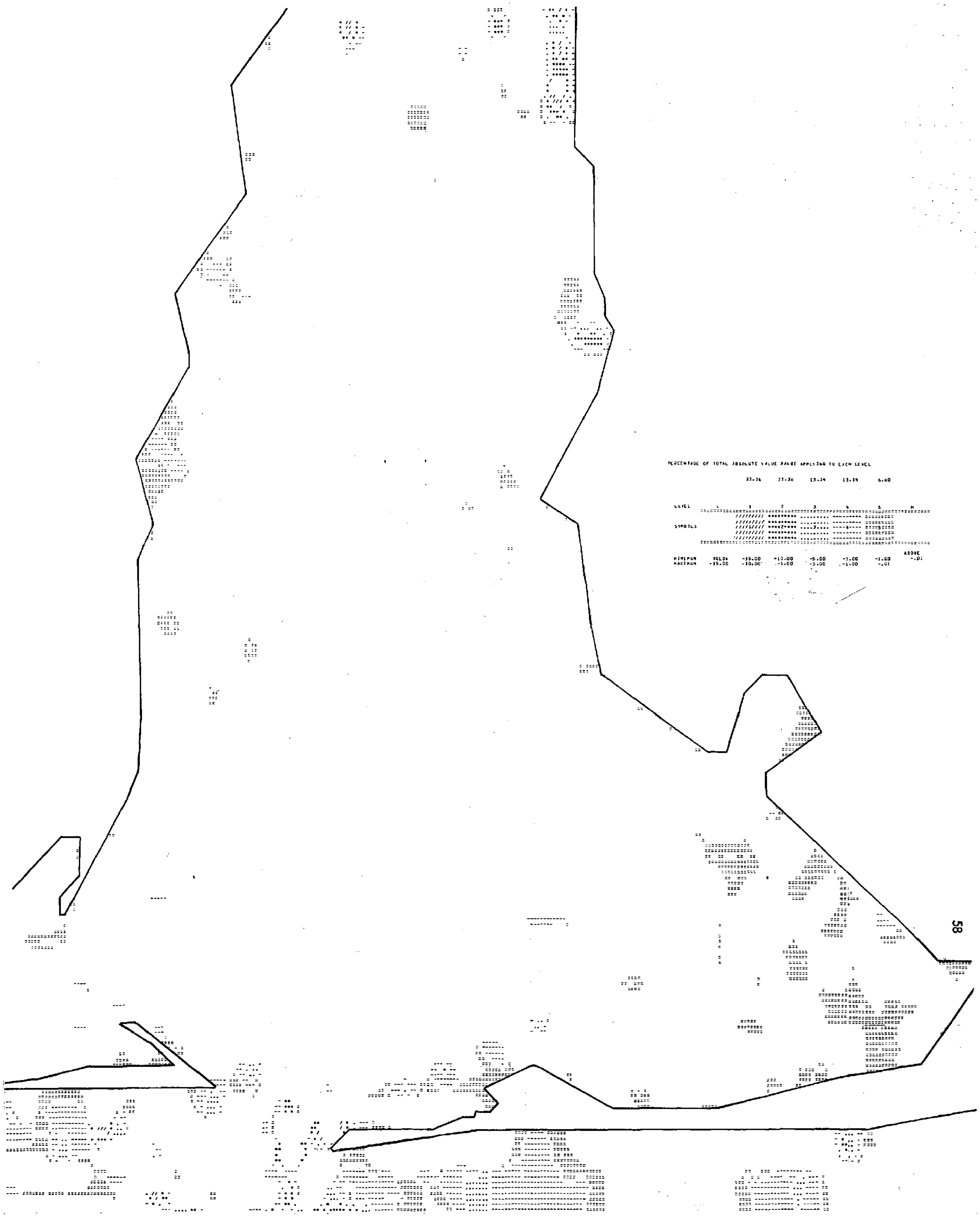

Figure 23. Areas of washout in Mobile Bay 1852-1973

A more detailed discussion of the bathymetric changes in passes of Mobile Bay and Mississippi Sound is provided separately in the section on shoreline changes. These details were obtained by contouring the soundings at larger scale. The computer-derived maps just described consisted of "smoothed" and interpolated surfaces that tended to obscure details but provided an excellent and objectively generalized picture of the whole bay. The SYMAP original graphics were produced on a 97 by 77 cm (38 in by 30.5 in) format and subsequently reduced photographically to 33 percent of this size for illustration in this report. The originals are on file at the Geological Survey of Alabama, Remote-Sensing Division.

A discussion of the bottom configuration of Mobile Bay is not complete without some information on profiles. A series of six east-west profiles was plotted from soundings from National Ocean Survey charts dated 1852, 1920, and 1973*. The graphs were made by averaging soundings for 0.8 km (0.5 mi.) grid squares and plotting profiles of the averages across the bay. Figure 24 shows the location of the profiles and figures 25, 26, 27, and 28 show the profiles, presented in order from north to south.

The northernmost profile (line 5, figure 25) reveals the man-made accretion immediately south of Mobile during the entire period 1852 to 1973. This accretion

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* The hydrographic data for each chart are not renewed each time a chart is compiled, but instead the National Ocean Survey apparently adds new soundings continually. It is not possible, therefore, to fix the compilation date of the hydrographic data for these charts, and these three general dates must suffice.

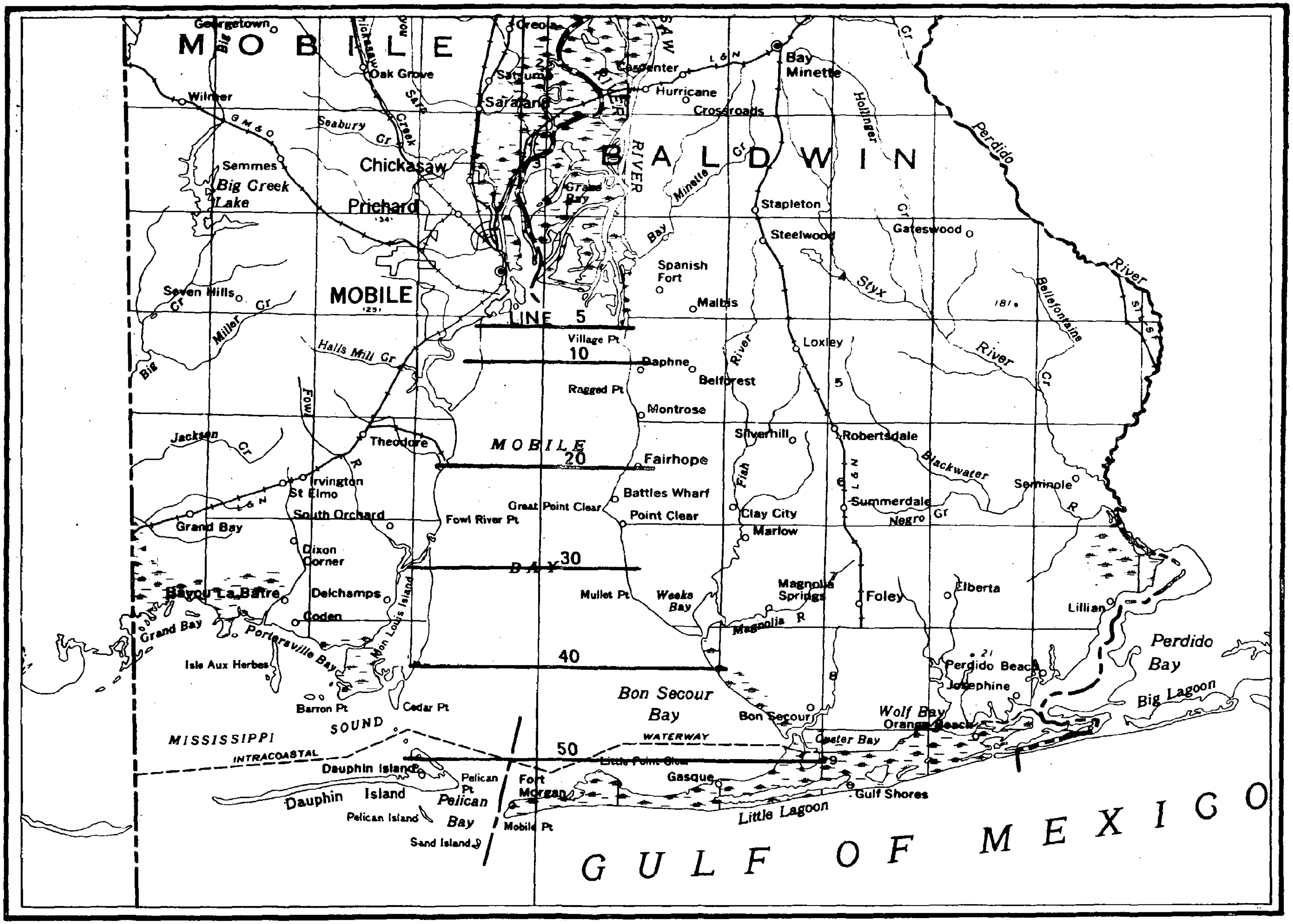

Figure 24.--Sampling transects for bathymetric profiles.

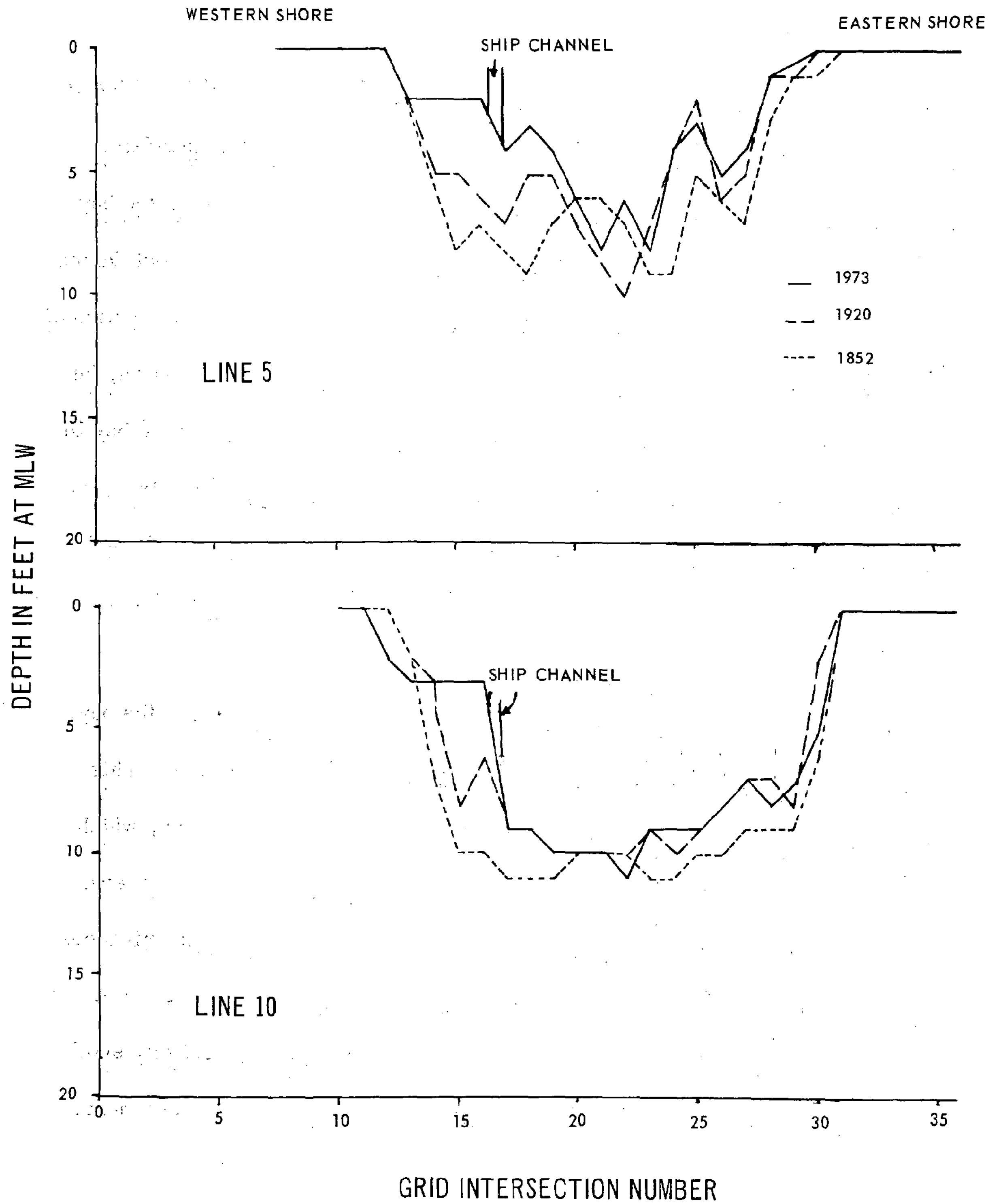

Figure 25. --Mobile Bay bathymetric profiles 5 and 10.

seems to be increasing somewhat, as the change is greatest after 1920. Line 10 (same figure) shows a continuation of the accretion west of the ship channels. Further south, the distribution of the filling becomes more even across the bay, as line 30 (fig. 26) illustrates. Moreover, this part of the bay filled most during the post-1920 period. Yet, farther south, line 40 (fig. 27) shows a continuation of this trend. The filling is of greater magnitude than the previous line shows, but this increase is in proportion to the widening and general deepening of the bay to the south. Most of the change in the middle of the bay occurred before 1920, except in the vicinity of the ship channel. The shelf fringing the edges of the bay is spreading towards the center but the bay bottom remains predominantly flat in this area.

The bottom configuration further south, across the widest part of the bay, is radically different than that to the north, as line 50 (fig. 28) reveals. This profile runs from Dauphin Island to Oyster Bay. The ship channel area, which is plotted in the vicinity of grid intersection numbers 12-17, has filled several feet, according to the graph, but the resolution of the grid does not permit plotting of the 40-foot dredged channel itself. The graph depicts only the general depths in the ship channel area for each date. Most of the fill is probably spoil from channel dredging. An overall filling trend is indicated immediately north

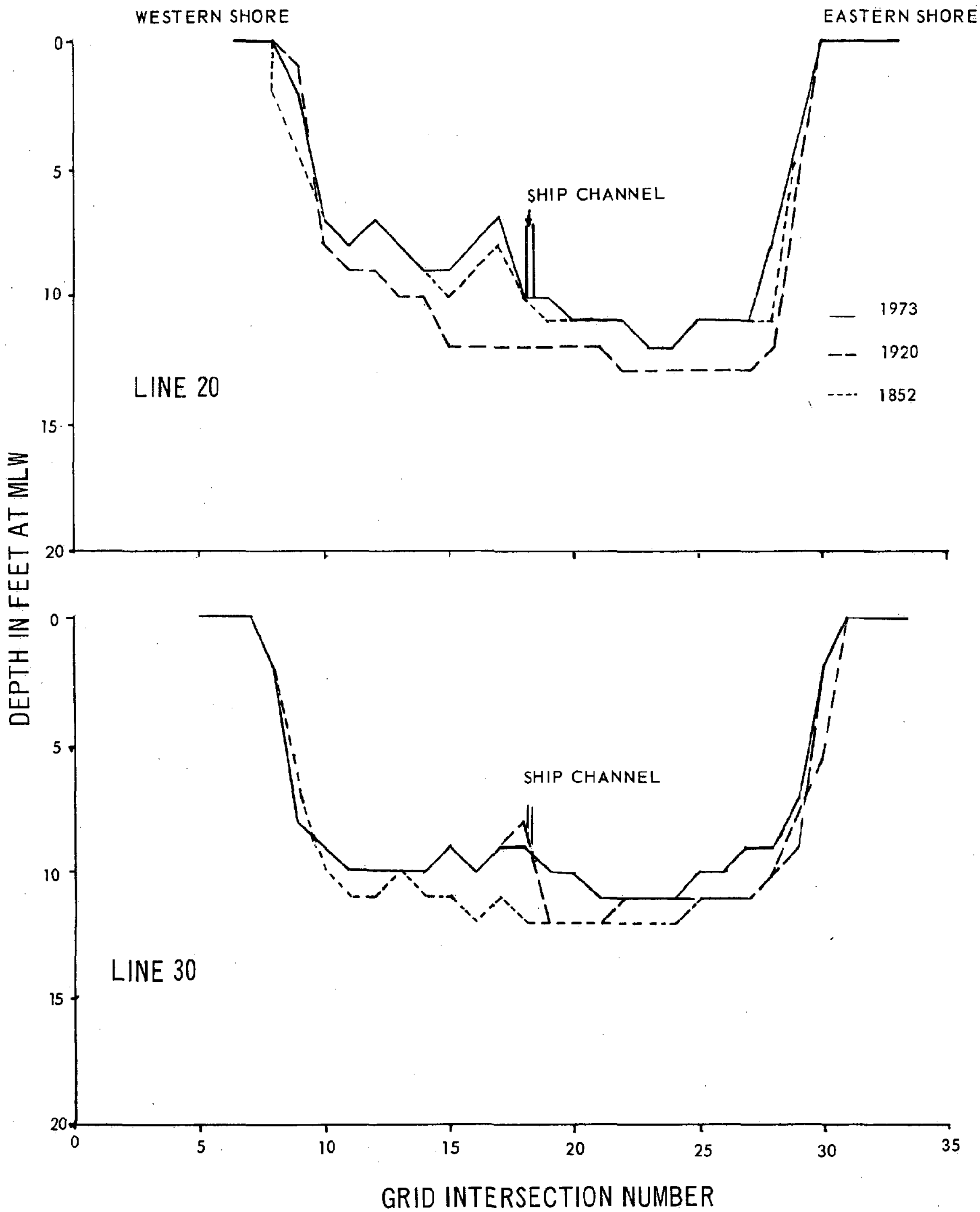

Figure 26. --Mobile Bay bathymetric profiles 20 and 30.

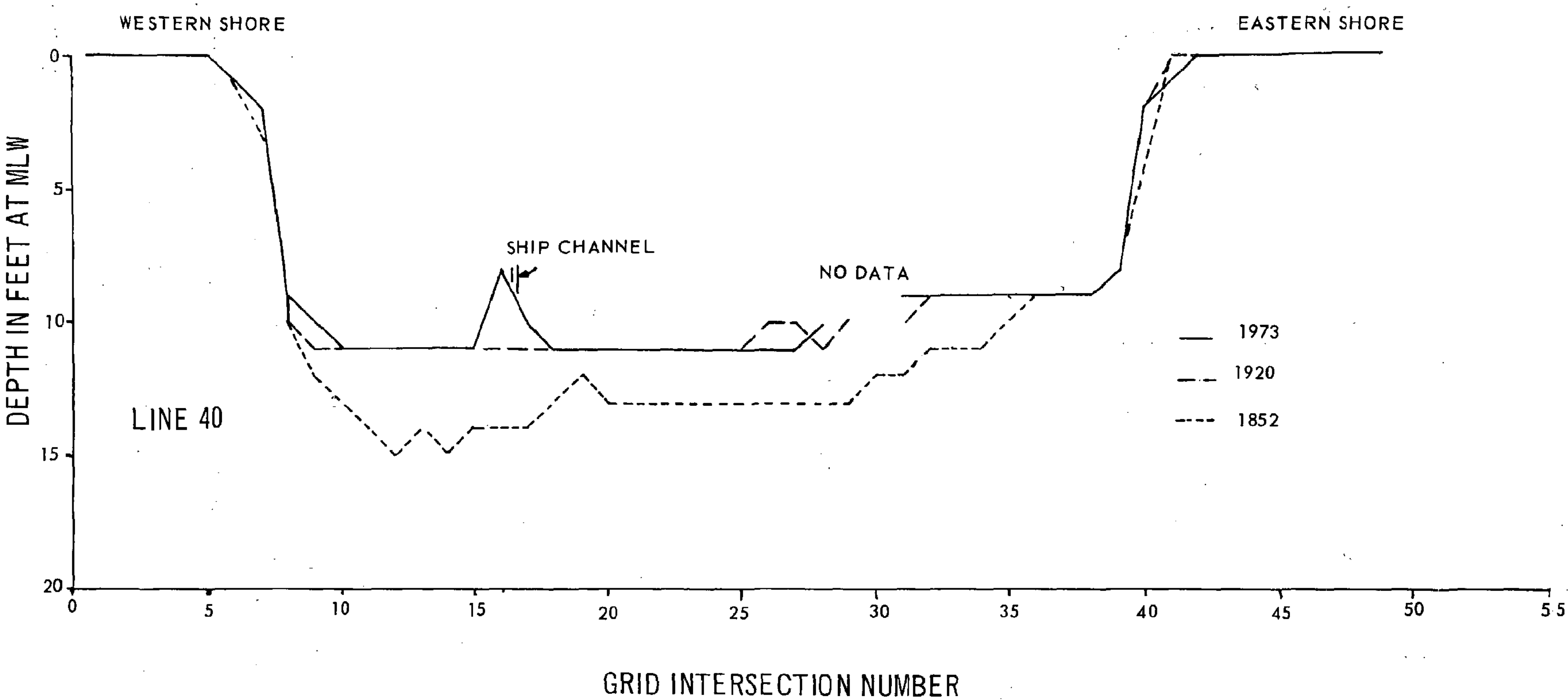

Figure 27. --Mobile Bay bathymetric profile 40.

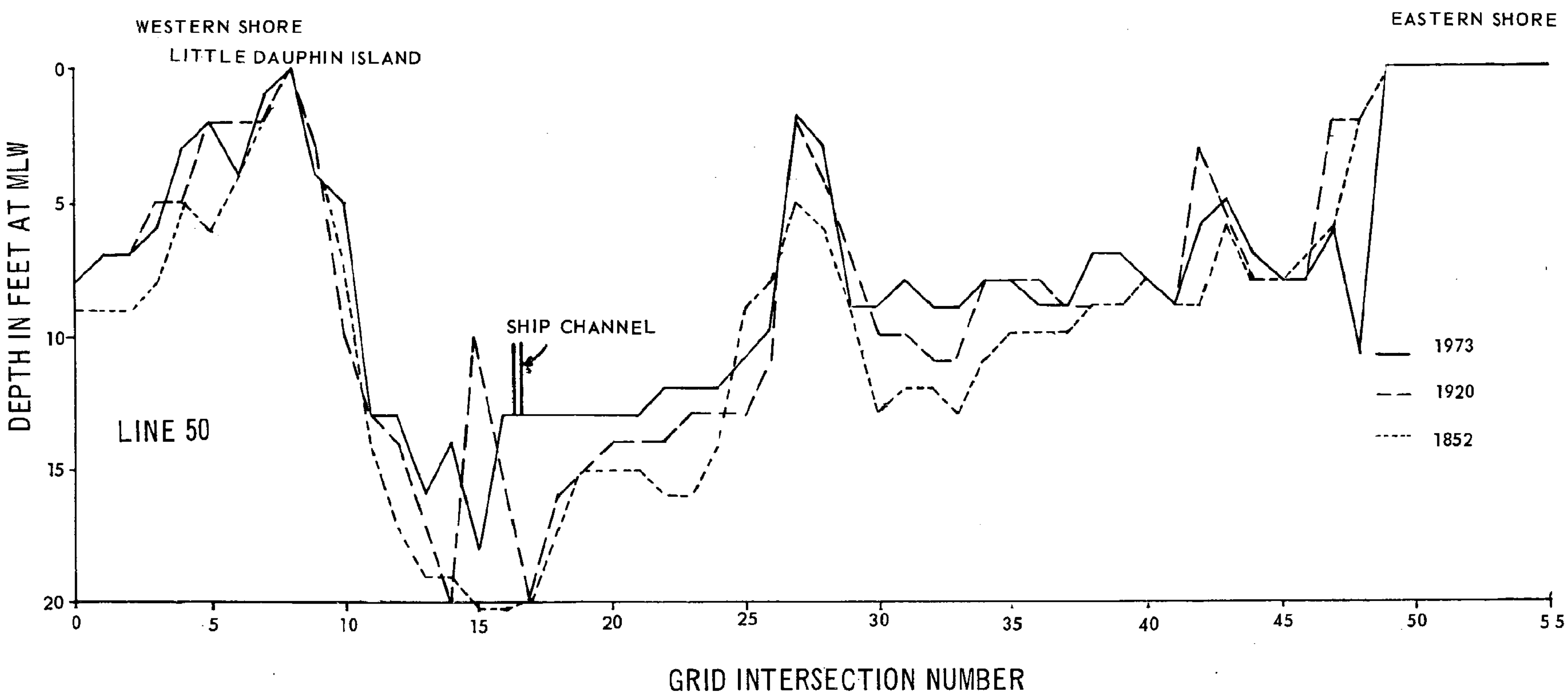

Figure 28. --Mobile Bay bathymetric profile 50.

of the Mobile Bay entrance as well as in Bon Secour Bay south of the intracoastal waterway.

PROCESSES CAUSING SHORELINE AND BATHYMETRIC CHANGES

Shoreline and bathymetric changes are a result of complex interactions among natural processes and, often, the activities of man. The apportionment of the effects of each natural process on a specific historical shoreline or near-shore bottom, or even on an existing one, is a most difficult problem requiring extremely detailed data. This information does not exist at this time for Mobile Bay. Observations can be made, however, on the general effects of natural and anthropogenetic processes as they operate within the coastal waters of Alabama. Changes result from the normal interactions of winds, waves, tides, and currents; severe weather disturbances; sediment budget variations; and sea level changes.

Winds, Waves, Tides, and Currents

Winds may cause extreme variation in the normal tidal range in Mobile and Perdido Bays, and Mississippi Sound. Waves generated by winds having a long fetch can impinge upon a windward shore and cause much erosion in just a few hours. Wind-generated longshore currents and rip currents may quickly remove and transport shore materials from an exposed shoreline.

In the coastal area of Alabama, average wind directions and velocities vary with the seasons. During the fall and winter months, winds are predominantly from the north or northwest, while spring and summer winds are from the south or southwest (Chermock, Boone, and Lipp, 1974. In January, 19 percent of the winds are from the north octant and 14 percent are from the northwest octant (fig. 29). Velocities may range as high as 13.3-28.0 km/hr (12-20 knots). In June, 15 percent of all winds are from the south octant and 14 percent are from the southwest octant. Velocities may range as high as 13.3-28.0 km/hr (12-20 knots) (Institute for Storm Research, 1974). The average annual wind direction and velocity is from the north at 13.3 km/hr (9.5 knots) (Crance, 1971).

Persistent high winds from the north and and northwest during the winter months tend to depress the water level in much of the bay and concurrently cause a buildup of waves along the south and southeast shores where wind fetch length is great. Under these conditions, severe erosion may occur along the northern shore of Morgan Peninsula.

During the summer months, and occasionally in the winter months, persistent and strong south and southwesterly winds cause a decrease in water level, especially in the lower bay. Waves and tides then build up in the upper bay, causing severe erosion along the western shore and lower Mobile delta, and water and waves periodically cover the causeway across the lower Mobile delta. These variations in water level cause complex currents that complicate the normal circulation within the bay.

Somewhat the same situation exists in Perdido Bay, although the effects are not as pronounced because of its smaller size.

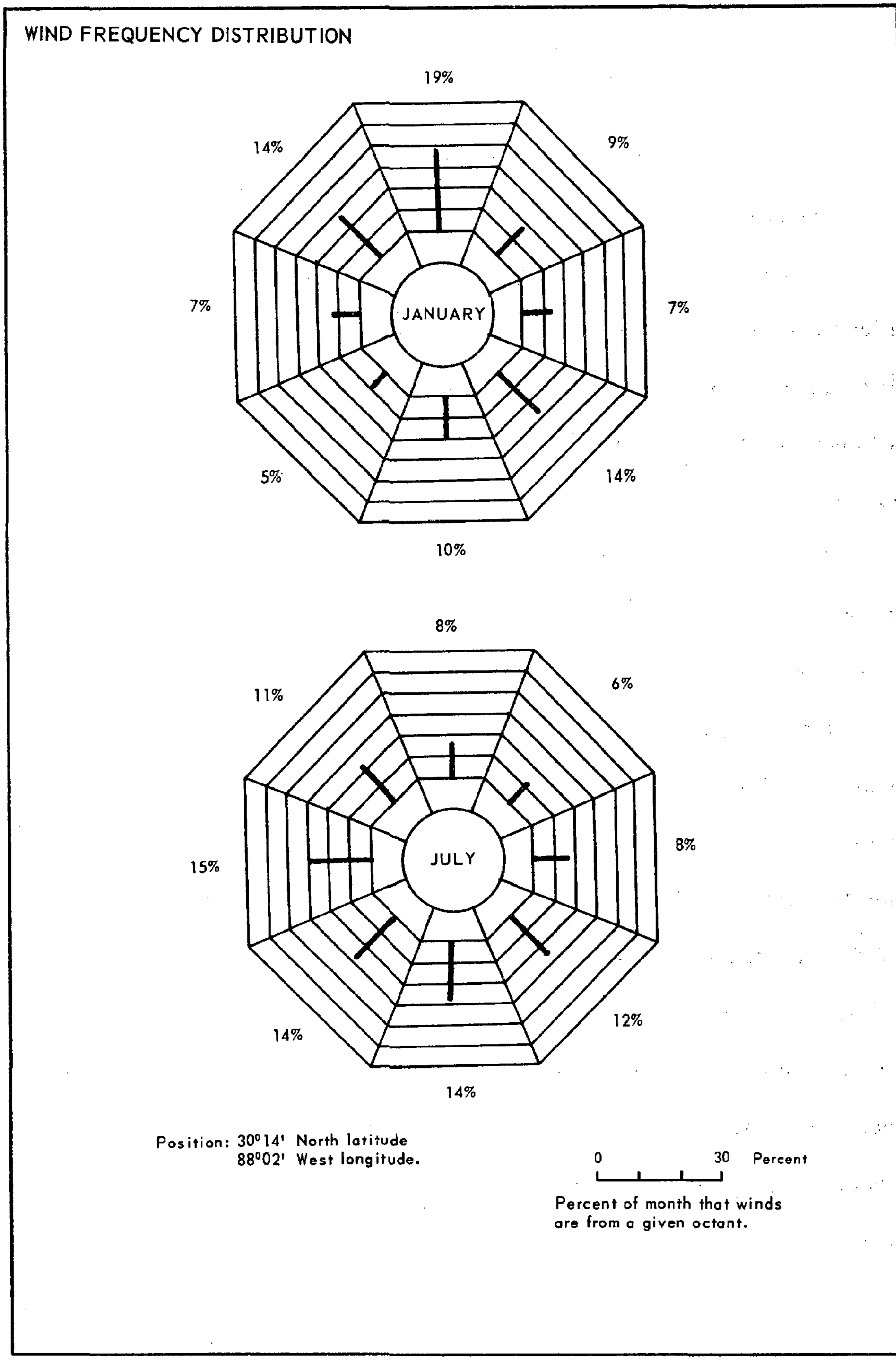

Figure 29. --Wind roses for coastal Alabama, January and July.

Severe Weather Disturbances

The coastal area of Alabama has experienced the effects of 24 tropical storms or hurricanes between 1901 and 1955. Simpson and Laurence (1971) predict that in an 80-km (50-mi.) segment of coastline between Biloxi, Mississippi, and the mouth of Mobile Bay, the probability of landfall of a tropical storm is 13 percent, of a hurricane 6 percent, and of a great hurricane 1 percent for any one year.

The aspects of such severe weather disturbances that cause the greatest changes to shorelines and near-shore bottoms are storm surges, waves, and currents (Hayes, 1967).

Storm surge, the rapid rise in sea level partially produced by hurricane winds and falling barometric pressure, may inundate vast areas of low-lying coastal areas, producing significant and widespread erosion and deposition of shoreline and near-shore sediments. Considering that a hurricane or tropical storm may last for several days, tremendous quantities of water can be amassed against the coastline (Hayes, 1967). Surges in Alabama have been recorded as high as 3.60 m (11.8 ft) above MLW and as low as 2.96 m (9.7 ft) below MLW. When a storm surge advances up a converging estuary such as Mobile Bay or Perdido Bay, its height increases as the water becomes more confined. The storm surge progresses more rapidly on a rising tide and may result in the formation of a wall-like wave of water moving up the estuary (Chermock, 1975.)

There is a great danger of damage by hurricane storm surge along much of the Alabama coastal area because many areas along Mississippi Sound, Dauphin Island, Morgan Peninsula, and the gulf shoreline are below 3.0 m (10 ft) elevation In these areas, surge with destructive waves can remove vast quantities of sediments and destroy coastal structures. Because the effects of storm surge may be attenuated by the barrier dune complex along the gulf shoreline and the eastern end of Dauphin Island, the gulf beaches are the areas most subject to surf erosion. Probably the most significant effect of hurricanes is the erosion produced by breaking waves. Large waves riding the crest of a large storm surge can cause great devastation especially to cliffed or dunal shorelines. Breaking waves also can generate strong longshore and rip currents which may remove sediments from the shore and near-shore areas (Hayes, 1967).

During severe weather disturbances, extremely rough sea conditions prohibit the use of surface ships for taking oceanographic measurements (Hayes, 1967), and high winds and rainfall make the use of current meters extremely hazardous. So, little is known about the currents generated under such conditions other than the obvious: they must be very strong.

Sediment Budget Variations

The sediment budget for the coastal system is the net amount of sediment in the coastal area after considering the quantity of material being introduced, the quantity temporarily stored (dunes) and the quantity being removed from the coastal system. Beaches are nourished and maintained by sand-size sediment contributed by major streams, updrift shoreline erosion, onshore movement of shelf sand by wave action (Brown, and others, 1974) and by current circulation. Sand losses are caused by transportation offshore into deep water, accretion along and against natural barriers and man-made structures, deposition in tidal deltas and hurricane washover fans, excavation for proposed construction, and eolian processes (Brown, and others, 1974).

Sediment is supplied to the coastal area by the Mobile River system and by the Perdido River system. Ryan (1969) estimates that the suspended sediment load reaching Mobile delta and bay averages 4.3 million metric tons (4.7 million tons) per year and ranges from 1.9 million metric tons to 7.5 million metric tons (2.1 million tons to 8.3 million tons) per year. Of the 4.3 million metric tons per year introduced, an estimated 1.3 million metric tons (1.4 million tons) per year, or 30 percent of the total introduced, passes through the estuarine system to the gulf. No quantitative data on bed load transported by the Mobile River system is available.

Similar data are not now available for Perdido River flowing into Perdido Bay (Boone, 1973).

Prevailing south and southeast winds generate waves that produce a westward-flowing current along the gulf shore. A net longshore drift of 49,699 m^3 (65,000 yd^3) per year at Perdido Pass has been reported to enter the Alabama coastal area. D.S. Gorsline, using wave-energy equations, calculated the net drift at Gulf Shores at 149,853 m^3 (196,000 yd^3) per year. This drift continues to the mouth of Mobile Bay, a major drift barrier, where much of the material is carried offshore. Drift volumes within the bays have never been estimated, but are probably small (U.S. Army Corps of Engineers, 1973).

These examples give only brief glimpses of a complex sedimentary budget. Obviously, much work needs to be done on the variations in movement and the fate of sediments within the coastal system of Alabama.

Sea Level Changes

Shoreline changes caused by variations in sea level are termed eustatic. Eustatic changes can arise through diastrophism, which is connected with changes in the form or depth of the ocean (Guilcher, 1954) or climatic changes, which cause variations in the volume of the continental ice sheets.

The National Ocean Survey has established 16 control tide stations along the gulf coast to continuously monitor tidal height and, during a period of at least 19 years, to determine changes taking place in the relative elevations of land and sea (Shalowitz, 1964). None of these stations is located in Alabama. Tide-gage data gathered over the past 50 years along the Florida gulf coast show that there has been a relative subsidence of 0.1 mm (0.04 in) per year. This measurement is obviously composed of sea-level changes as well as land-level changes (Lazarus, 1965). However, Lazarus attributes most of this change to land subsidence and assigns a value of 0.1 mm per year for the gulf coast from the mouth of the Mississippi River to Key West. Based upon the superimposition of this local subsidence rate on the oscillations of sea level on a worldwide basis as these varied with time. Lazarus (1965) determined that sea level rose rapidly from -112 m (-368 ft) MSL about 18,000 years before the present (B.P.) to -3.2 m (-10 ft) MSL about 5,800 years B.P. The rise in sea level slowed appreciably between 5,800 years B.P. and the present time, rising in an erratic manner in response to glacial cycle until the present stand was reached (Lazarus, 1965).

Tidal gage records over the past few decades show evidence that changes in the relative levels of land and sea are still in progress (Bird, 1969). On a low-lying coast such as that bordering much of the coastal area, a continuing relative rise in sea level will have a marked effect on the configuration of the shoreline.

DETAILED ASSESSMENT OF SHORELINE AND BATHYMETRIC CHANGES

Historical shoreline and bathymetric change assessment shows that the coastal shoreline of Alabama is being significantly modified by winds, currents, and tides. Most of the coastal shoreline shows either a net accretion or a net erosion. A very few areas exhibit a state of equilibrium in shoreline movement over the measured time interval.

Since shoreline erosion is of primary concern, a map of shorelines showing a net erosional trend during the period of measurement was prepared (pl. 1). The trends shown on plate 1 represent the net changes between 1917 and 1956-74. Short-term changes caused by hurricanes, tropical storms, excessive winds, abnormally high tides, although important, obviously cannot be shown on this map. Measurements made by opisometer during the compilation of this map show that of a total of 811.4 km (503.9 mi.) of shoreline, 355.7 km (220.9 mi.) showed a net erosional trend, and 455.7 km (283.0 mi.) showed a net accretional trend, or a net state of equilibrium as determined by the methods of this study. Some caution is advised in the use of the figures because the limitations of the method, as mentioned previously, do not allow for accurate measurements of small net changes.

Some areas are undergoing more rapid erosion or accretion and must be analyzed and described in more detail. For this study, the shoreline has been divided into nine regions: 1) the Mobile delta, 2) Mobile harbor, 3) the western shore, 4) Mississippi Sound, north shore, 5) Dauphin Island, 6) the eastern shore 7) Morgan Peninsula, bay shore, 8) the gulf shore, and 9) Perdido Bay. These regions are shown on plate 1. The areas of erosion, accretion or shoreline stability will be emphasized, along with consideration of the possible causes.

Mobile Delta

The Mobile delta is a depositional feature that began filling the Alabama River estuary some 3,000 years ago (Russell, 1967). This prograding delta has filled over 64 km (40 mi.) of the original estuary. Most of the delta has remained in a near-natural state with the exceptions of the lower terminus, where much land filling and causeway construction (1927) has occurred, and on Blakeley and Pinto Islands where much landfill and industrial/commercial expansion has taken place.

In the analysis of shoreline changes, the Mobile delta was divided into two regions, one being that part of the delta least subject to alterations by man, designated as the Mobile delta region, and the other being that area most subject to the constructions of man, the Mobile harbor region. Although some mingling occurs, this division was established to facilitate the differentiation of changes in shoreline caused by natural processes from those changes due to man's activities.

Between 1917 and 1967, the shoreline of the Mobile delta has shown a small net erosional trend even though a few areas exhibit a state of equilibrium. Erosion has occurred principally along the channel margins of distributary rivers such as the western bank of the Blakeley River, the eastern bank of the Apalachee River, and along areas of both banks of the Tensaw River and Spanish River (figs. 30 and 31). Most of the accretion has occurred within the interdistributary bays and along the remaining banks of the distributaries. The tips of the natural levees marginal to the distributaries show both erosion and accretion. Figure 32 shows graphically the rates of accretion at the tip of the western natural levee of the Apalachee River. Between 1953 and 1967, there was a distinct erosional trend in all the interdistributary bays, which reverses the accretional trend of the past 36 years.

Between 1917 and 1967, net change of minus 8.92 ha (22.04 a.) of area occurred in the Mobile delta. In an environment where increased sediment deposition and land-building should occur, a large net addition should be expected. That such an accretion did not occur indicates that the delta's progradation has decelerated. Such a situation might be partly caused by a decrease in sediment being transported downstream by the Mobile River as a result of upstream impoundments,

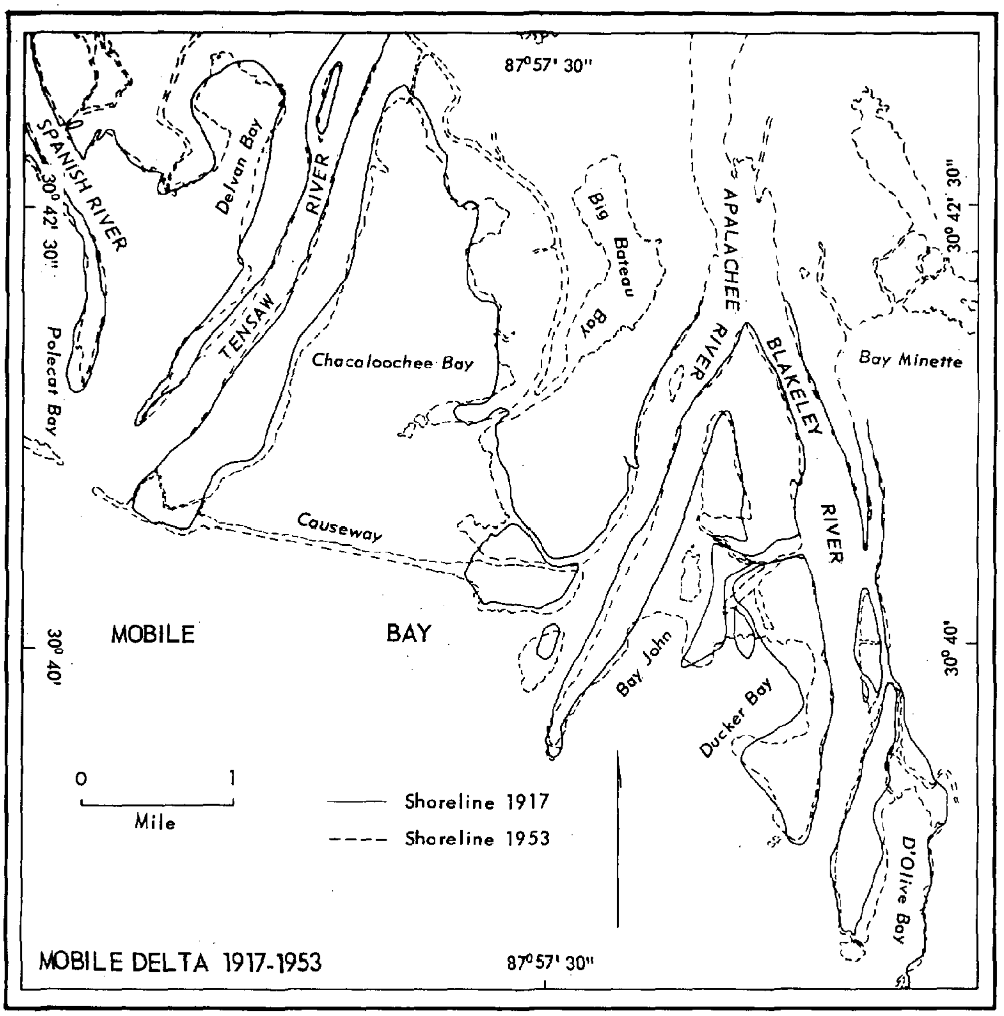

Figure 30.--Shoreline changes in the Mobile delta region, 1917-1953.

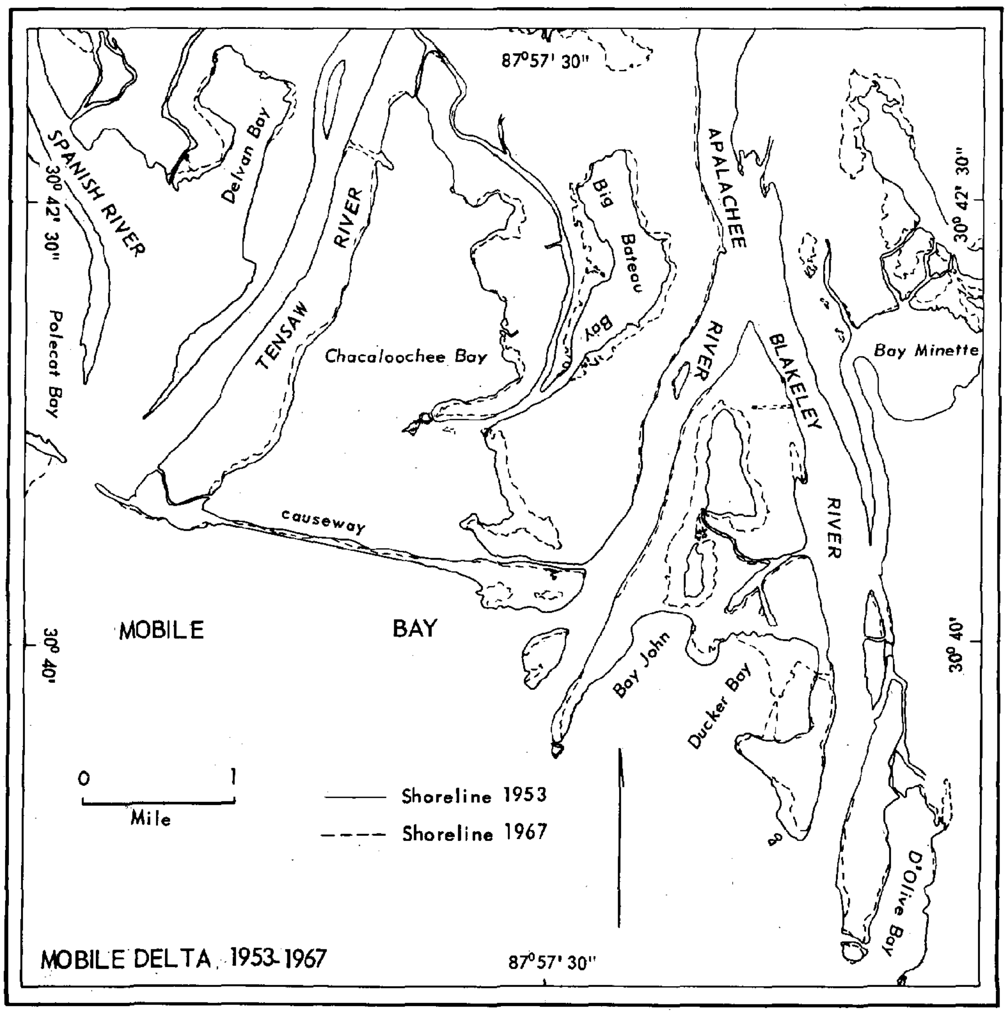

Figure 31.--Shoreline change in the Mobile delta region, 1953-1967.

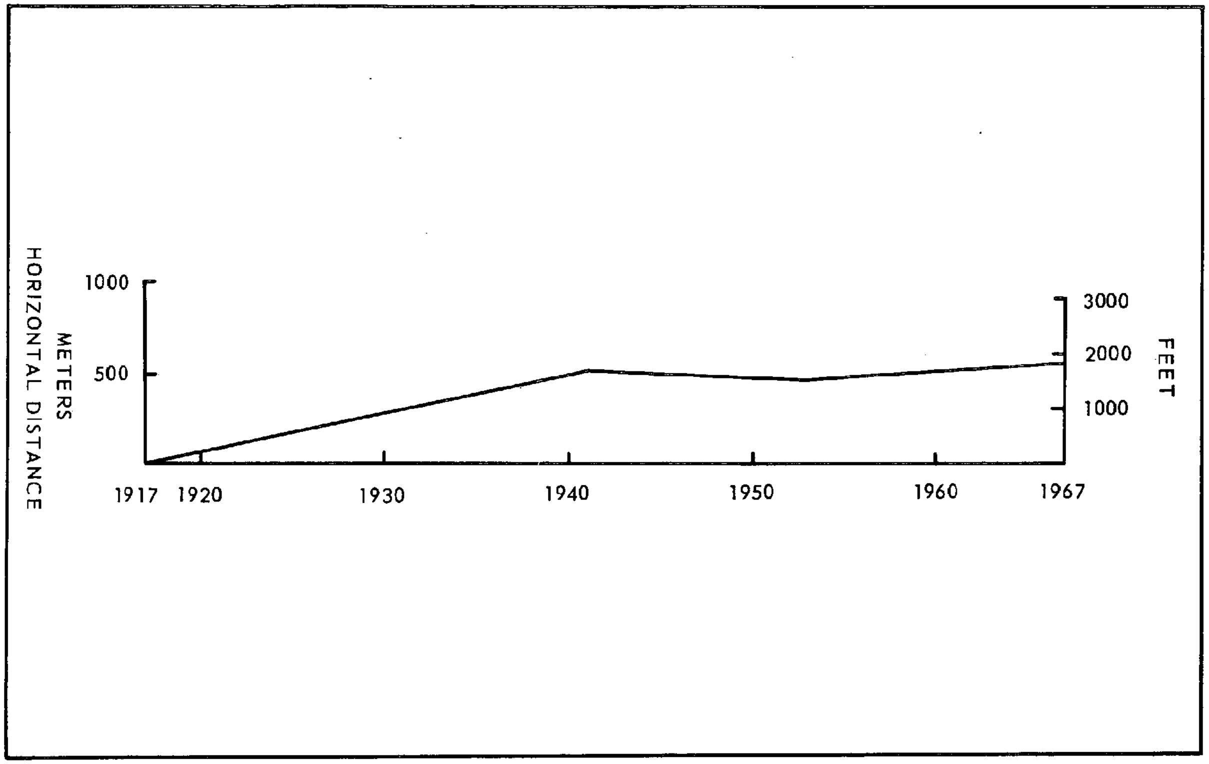

Figure 32.--Changes in the rate of accretion for various time periods at the tip of the western natural levee of the Apalachee River, 1917-1967.

or by short periods of high discharge (floods). The greatly increased velocity of water flowing over the delta during such floods could cause much erosion in a short period.

Mobile Harbor

The region designated Mobile harbor lies between 30°37'30" and 30°44'00" north latitude and between 88°04'00" and 88°04'00" west longitude (pl. 1).

The most significant characteristic of the Mobile harbor area is the extensive accretion of shoreline caused by the continued spoils disposal and landfill carried out in the development of the harbor and the adjacent industrial/commercial complex. Table 5 shows the actual areas of landfill at various intervals since 1917. Some 668.31 ha (1,650.73 a.) of land was made by the combined efforts of spoils disposal and landfill in the area shown in figure 33.

Table 5.--Area of landfill, Mobile harbor, 1917 to 1974, in hectares (acres)

Period		Area built up	
1917-1940		86.62 ha	(213.95 a.)
1940-1953		80.99 ha	(200.04 a.)
1953-1967		274.95 ha	(679.14 a.)
1967-1974		225.75 ha	(557.60 a.)
	Total	668.75 ha	(1,650.73 a.)

Many other coastal areas have been filled, but not at a rate as rapid as that in the Mobile harbor region. Crance (1971) reported a total of 871 ha (2,152 a.) of estuary filled above MLW in Alabama between 1953 and 1971. The total is subdivided into various areas of coastal Alabama, as shown in table 6.

Figures 33 and 34 show the areas of accretion in Mobile harbor between various time periods from 1917 to 1974. Most of this "made-land" occurs on Blakeley Island, Pinto Island, McDuffie Island, and Little Sand Island. Figure 35 shows the rate of construction of made land during various periods between 1917 and 1974. The highest rate concurs with the period of rapid development in Mobile during the 1950's and 1960's.

Western Shore

The western shore of Mobile Bay begins, for the purposes of this study, at the Brookley Aerospace Complex and continues down the entire western shore of Mobile Bay to Cedar Point. Three major tidal creeks, Dog River, Deer River, and Fowl River, enter the bay on the western shore. The shoreline consists of a narrow sandy or marshy shoreline backed mostly by actively eroding seacliffs ranging from 1.5 to 4.6 km (5 to 15 ft) high as far south as Alabama Port. Trees felled by the constant erosion may be seen along almost the entire shoreline.

Table 6.--Filled areas in the Alabama estuaries

Area	Emergent spoil banks (MLW)	Causeways	Housing, industry or other uses	Total
Mississippi Sound				34.6 ha (85 a.)
Graveline, Aloe and Dauphin Island Bays	0.8 ha (2 a.)	0.8 ha (2 a.)	16.2 ha (40 a.)	
Dauphin Island Airport	0.4 ha (1 a.)		14.2 ha (35 a.)	
Miscellaneous			2.0 ha (5 a.)	
Mobile Bay				347.2 ha (858 a.)
Brookley Field extension			83.4 ha (206 a.)	
McDuffie Island area	5.6 ha (14 a.)	1.2 ha (3 a.)	93.1 ha (230 a.)	
Battleship Park			73.2 ha (181 a.)	
Meaher Park			35.6 ha (88 a.)	
Pinto Island			12.1 ha (30 a.)	
Little Sand Island area			14.5 ha (36 a.)	
Miscellaneous		14.2 ha (35 a.)	14.2 ha (35 a.)	
Mobile Delta				484.0 ha (1,119 a.)
Polecat Bay			405.5 ha (1,002 a.)	
Sardine Pass			50.2 ha (124 a.)	
Miscellaneous		14.2 ha (35 a.)	14.2 ha (35 a.)	
Perdido Bay		0.4 ha (1 a.)	4.0 ha (10 a.)	4.4 ha (11 a.)
Little Lagoon			0.8 ha (2 a.)	0.8 ha (2 a.)
Total	6.8 ha (17 a.)	30.8 ha (76 a.)	833.3 ha (2,059 a.)	870.9 ha (2,152 a.)

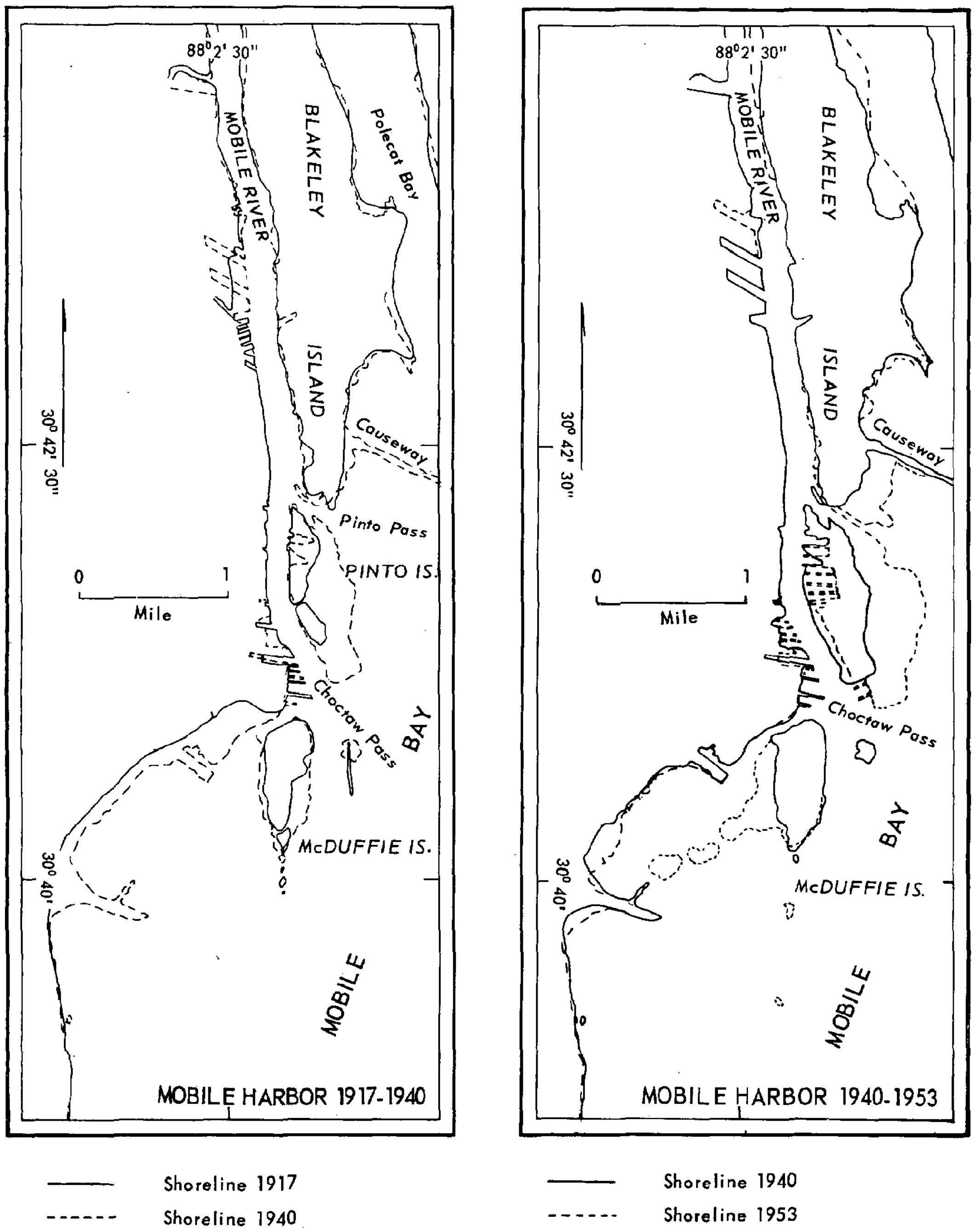

Figure 33.--Areas of shoreline changes in Mobile harbor between 1918-1940 and 1940-1974.

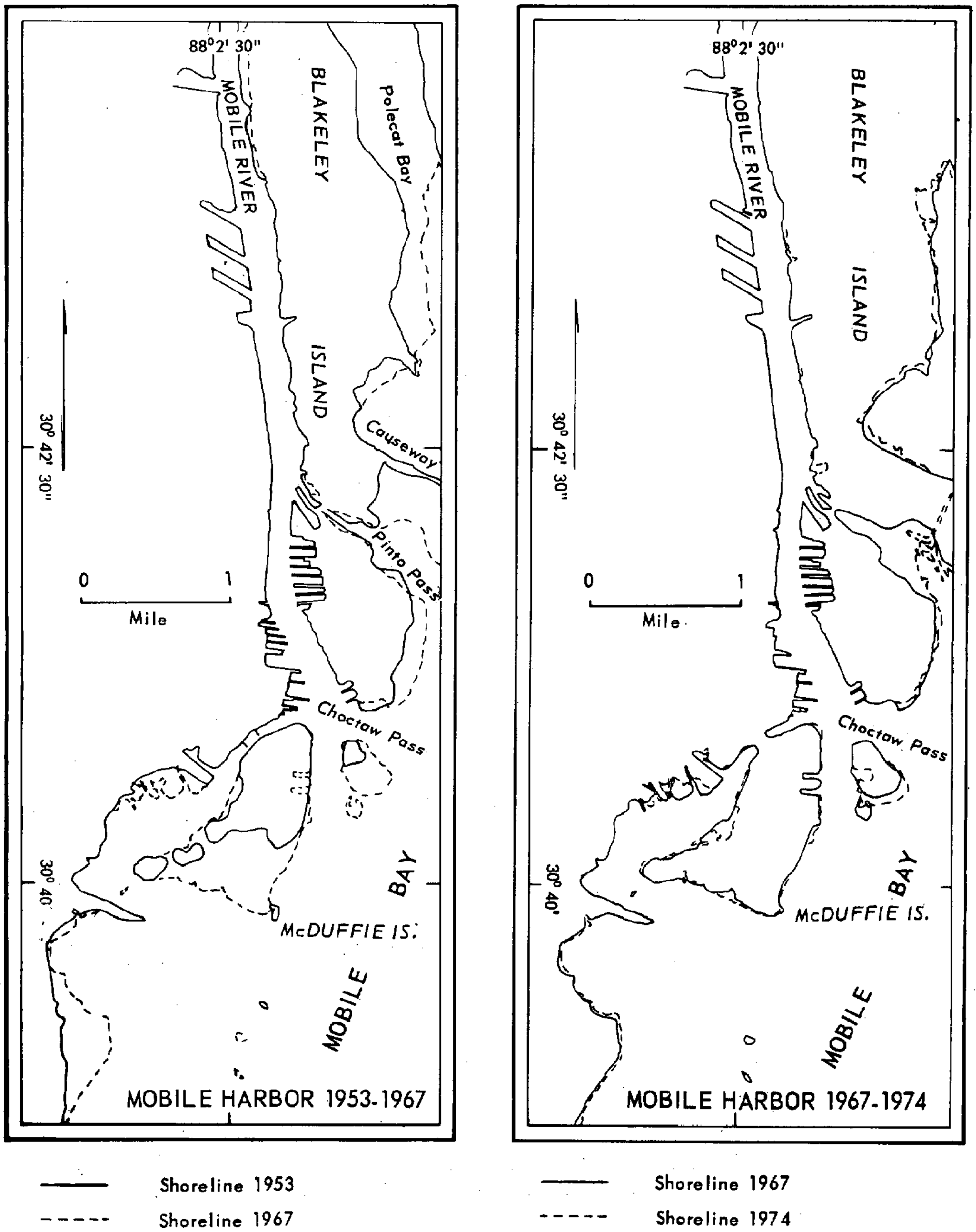

Figure 34.--Areas of shoreline changes in Mobile harbor between 1953-1967 and 1967-1974.

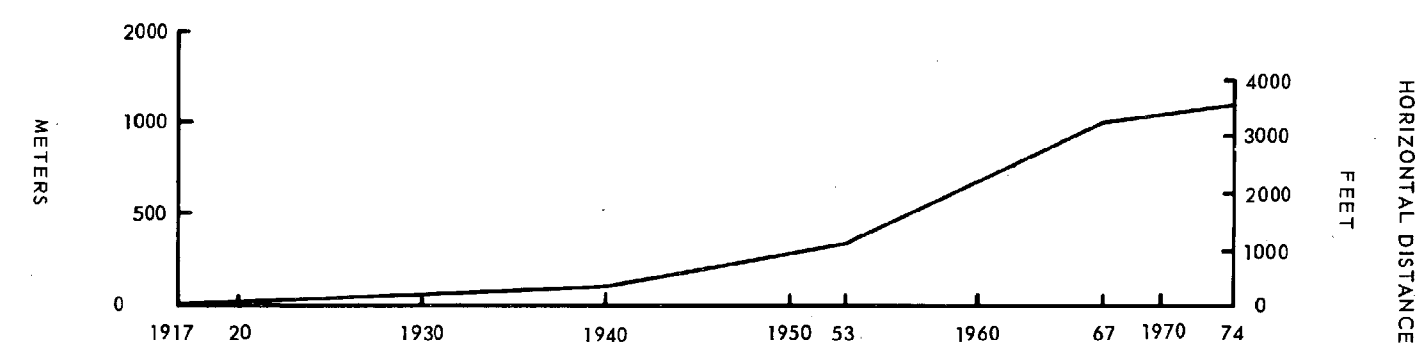

Figure 35.--Changes in the rate of landfill for various time periods at McDuffie Island, 1917-1974.

All along the western shore of Mobile Bay south from Brookley Aerospace Complex to Cedar Point there has occurred a persistent and significant erosional trend of from less than 1.52 m (5 ft) per year in most areas to as much as 2.60 m (8.56 ft) per year and averaging 0.97 m (3.17 ft) per year at Cedar Point based on various intervals of time. Table 7 shows measurements made of the shoreline changes at points identifiable on U.S. Geological Survey 7.5-minute topographic sheets. As this table shows, erosion at measured points has ranged from 12 m (39 ft) at Pt. Judith to 149 m (488 ft) at Cedar Point during 1917-1974. The areas between Dog River Point and Fowl River Point and between Delchamps Bayou and Cedar Point show the most severe amounts of erosion (pl. 1).

Figure 36 shows the shoreline changes between Dog River Bridge and Fowl River Point during various time periods between 1917 and 1967. The persistent and severe erosion shown in this area is broken only by accretion caused by spoils disposal in an area north of the Hollingers Island Channel (proposed Theodore Ship Channel). Erosion in the area is threatening waterfront residents throughout the area.

The severe erosion along the shore between Alabama Port and Cedar Point has already partly destroyed a railroad right-of-way to the east of Highway 163. Erosion is now threatening the highway itself at some points. The Cedar Point

Table 7. --Shoreline changes measured at selected identifiable points along the western shore of Mobile Bay.

	Location	Change*	Time period	Average annual change
1.	Dog River Point (at bench mark)	-83.8m (-275 ft)	1917-1967	1.68m (5.51 ft)
2.	Mobile Yacht Club (at pier)	-120.1m (-394 ft)	1917-1967	2.40m (7.87 ft)
3.	Deer River Point (at new pier)	-47.9m (-157 ft)	1917-1967	0.96m (3.15 ft)
4.	Bellefontaine (at name on map)	-36.0m (-118 ft)	1917-1958	0.88m (2.88 ft)
5.	Sunny Cove (at name)	-52.7m (-173 ft)	1917-1958	1.29m (4.23 ft)
6.	Fowl River Point (at bench mark)	-43.3m (-142 ft)	1917-1958	1.05m (3.46 ft)
7.	Mon Louis (at name)	-24.1m (- 79 ft)	1917-1958	0.59m (1.93 ft)
8.	Faustinas (at name)	-29.9m (- 98 ft)	1917-1958	0.73m (2.40 ft)
9.	Pt. Judith (at name)	-11.9m (- 39 ft)	1917-1974	0.20m (0.68 ft)
10.	Alabama Port (at name)	-43.3m (-142 ft)	1917-1974	0.76m (2.49 ft)
11.	Cedar Point (at30°20'00"N. latitude	-107.9m (-354 ft)	1917-1974	1.90m (6.22 ft)
12.	Cedar Point (at Hwy 163 symbol)	-148.7m (-488 ft)	1917-1974	2.61m (8.56 ft)

*Positive changes show accretion; negative changes show erosion.

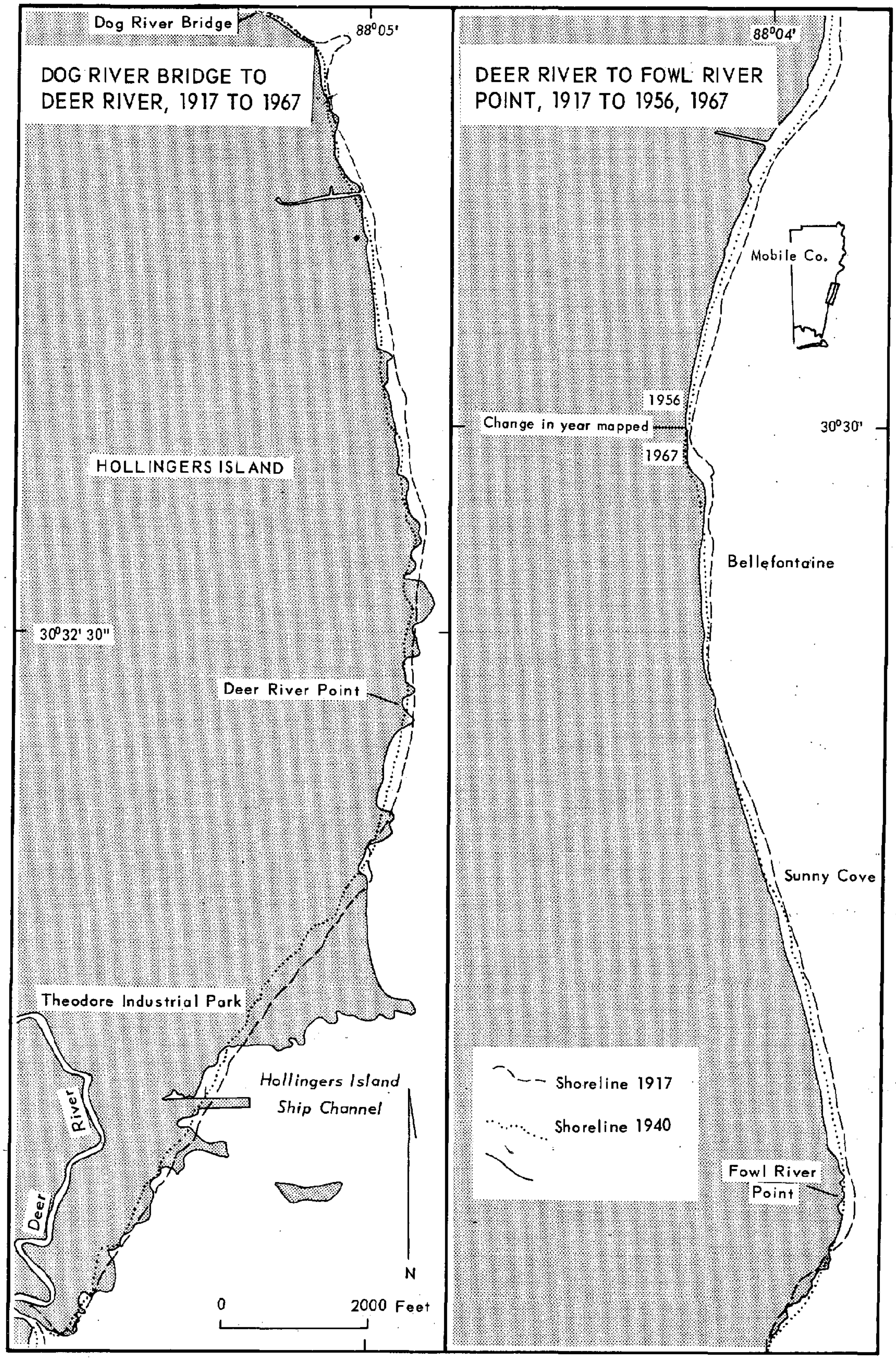

Figure 36. --Shoreline changes between Dog River Bridge and Fowl River Point between 1917 and 1967.

area is very important to the continued protection of the salt marshes of southern Hollingers Island in Mississippi Sound from the full effects of winds, waves, and currents from Mobile Bay. The southern tip of Cedar Point has persistently shown one of the highest rates of erosion recorded for the coastal area. Between 1917 and 1974, 149 m (488 ft) of erosion has been measured (table 7). The change in rate of erosion for various time periods is shown in figure 37.

Mississippi Sound, North Shore

The northern shoreline of Mississippi Sound is mostly made up of low-lying salt marsh with numerous tidal creeks, the principal ones being West Fowl River, Bayou Coden, and Bayou La Batre. The shoreline of Mississippi Sound, including the barrier islands to the south, totals 201 km (125 mi.), excluding the length of tidal streams, of which 162 km (101 mi.) consist of tidal marsh (Crance, 1971). Most of the region's 4,762 ha (11,762 a.) (Crance, 1971) of tidal marsh is found around Grand Bay, Fowl River Bay, Heron Bay, and on the numerous small islands in the Sound. With the exception of residential and commercial fisheries development in the principal tidal creeks, most of the northern shoreline remains in a natural state.

The southern shoreline of Mississippi Sound is comprised of sandy barrier islands that protect the northern marshy coast from the full impact of erosional agents. These islands will be discussed more fully in a later section.

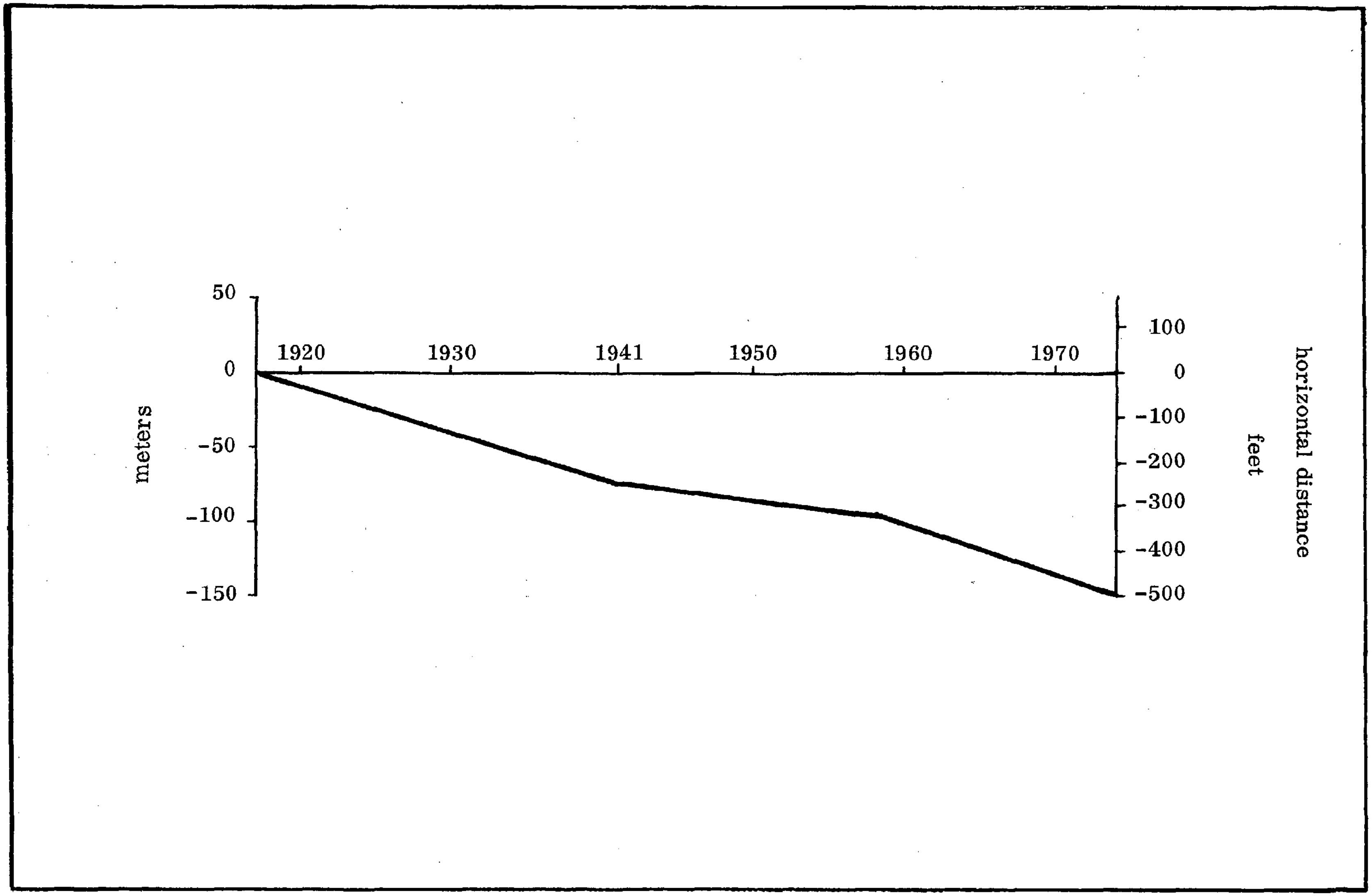

Figure 37.--Rates of erosion at Cedar Point between 1917 and 1974.

Between 1917 and 1958, most of the northern shoreline of Mississippi Sound experienced net shoreline erosion. The amount of erosion measured at selected points identifiable on U.S. Geological Survey 7.5-minute topographic maps of the area varied between 47.85 m (157 ft) on Marsh Island (Grand Bay) and 132.28 m (434 ft) on Marsh Island (Portersville Bay) as shown on table 8. These represent erosional trends ranging from 1.17 m (3.84 ft) per year to 3.77 m (10.56 ft) per year for those specific points. The changes in the rate of erosion for selected points over various time periods are shown in figure 38.

The generalized areas of erosion in Mississippi Sound are shown on plate 1. Most of the erosion of Mississippi Sound has occurred on exposed marshy headlands and on exposed shorelines at the numerous islands. Cat Island lost an average of 59.89 m (196.5 ft) of its southern shore, and Isle aux Herbes lost an average of 99.06 m (325.0 ft) of its southwestern shore between 1917 and 1958 (table 9).

It is estimated that many exposed shorelines of Mississippi Sound are eroding at an average rate of 1 to 2 m (3.28 to 6.56 ft) per year, on the basis of measurements made at selected points and average rates measured.

Dauphin Island Area

Dauphin Island is part of a chain of barrier islands protecting Mississippi Sound from erosional forces from the Gulf of Mexico. These islands absorb almost the full

Table 8.--Shoreline changes measured at selected identifiable points along the northern shore of Mississippi Sound

Location	Change*	Time period	Average annual erosion
1. Barron Point	-96.0 m (-315 ft)	1917-1955	2.34 m (7.68 ft)
2. Cat Island (southeast shore)	-101 m (-331 ft)	1917-1958	2.46 m (8.07 ft)
3. Marsh Island (southeast shore) (Portersville Bay)	-132 m (-434 ft)	1917-1958	3.77 m (10.56 ft)
4. Isle aux Herbes (eastern shore)	-71.9 m (-236 ft)	1917-1958	1.76 m (5.76 ft)
5. Isle aux Dames (88°18'00" W. longitude	-81.1 m (-276 ft)	1917-1958	2.05 m (6.72 ft)
6. Point aux Pins (at range line)	-71.9 m (-236 ft)	1917-1958	1.75 m (5.76 ft)
7. Marsh Island (mid-island) (Grand Bay)	-47.9 m (-157 ft)	1917-1958	1.17 m (3.84 ft)
8. Grand Batture Islands (South Rigolets Island, 1,000 m east of state line)	-120 m (-393 ft)	1917-1958	2.93 m (9.60 ft)

* Positive changes show accretion; negative changes show erosion.

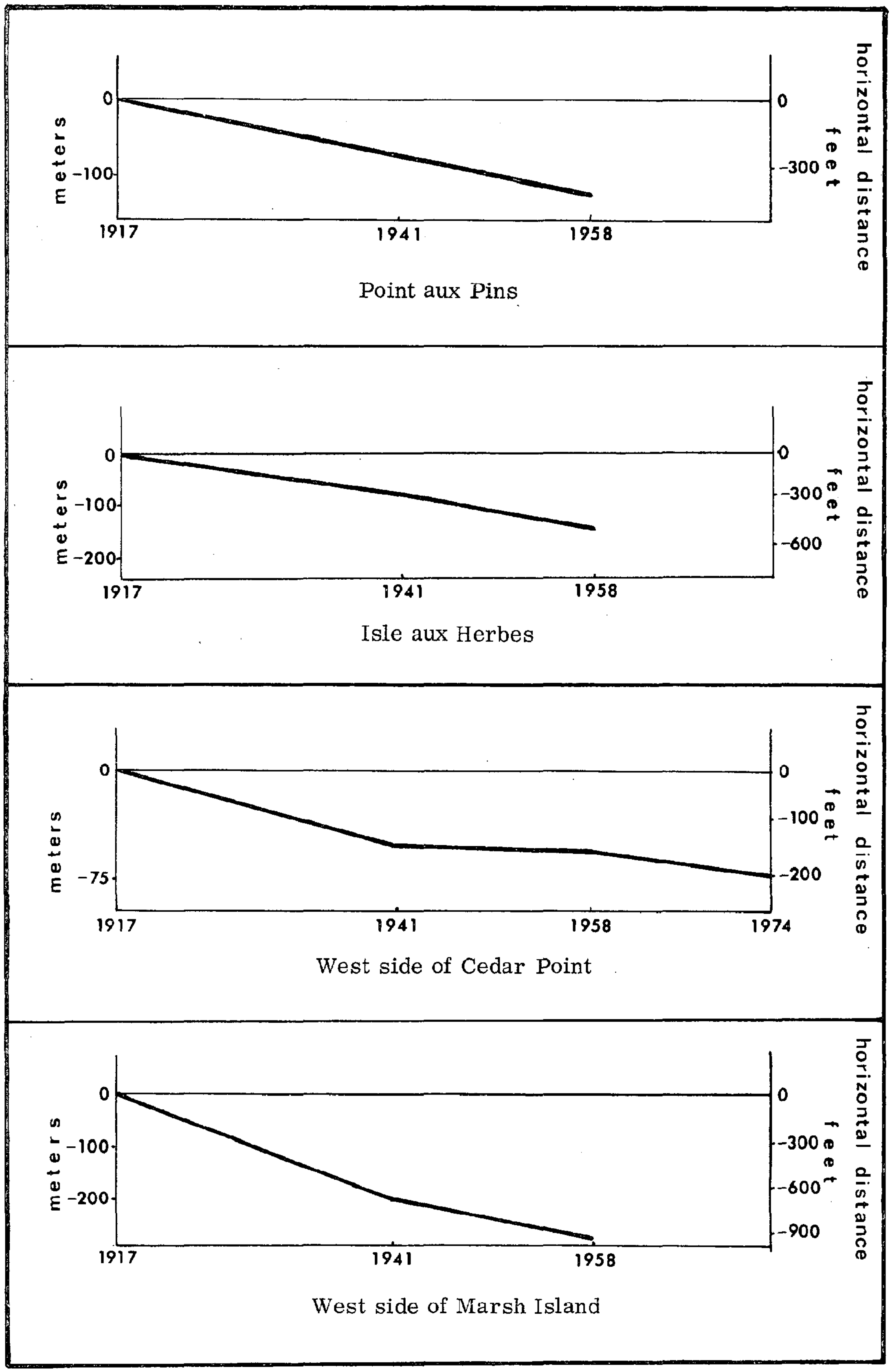

Figure 38.--Changes in the rate of erosion at selected points along the northern shore of the Mississippi Sound.

Table 9. --Changes in area and average erosion rates for selected areas in Mississippi Sound

Location	Area in 1917	Area in 1958	Change in area	Average erosion	Average annual erosion
1. Barron Point to Barry Point area	-	-	-	45.72 m (1) (150.0 ft)	1.12 m (3.66 ft)
2. Cat Island	9.29 ha (22.96 a)	9.29 ha (22.96 a)	0	59.89 m (1) (196.5 ft)	1.46 m (4.79 ft)
3. Marsh Island (Portersville Bay)	36.06 ha (89.02 a)	27.14 ha (67.03 a)	-8.92 ha (-22.4 a)	87.08 m (1) (285.7 ft)	2.12 m (6.97 ft)
4. Isle aux Herbes	314.15 ha (775.94 a)	267.30 ha (660.24 a)	-46.85 ha (-115.7 a)	99.06 m (2) (325.0 ft)	2.42 m (7.93 ft)
				41.76 m (3) (137.0 ft)	1.02 m (3.34 ft)
5. Point aux Pins	-	-	-9.67 ha (-23.87 a)	79.25 m (1) (260 ft)	1.93 m (6.34 ft)

(1) Shore having southern exposure
(2) Shore having southwestern exposure
(3) Shore having eastern exposure

impact of winds, wave action, tides, and currents; and their configuration is constantly changing.

Dauphin Island is 24.35 km (15.13 mi.) long and varies from 305-549 m (1,000-1,800 ft) wide across the western sandy spit to 2.6 km (1.6 mi.) wide across the forested main body of the island near the eastern end. Elevations at the east end of the island are generally between 1.5 and 3 m (5 and 10 ft), excepting a large east-west trending dune system as much as 14 m (45 ft) above mean sea level. Most of the population of Dauphin Island is concentrated in the eastern 11 km (7 mi.) of the island, either along the bay margins of the main body of the island or along the first 5 or 6 km (3 or 4 mi.) of the spit, where much new residential development has occurred.

The shorelines of Dauphin Island have been greatly modified throughout its known history. Shortly after 1717, a Frenchman, S^r Du Sault, produced a map of the island that indicated strongly that at that date, Dauphin Island and Petit Bois Island, presently immediately west of Dauphin Island, were connected. At some later date the island was breached. This conclusion was reached because the "Isle Dauphine" shown on the circa 1717 map has a hump on the western spit very similar to the hump of the present day Petit Bois Island. Also, the next island to the west on the circa 1717 map was called "Isle à Corne", Horn Island, which is the island to the west of the present day Petit Bois Island.

Between 1909 and 1917 a hurricane breached Dauphin Island, dividing it into two smaller islands separated by 8.5 km (5.3 mi.) of open water, shoals, and scattered remnants of the former island. The western island was 6.1 km (3.8 mi.) long and the eastern island was 6.7 km (4.2 mi.) long (fig. 39).

Between 1917 and 1942, the hurricane-created tidal inlet filled with sediment, thus rejoining the two islands to form one island. Air photos taken on March 23, 1950, show Dauphin Island again breached by the hurricane of September 4, 1948. Tides generated by this hurricane were reported to be 1.8 m (6 ft) above normal at Coden and Bayou La Batre (U.S. Army Corps of Engineers, 1973). The island was breached about 1,219 m (4,000 ft) west of Oro Point. The breached area was approximately 427 m (1,400 ft) wide and, by the date of the photos, was probably covered only at high tide. A washover fan extended over much of the length of the island but was best developed for a distance of 3.2 km (2 mi.) west of Bayou Heron channel.

Extensive residential development has occurred in this area since 1950 (fig. 40). Because this area has been breached twice by hurricanes in this century, there is every reason to believe that it will again be breached, at great cost to private property in the area. Paradoxically, most of the new residential development has

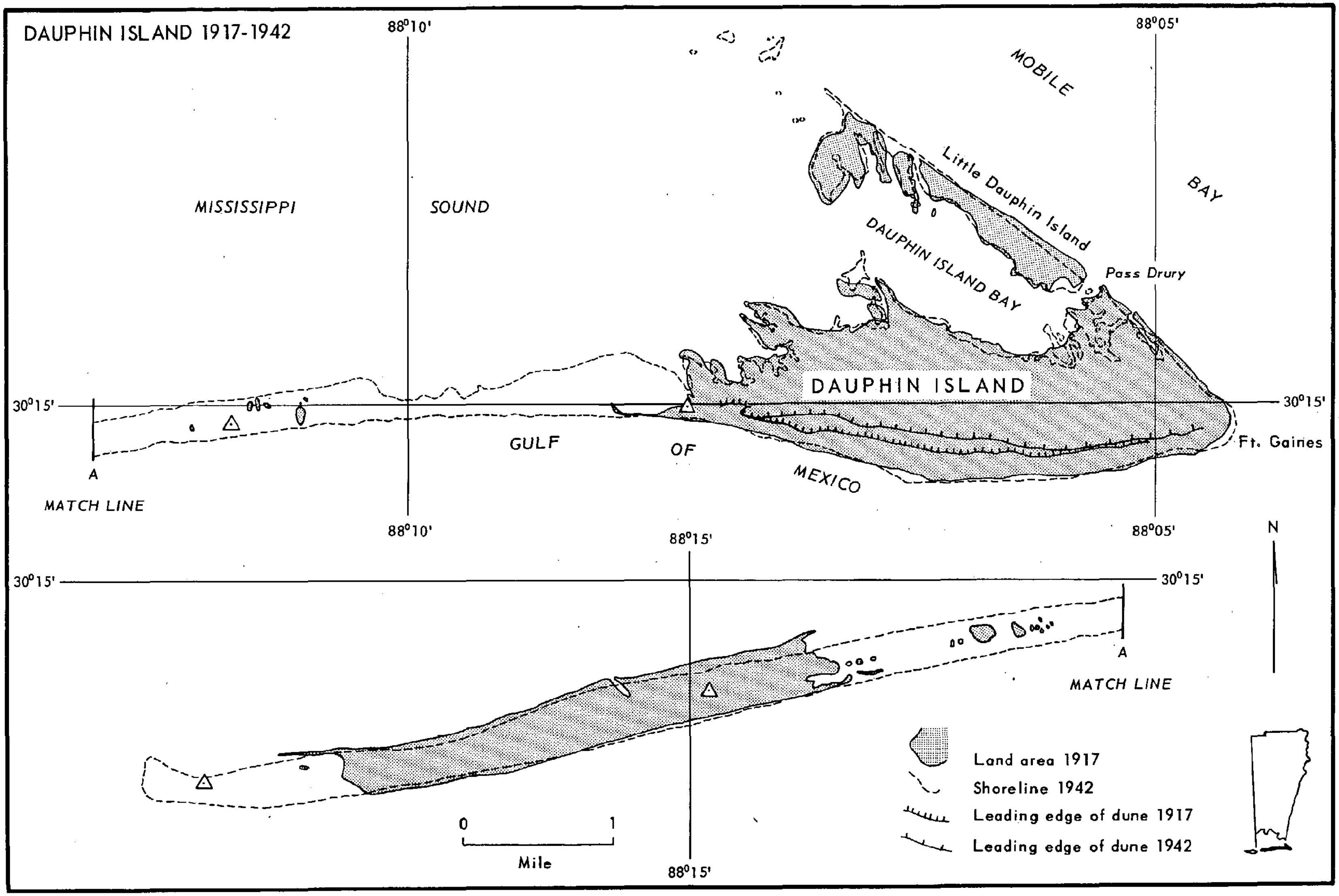

Figure 39. --Areas of shoreline changes at Dauphin Island between 1917 and 1942.

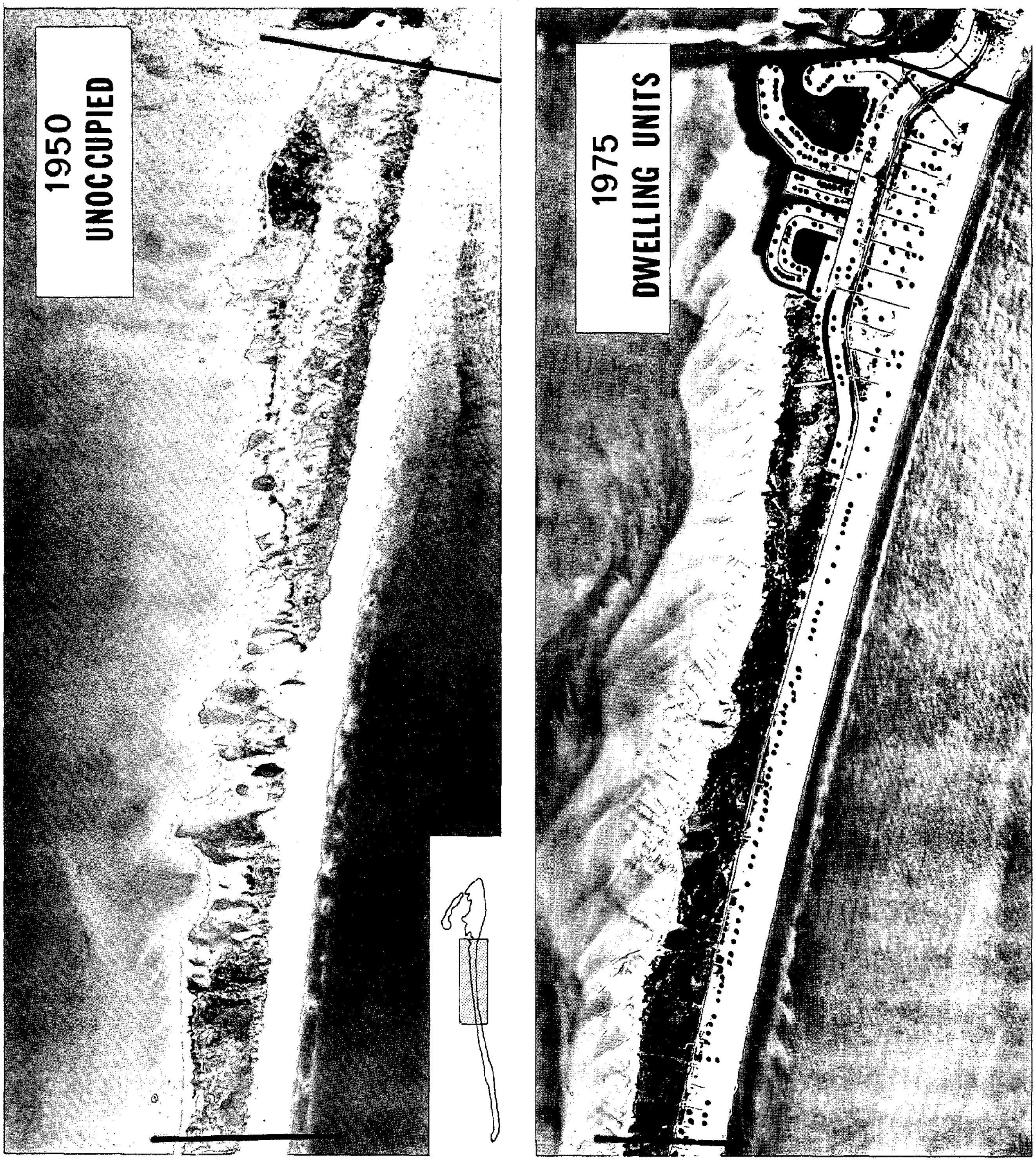

Figure 40.--Increase in occupance of a part of Dauphin Island between 1950 and 1975. Dwelling units mapped by field survey in 1975. U.S.D.A. photos dated 1950 (left), 1960 (right). Scale 1:20,000.

occurred in areas most susceptible to storm damage, while large tracts of subdivided land in the eastern part of the island protected by the large primary dunal complex and a forest of pines are relatively undeveloped.

The barrier dune complex slowly migrated north as much as 156 m (513 ft) between 1917 and 1942, forming a precipitation ridge where it is slowed or halted by the forest edge (fig. 39). No measurable movement was detected between 1942 and 1958 (fig. 41). Movements shown on figure 41 are attributed to differences in mapping techniques.

Figure 41 shows a general trend of erosion along the gulf shore of the island and general elongation along the western end of the island. Figure 42 shows the rate of erosion for various time periods at locations along the gulf shore of the island. Shoreline erosion on the part of the island that was westernmost in 1917 (fig. 43) averaged 176.0 m (577.5 ft) over the period 1917 to 1974 or 3.09 m (10.13 ft) per year. The maximum measured erosion was 201.2 m (660 ft), an average of 3.53 m (11.58 ft) per year for the period 1917 to 1974. Shoreline erosion on the entire gulf shore for the period 1942 to 1974 averaged 63.70 m (209 ft) or 1.93 m (6.34 ft) per year excluding the accretion on the western tip of the island. This accretion has added a total of 2.9 km (1.8 mi.) to the length of Dauphin Island from 1917 to 1974.

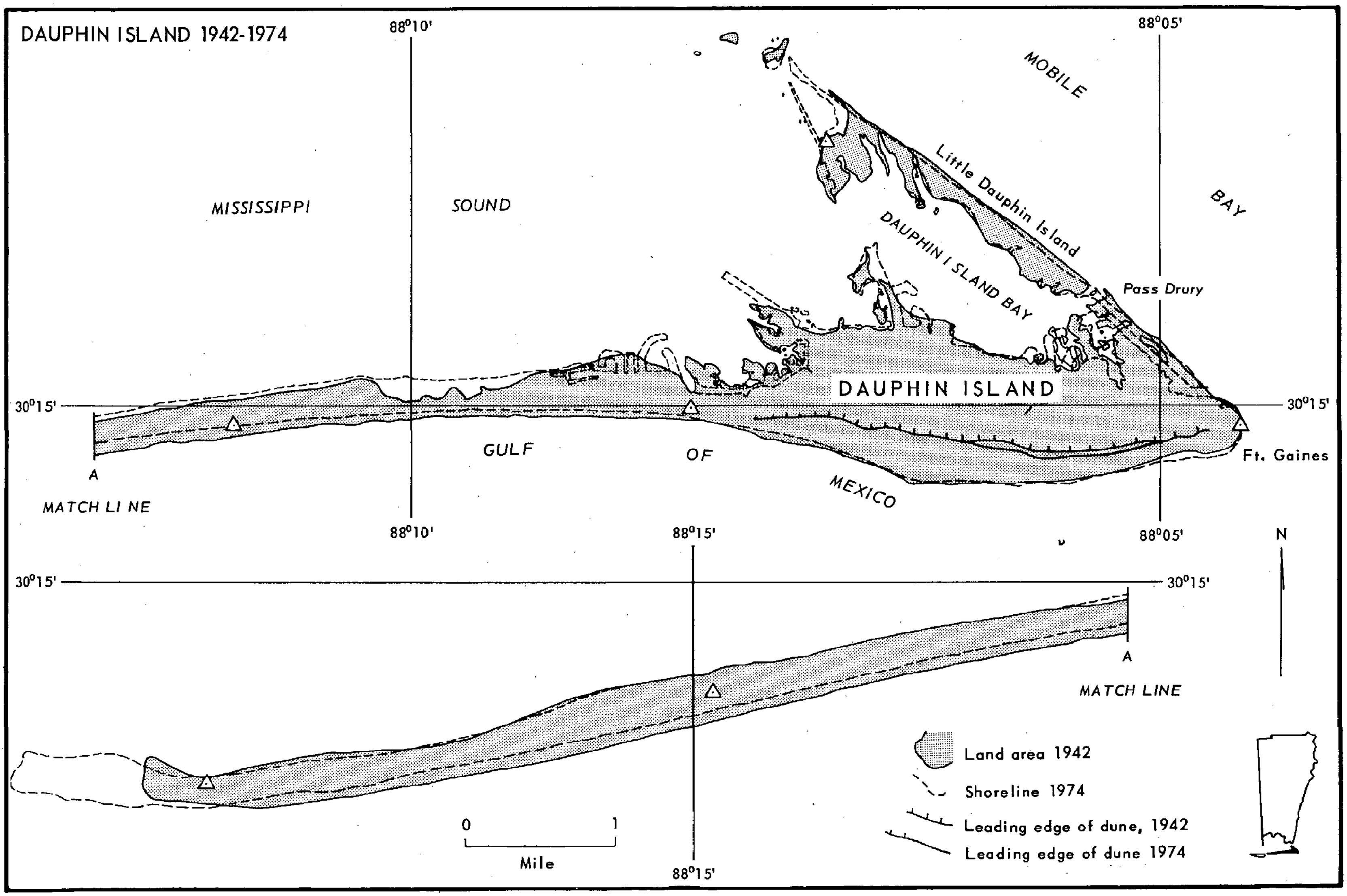

Figure 41. --Areas of shoreline changes at Dauphin Island between 1942 and 1974.

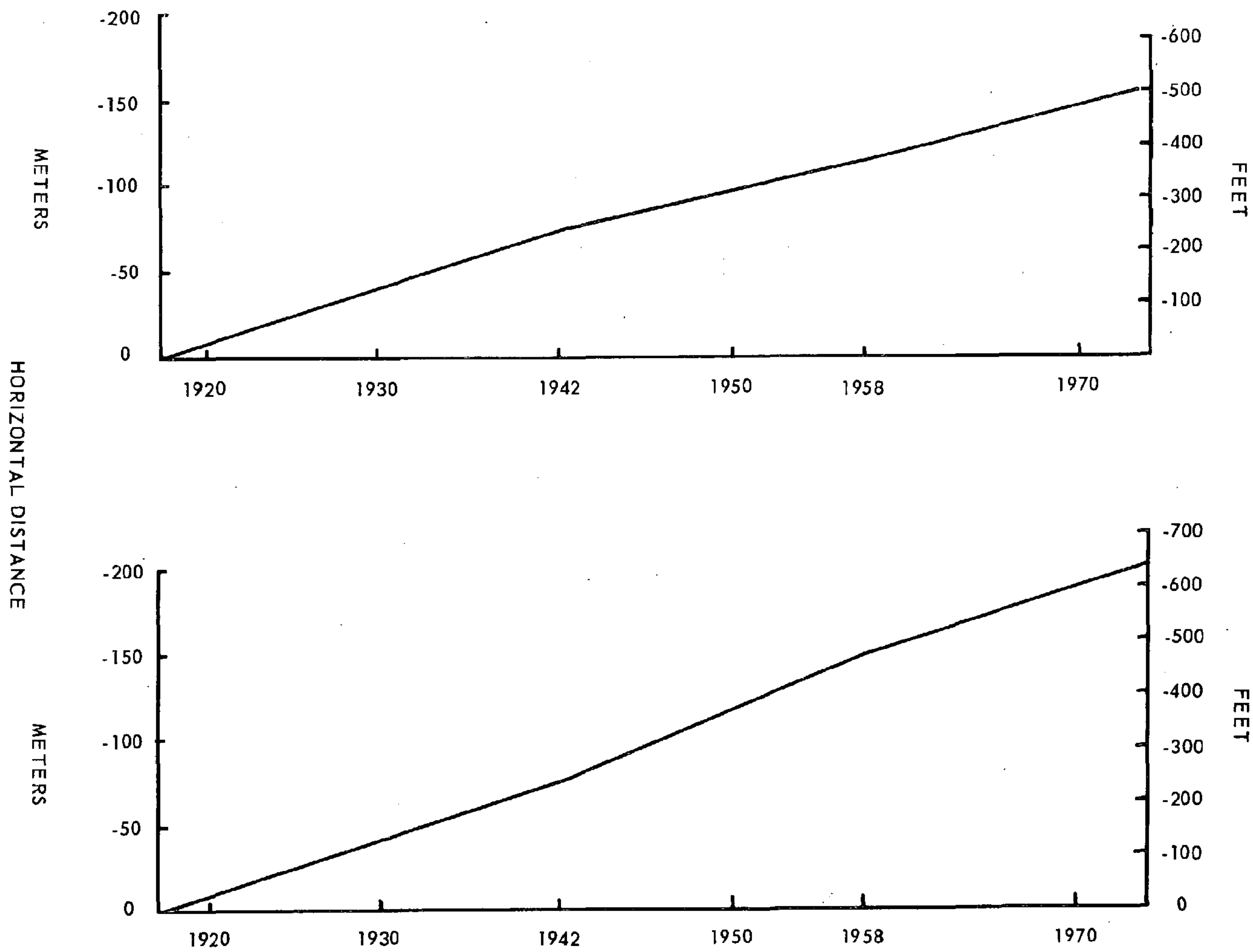

Figure 42.--Changes in the rates of erosion for various time periods for Bienville Beach, Dauphin Island (88°07' W.) (upper graph) and west-central Dauphin Island (lower graph).

Figure 43.--Rate of accretion for the western tip of Dauphin Island.

The accretion measured at the western tip of the island for various intervals of time is shown in table 10. Because of the different orientations of the longest axis of change, the amounts for the various time periods do not equal the total for the period of measurement.

Table 10.--Amount of accretion at the western tip of Dauphin Island, 1917-1974.

1917-1942	1,270 m (4,166 ft)
1942-1958	635 m (2,083 ft)
1958-1974	1,429 m (4,687 ft)
1917-1974	2,730 m (8,957 ft)

The bathymetry of the Mobile Bay entrance and the passes associated with Little Dauphin Island is heavily influenced by dredging and associated spoil accumulation. The Mobile Ship Channel and Pass aux Herons (Pass Heron) are both dredged regularly, and the spoil from this is added to the sedimentalogical regime of the bay entrance. The areas adjacent to the main entrance are filling, and the relief of the gulf bottom is becoming flatter (figs. 44, 45, 46, and 47). Passes that are not regularly dredged are closing or have closed, such as Big Pass Margaret, Little Pass Margaret, Bayou Matagua, and Pass Drury (Gazzier, 1972).

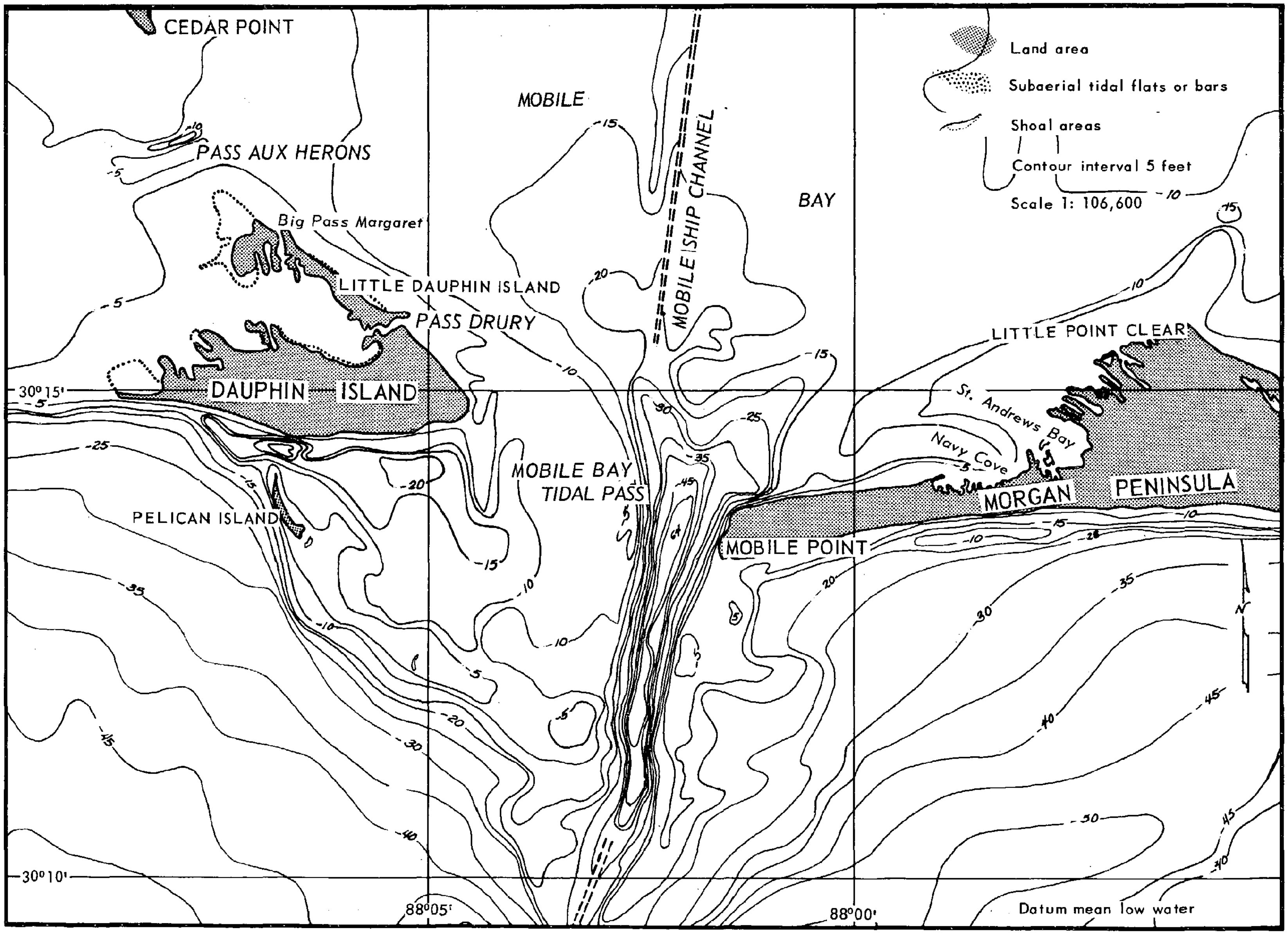

Figure 44.--Bathymetric contours, Mobile Bay entrance and associated passes, 1929 (data from USCGS chart 1266, 1929).

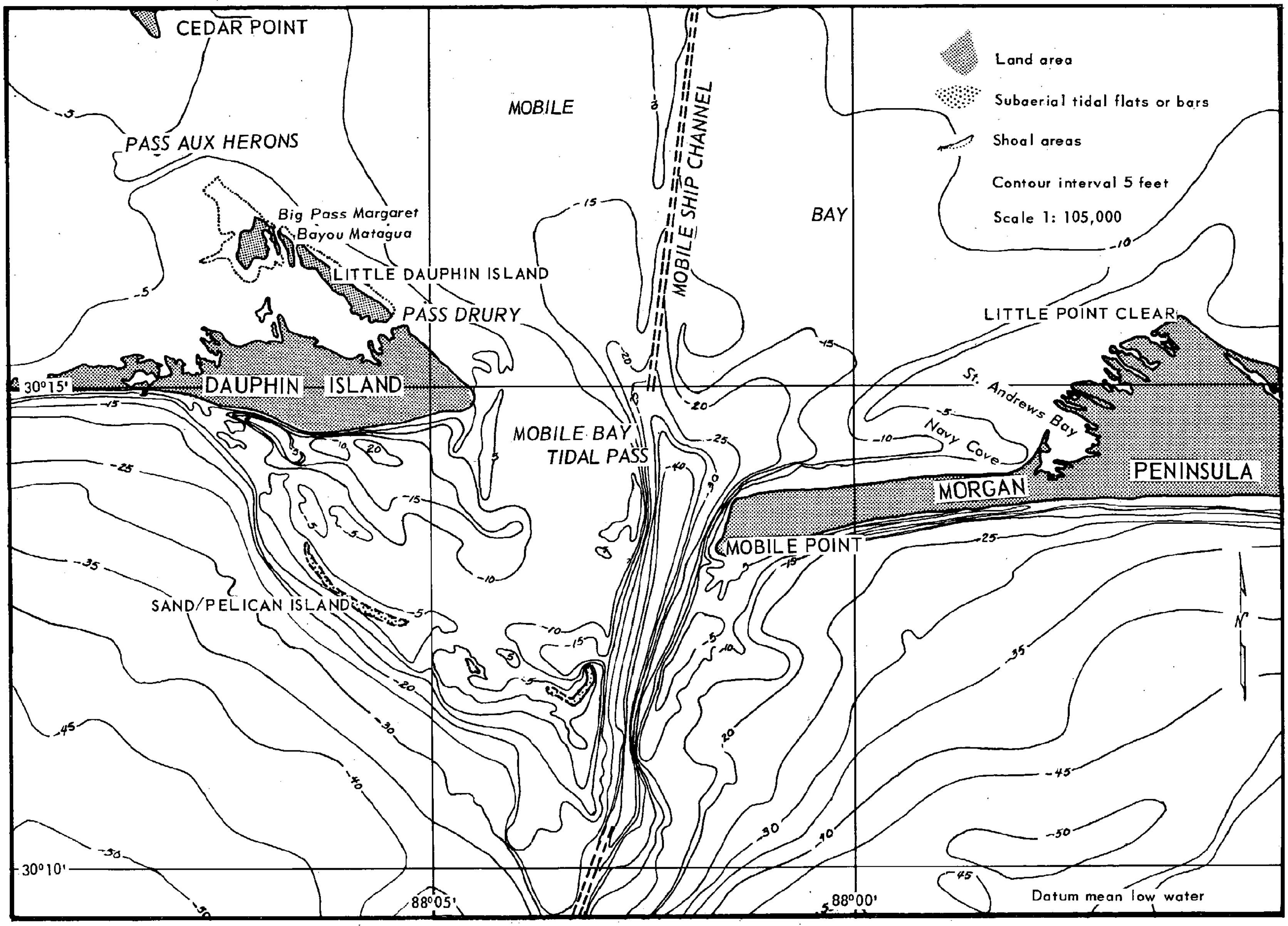

Figure 45. Bathymetric contours, Mobile Bay and associated passes, 1941 (data from USCGS chart 1266, 1941).

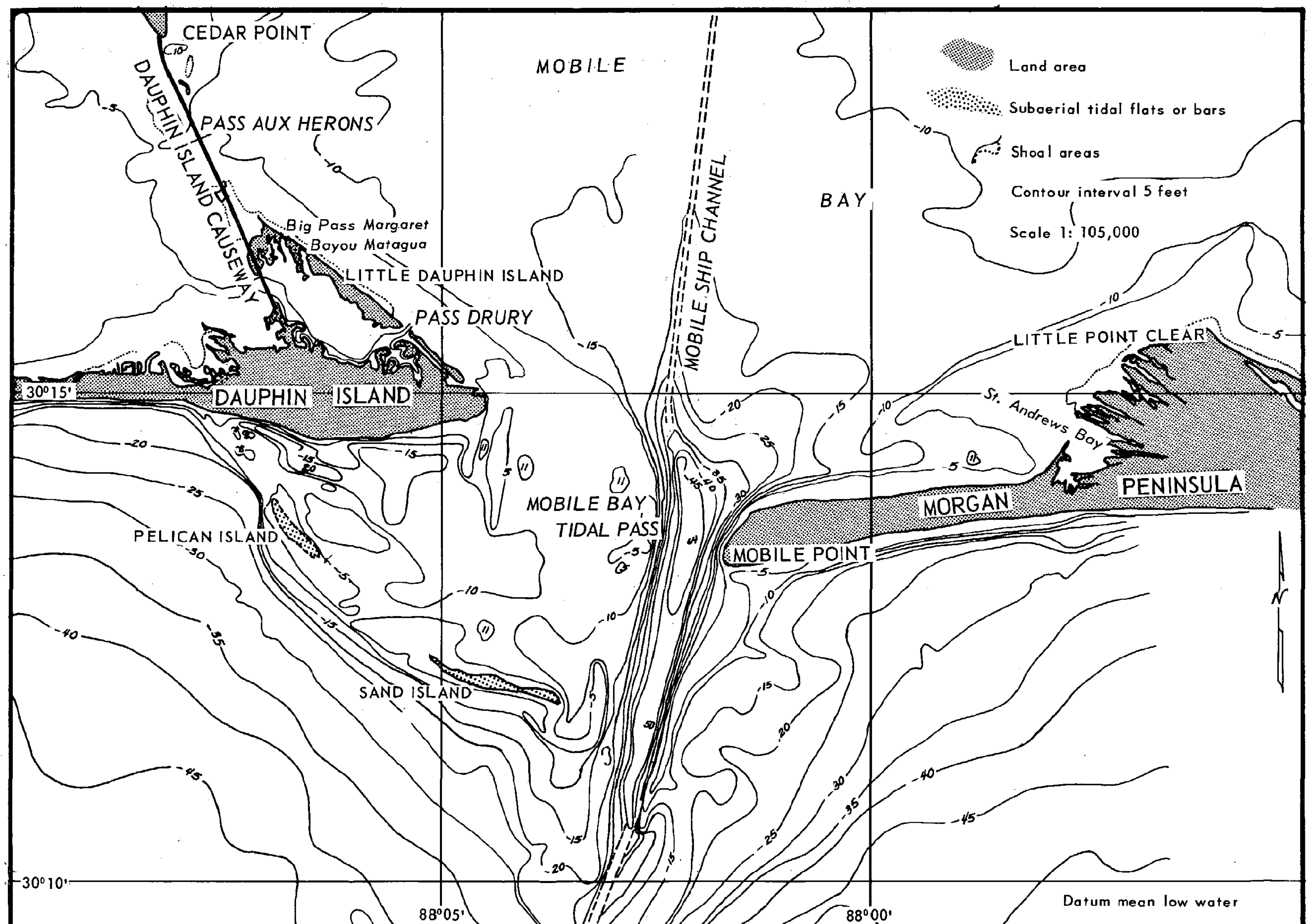

Figure 46.--Bathymetric contours, Mobile Bay entrance and associated passes, 1961 (data from USCGS chart 872, 1962).

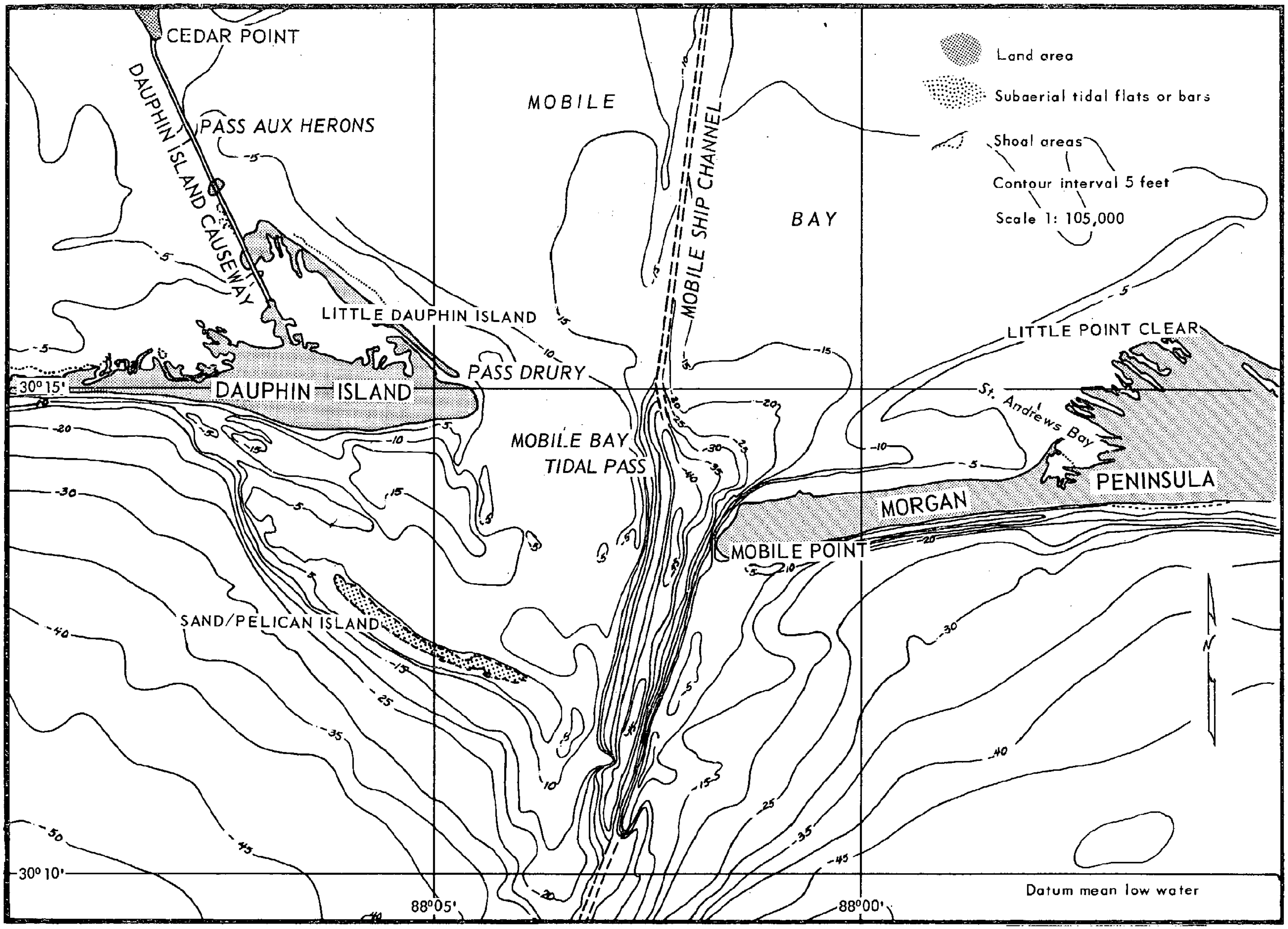

Figure 47.--Bathymetric contours, Mobile Bay entrance and associated passes, 1973 (data from USCGS chart 1266, 1973).

Pass Drury has been replaced by an artificial channel between Little Dauphin and Dauphin Island, parallel to the long axis of Little Dauphin (fig. 47). Several areas of drifting sandbanks have formed near Peavy Island and in Dauphin Island Bay (Gazzier, 1972, p. 38).

The bathymetric contours for 1929 (fig. 44) show a depression with depths of more than 6 m (20 ft) south of the east end of Dauphin Island. By 1973, this depression accumulated an average of 1.22 m (4 ft) of sediment in its deepest part between 1929 and 1973 (fig. 47).

Southwest of the Mobile Bay entrance is Sand/Pelican Island, an emergent bar of an ebb-tidal delta. The bar is in a dynamic state and its shape, size, and location have changed continuously throughout historic times. It is especially affected by severe weather disturbance. The bar increased steadily from 1929 to 1973 and the present island is approximately 2.74 km (1.70 mi.) long and supports vegetation on the southeast end (fig. 48).

East of Sand/Pelican Island adjacent to the Mobile Ship Channel is a small, intermittently subaerial bar called Sand Island on the Fort Morgan $7\frac{1}{2}$-minute quadrangle map of 1958. This is probably a channel-margin bar (Hayes and others, 1973).

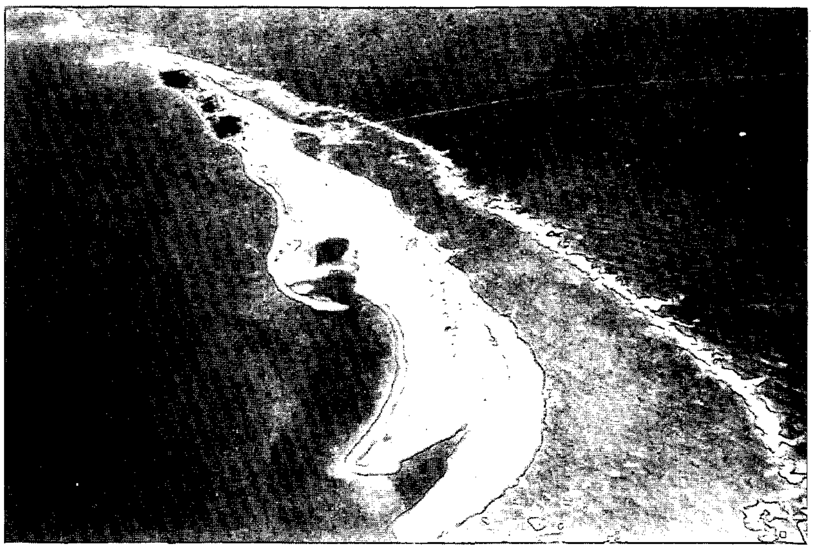

Figure 48.--Sand/Pelican Island, 1975.

Concurrent with the accretionary trend of the western tip of Dauphin Island there has been a pronounced change in the configuration of Petit Bois Pass, which separates Dauphin Island and Petit Bois Island. As previously mentioned, circa 1717, the pass probably was not in existence. The earliest coastal survey available, the survey of 1848, shows the pass to be well developed. The width of Petit Bois Pass has varied from 2.61 km (1.62 mi.) in 1848 to 7.51 km (4.66 mi.) in 1974 (table 11). During this same interval the pass migrated 12.40 km (7.71 mi.)

Table 11.--Width and westward migration of Petit Bois Pass at various time periods between 1848 and 1974

Year	Width		Westward migration*	
1848	2.61 km (1.62 mi.)			
1917	6.52 km (4.05 mi.)		8.57 km (5.32 mi.)	1848-1917
1942	7.65 km (4.75 mi.)		2.61 km (1.62 mi.)	1917-1942
1958	8.48 km (5.27 mi.)		1.31 km (0.81 mi.)	1942-1958
1974	7.51 km (4.66.mi.)		Imperceptible	1958-1974
		Total	12.40 km (7.71 mi.)	1848-1974

*Westward migration was measured by calculating the westward movement of the eastern tip of Petit Bois Island.

westward. Figures 49 and 50 illustrate the changes in the configuration of Petit Bois Pass between 1848 and 1974. The widening of the pass and its westward migration are clearly shown. However, not only has the pass been modified in width and location, but also changes in the configuration of the bottom have occurred.

Between 1917 and 1933, very little apparent change in the bottom configuration of the pass occurred. This lack of change may have been due to slight stabilization of coastal erosion and accretion during this period, or may merely reflect use of older sounding data on the 1933 edition of the charts (fig. 51).

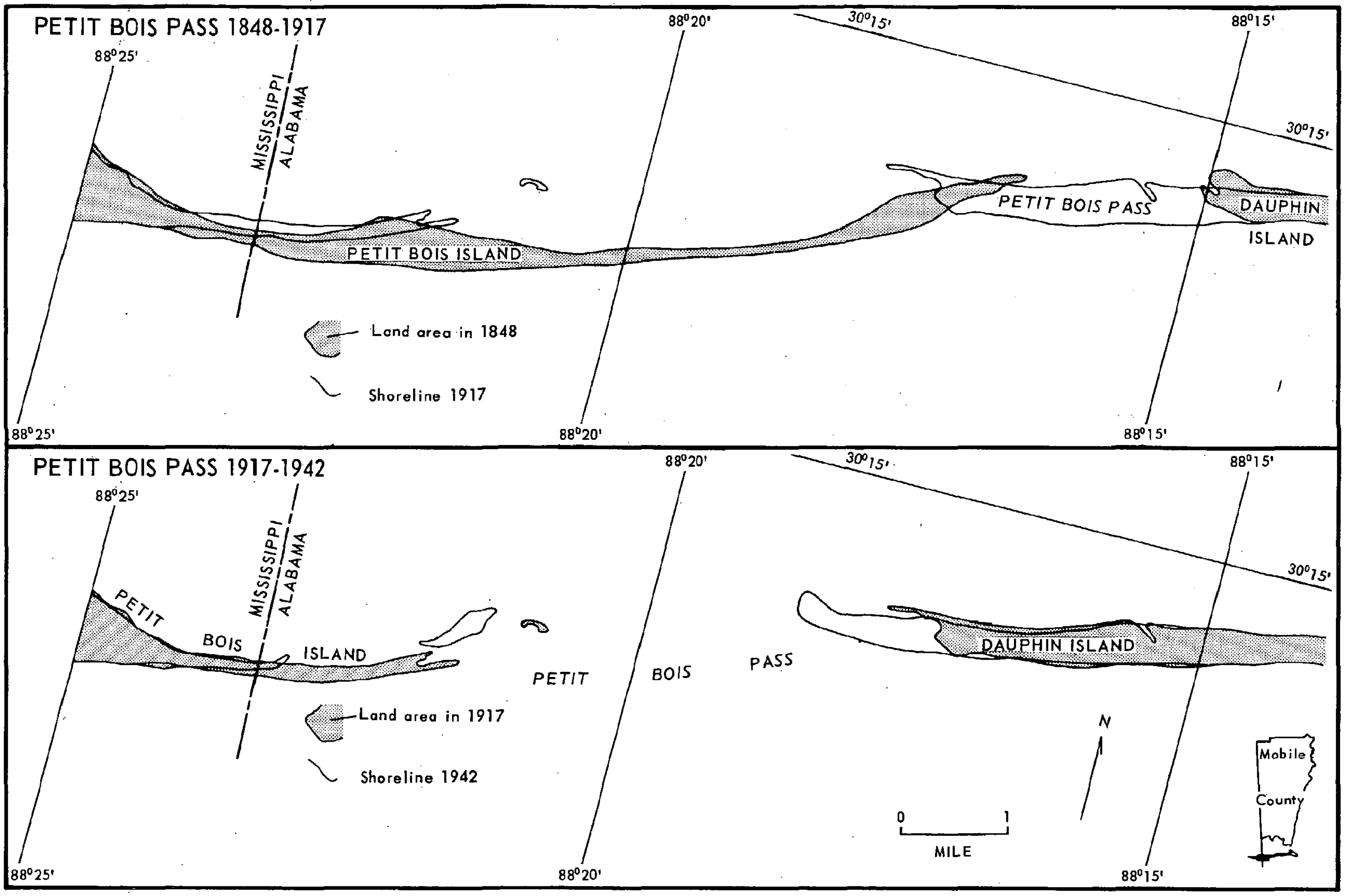

Figure 49. --Changes in the configuration of Petit Bois Pass between 1848 and 1942.

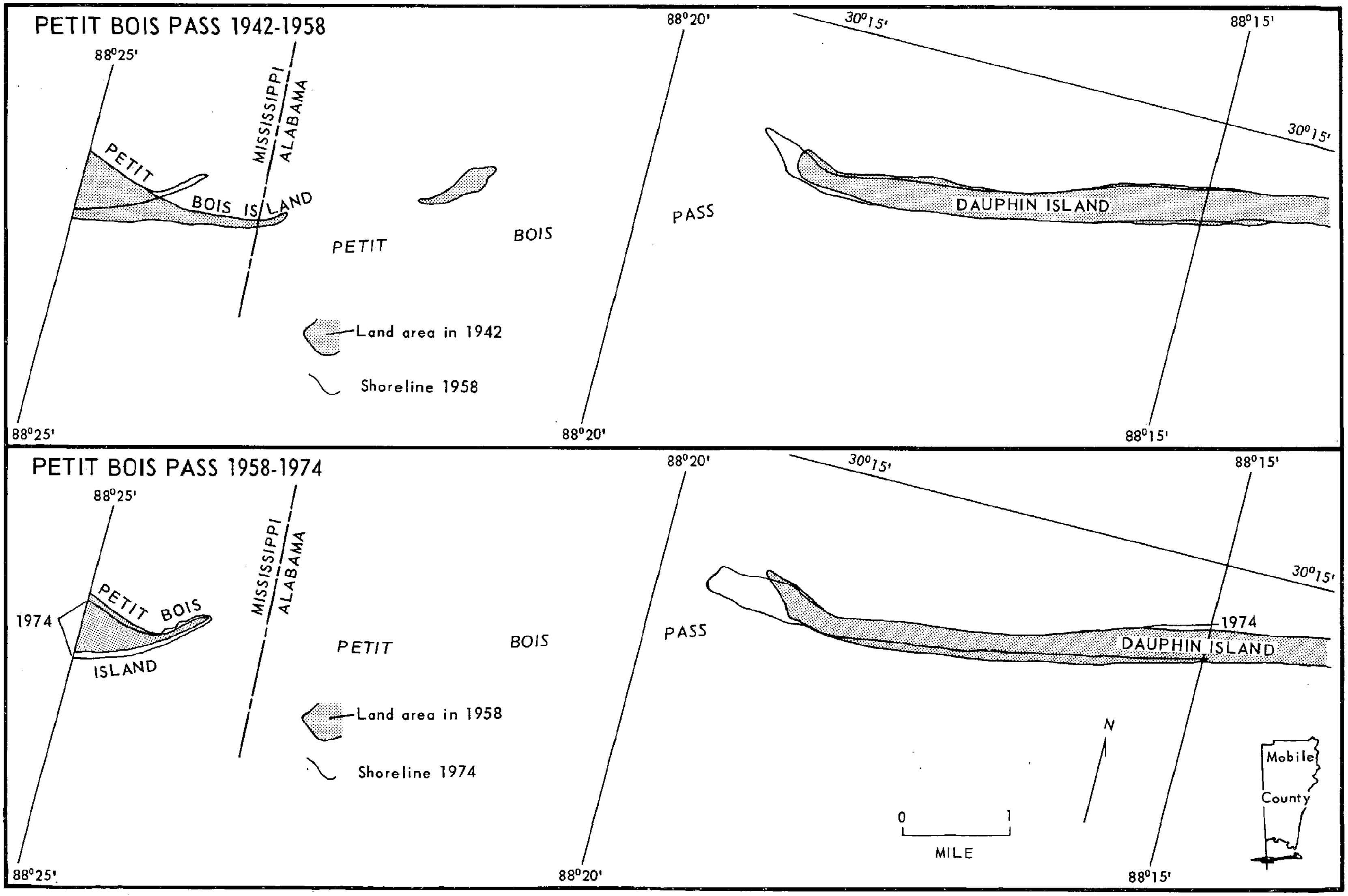

Figure 50. --Changes in the configuration of Petit Bois Pass between 1942 and 1974.

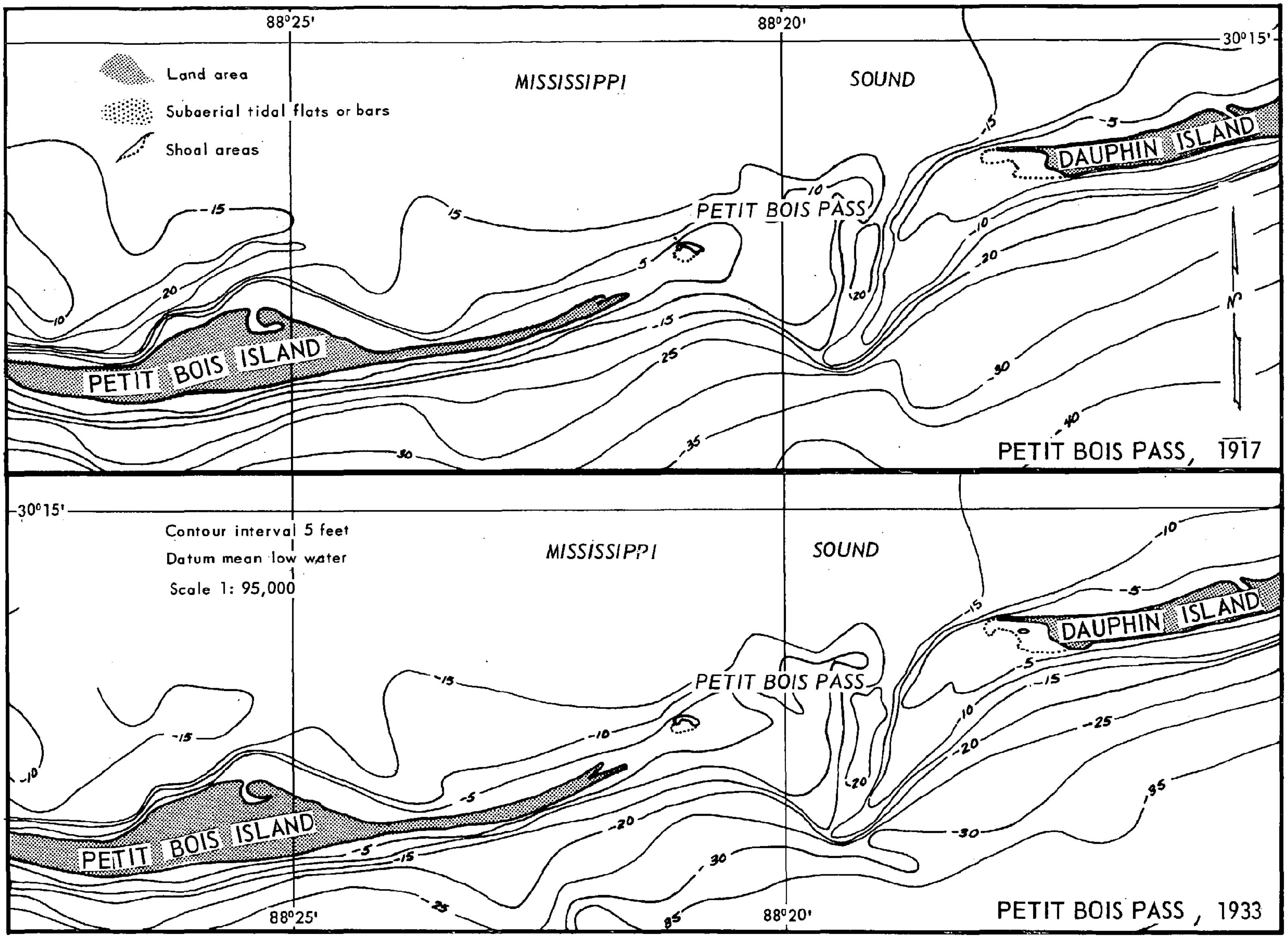

Figure 51. Bathymetric contours, Petit Bois Pass, 1917 and 1933 (data from USCGS charts 1267, 1917 and 1933).

The bathymetric map for 1961 shows several significant changes in the islands' shorelines; the western tip of Dauphin Island prograded westward and the easternmost spit of Petit Bois Island apparently was eroded to such an extent that it was covered by the highest tides (fig. 52). The change in the configuration of the islands, however, did not affect the bottom configuration greatly. The tidal scour channel just west of Dauphin Island (at about longitude 88°19'), as delineated by a 20-foct contour line, became narrower and more elongate, but the basic configuration of the bottom changed little.

By 1973, however, the eastern spit of Petit Bois Island had been eroded to below MLW, producing a wider outlet for the waters from Portersville Bay. This has reduced current velocities through the scour channel, and different patterns of sedimentation and erosion have been produced. The eastern end of Petit Bois Island has become a series of sand shoals in the pass, and an ebb-tidal bar (delineated by the closed 10-ft contour line from longitude 88°19' to 88°20') is beginning to form at the seaward end of the scour channel (fig. 52).

If Petit Bois Pass is considered only as the area of open water between the western end of Dauphin Island and the eastern tip of Petit Bois Island, then the pass migrated westward along with the islands during the period from 1917 to 1973. However, it is significant that the scour channel, the deepest part of the pass, remained stationary during this period; even after 1961, when the

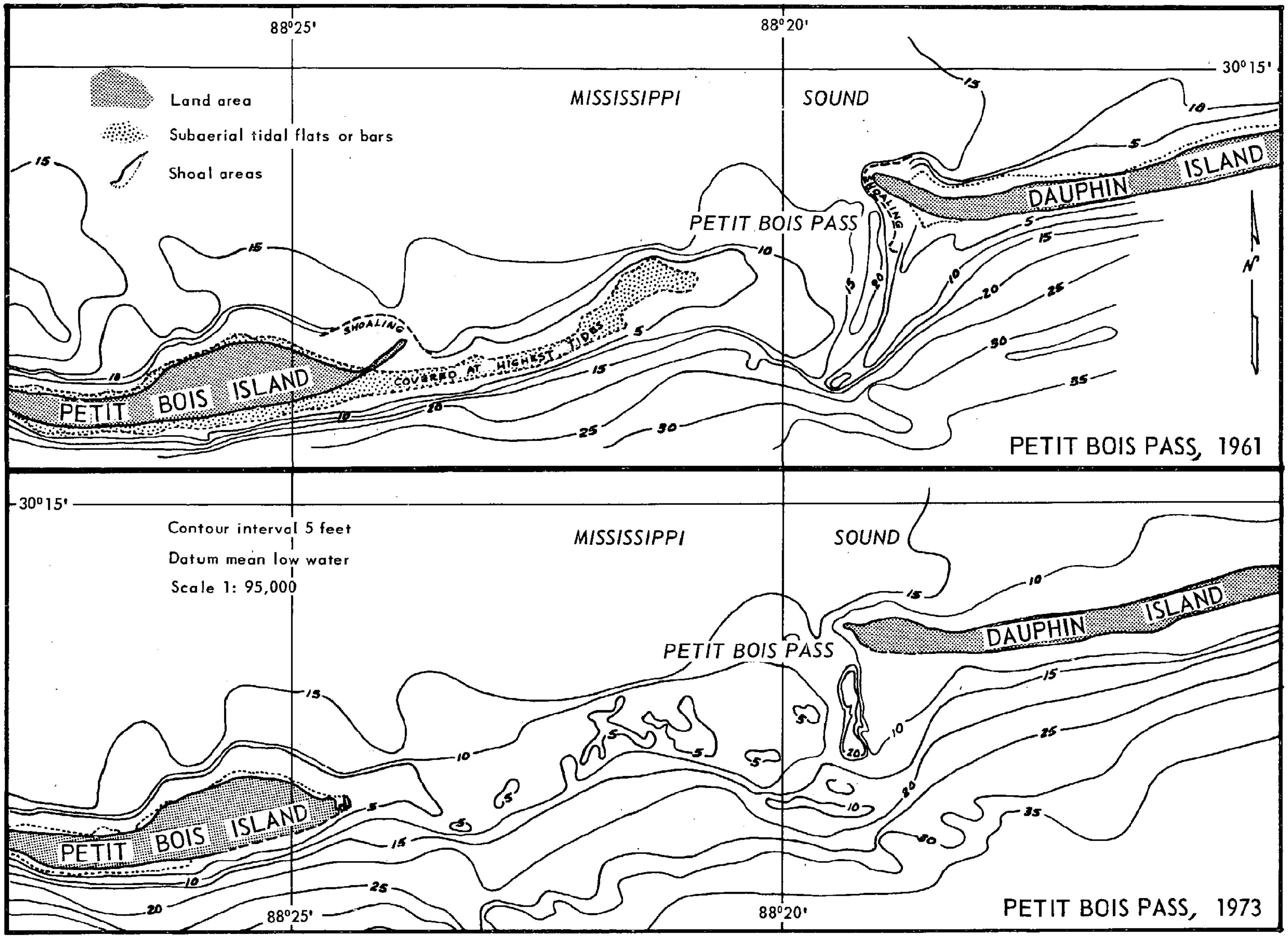

Figure 52. Bathymetric contours, Petit Bois Pass, 1961 and 1973 (data from USCGS charts 873, 1962, and 1267, 1973).

western tip of Dauphin Island had prograded across the northern end of the channel, and should have deflected ebb-tidal currents and somewhat reduced their velocity, the channel remained in the same place and maintained its general depth.

Only recently, since erosion of the eastern end of Petit Bois Island widened the pass significantly, has the scour channel become shallower and less well defined. This suggests that Petit Bois Pass channel has been "pinned" in place by some geologic factor or factors; possibly by the pre-Pleistocene channel of the Escatawpa River (P.A. Boone, personal communication, 1975).

Eastern Shore

The eastern shore of Mobile Bay extends from D'Olive Bay about 2.0 km (1.24 mi.) south of Spanish Fort (Bridgehead) southward some 48 km (30 mi.) to the mouth of Bon Secour River. The shore from D'Olive Bay to Magnolia Beach south of Fairhope is generally a sandy beach backed by a sea cliff 3 to 33.5 m (10 to 110 ft) high. South of Magnolia Beach, the shore consists of low-lying wetlands varying from less than 0.5 km (0.31 mi.) to more than 1.5 km (0.93 mi.) wide.

Most of the eastern shore has undergone accretion or has maintained a state of dynamic equilibrium between 1917 and 1967 or 1974.

The major shorelines of net accretion between 1917 and 1967 are the shore from Village Point south to Red Bluff, the shore south from Great Point Clear for 5.1 km (3.2 mi.), and the shore from Dorgans Landing at the mouth of Weeks Bay south to the mouth of Skunk Bayou just north of Weeks Bay.

Erosion along the eastern shore occurs intermittently and is of less magnitude than in most other areas studied. However, some shorelines showing erosion are in highly desirable residential areas and thus could require expensive erosion-control construction. Erosion has occurred sporadically along the shore from Loyola Villa to Great Point Clear between 1917 and 1956-1967. Net erosion of a shore just south of Loyola Villa was 60 m (197 ft) between 1917-1956 or 1.5 m (5.0 ft) per year.

Other minor areas of erosion are Red Bluff, Seacliff, the area between Darling Landing and Mullet Point and several areas south of Mullet Point. Shoreline changes at various points identifiable on U.S. Geological Survey 7.5-minute topographic maps are shown in table 12. Variations in the rate of shoreline change are shown for Village Point and an area south of Magnolia Beach in figure 53.

Table 12.--Shoreline changes measured at selected identifiable points along the eastern shore of Mobile Bay

Location	Change*	Time period	Annual rate
Village Point	+108 m (+354 ft)	1917-1967	2.16 m (7.08 ft)
Red Bluff	-36.6 m (-120 ft)	1917-1967	0.73 m (2.4 ft)
Seacliff	-12 m (-78 ft)	1917-1967	0.24 m (0.78 ft)
Fairhope municipal wharf	+60 m (+197 ft)	1917-1967	1.2 m (3.9 ft)
Loyola Villa	-60 m (-197 ft)	1917-1956	1.5 m (5.0 ft)
Great Point Clear	+36 m (+118 ft)		0.92 m (3.0 ft)
Point Clear	+54 m (+177 ft)		1.4 m (4.5 ft)
Near Mullet Point Park 30°25' N. latitude	-47.9 m (-157 ft)		1.2 m (4.0 ft)

* Positive changes show accretion; negative changes show erosion.

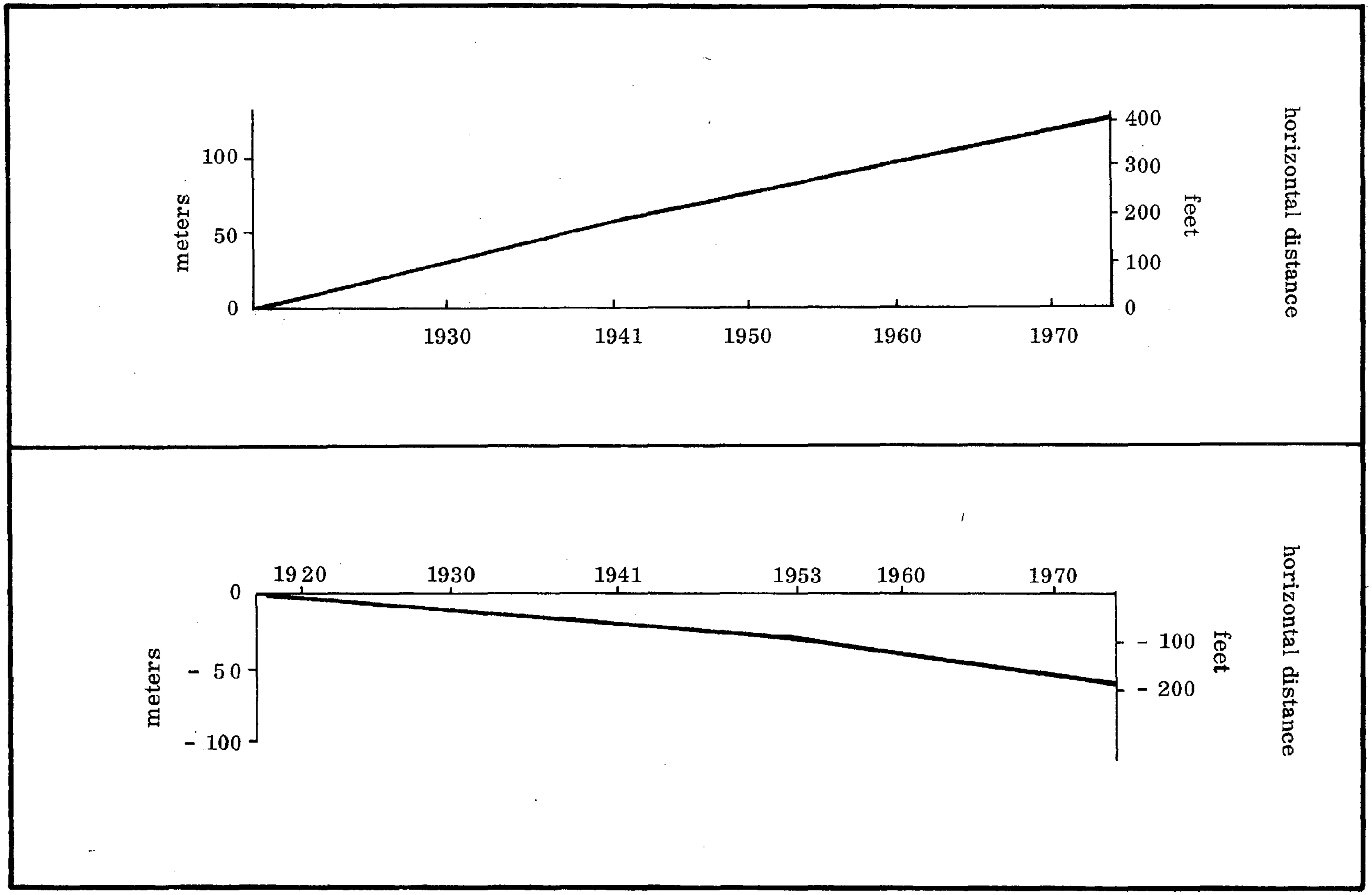

Figure 53.--Rates of accretion at Village Point (upper graph) and erosion for an area south of Magnolia Beach (lower graph).

Morgan Peninsula, Bay Shore

Morgan Peninsula is a large baymouth bar extending westward from the eastern shore of Mobile Bay. This peninsula, which varies from 0.28 km (0.46 mi.) to 3.59 km (2.23 mi.) wide and is 29.0 km (18.0 mi.) in length, separates the bay water from the gulf water, and insures the maintenance of an estuarine environment in Mobile Bay, and care should be exercised to insure its continued effectiveness as a protective barrier. Erosion, measurable along much of the northern shore and probably existing along almost the entire length of the shore from the mouth of Bon Secour River to Fort Morgan, is a major concern for residents of the shore from Seymour Bluff to Catlins Bayou. Measurements of the change in shoreline configuration between 1917 and 1974 show that as much as 52 m (170 ft) of erosion may have occurred from the mouth of Bon Secour River to Catlins Bayou during that time.

Although no measureable erosion was discerned between Catlins Bayou and Three Rivers during 1917-1942, shoreline erosion did occur between 1974 in the Edith Hammock area. Some areas showed as much as 30.5 m (100 ft) of erosion between 1942 and 1974, although the average amount was closer to 15.3 m (50 ft).

From Three Rivers to the eastern seawall of Fort Morgan, much erosion and shoreline modification has occurred. From Little Point Clear to St. Andrews Bay, termini of bayward-projecting ancient spits lost from 61 to 244 m (200 to 800 ft) between 1917 and 1974. From Navy Cove to the eastern seawall of Fort Morgan, losses on the order of 61 m (200 ft) were noted.

Examination of bathymetric data from 1929 to 1973 (figs. 44, 45, 46, and 47) reveals that St. Andrews Bay, Navy Cove, and the bay north of Fort Morgan are becoming progressively shallower. The southwest cove of St. Andrews Bay has also become a shoal area. This trend probably reflects deposition of material eroded from the shoreline west of Little Point Clear, as well as material from the spoil banks on the south side of the Intracoastal Waterway north of Morgan Peninsula, and from the spoil banks northwest of the peninsula along the Mobile Ship Channel.

A long underwater spit, known locally as Dixie Bar, extends about 5.6 km (3.4 mi.) south into the gulf from Mobile Point. Between 1929 and 1973, this spit became somewhat more narrow and elongate, and the southern tip appears to have moved slightly west (figs. 44 and 47). This trend indicates little or no deposition on the spit, either because the longshore currents are strong enough to erode it, or that very little material is being eroded from the gulf shore of the peninsula to the east (fig. 47).

Gulf Shore

The Gulf shore region of coastal Alabama extends from Mobile Point to the Florida state line and is some 50 km (31 mi.) in length. The shoreline of white sandy beaches is backed by low dunes.

In 1917, several tidal inlets existed. These inlets opened into Little Lagoon and Shelby Lakes. The inlet connecting Little Lagoon to the Gulf was 1.1 km (0.7 mi.) west of Gulf Shores beach. This inlet was approximately 80 km (262 ft) wide. A second inlet along the gulf shoreline was approximately 1.7 km (1.1 mi.) west of Romar Beach, as located on the Foley, Alabama, 15-minute U.S. Geological Survey topographic map. This inlet connected the easternmost lagoon on the Shelby Lakes with the gulf, and was approximately 20 km (66 ft) wide. By 1941, both of these inlets had closed and a second inlet to Little Lagoon had opened. This inlet, 3.5 km (2.2 mi.) west of the inlet of 1917, was about 60 m (197 ft) wide. High-altitude infrared photography taken in 1974 of this area showed no passes open into either Little Lagoon or Shelby Lakes, although some water possibly flows through the western inlet of Little Lagoon at the highest high tide.

Between 1917 and 1974, the gulf shore eroded by an average of -23.8 km (-78 ft) between Fort Morgan and Alabama Point. This net erosion along the gulf shore occurred in the areas indicated on plate 1. Measurements of shoreline changes at various locations identified on the Weeks Bay, Alabama, and the Foley, Alabama, 15-minute U.S. Geological Survey topographic maps are shown in table 13.

Table 13.--Shoreline changes measured at identifiable points along gulf shore of Alabama

Location	Change	Time period	Annual rate
Mobile Point	+344 m (+1129 ft)	1917-1974	6.04 m (19.8 ft)
Gulf Highlands	-31 m (-102 ft)		0.5 m (1.8 ft)
Gulf Shores	indiscernible		
Romar Beach	-47 m (-154 ft)		0.8 m (2.7 ft)

Perdido Bay

Perdido Bay is an estuary lying north of a bay-barrier complex that trends normal to the gulf shore at the Florida-Alabama state boundary. The shores of Perdido Bay are well drained because elevations rise abruptly to 9 to 21 m (30 to 70 ft) on the west-central side of the bay and 1.5 to 4.6 m (5 to 15 ft) along the remaining shore (Parker, 1968).

Perdido Bay itself has shown little measurable change along the Alabama shoreline, according to presently available information. Areas of small amounts of erosion probably do exist within Perdido Bay but are too small to be discerned by methods used in this study. Significant changes in the configuration of Perdido Bay have occurred in the area of Perdido Pass.

Changes in the configuration of Perdido Pass are among the most extensive recorded in this study. Shorelines at various intervals between 1867 and 1974 are shown in figures 54 and 55. In 1867 the Perdido River channel (presently called Old River) flowed around the east end of Ono peninsula (now Ono Island) then westward to enter the gulf (fig. 54). By 1890-1892, this river channel had been partly abandoned and the major flow from Perdido Bay entered the gulf through a channel in Ono peninsula excavated by local residents between 1867 and 1892 (U.S. Army Corps of Engineers, 1973). By 1918, water exchange occurred through two inlets separated by an island (fig. 54). This configuration possibly was caused by the hurricane of September 8, 1917. Gradually the accretion resulting from the westward littoral drift closed these two inlets to form a single inlet by 1941 (fig. 55). Between 1941 and 1974, the persistent littoral drift had caused the pass to migrate westward until arrested by the construction of a seawall in the 1960's. Ryan (1969) mentions that the pass in its natural state was some 1.8 m (6 ft) deep and presented great hazard to navigation. Safe navigation has been assured since the construction of several seawalls, which stabilize the inlet and protect a bridge over the inlet.

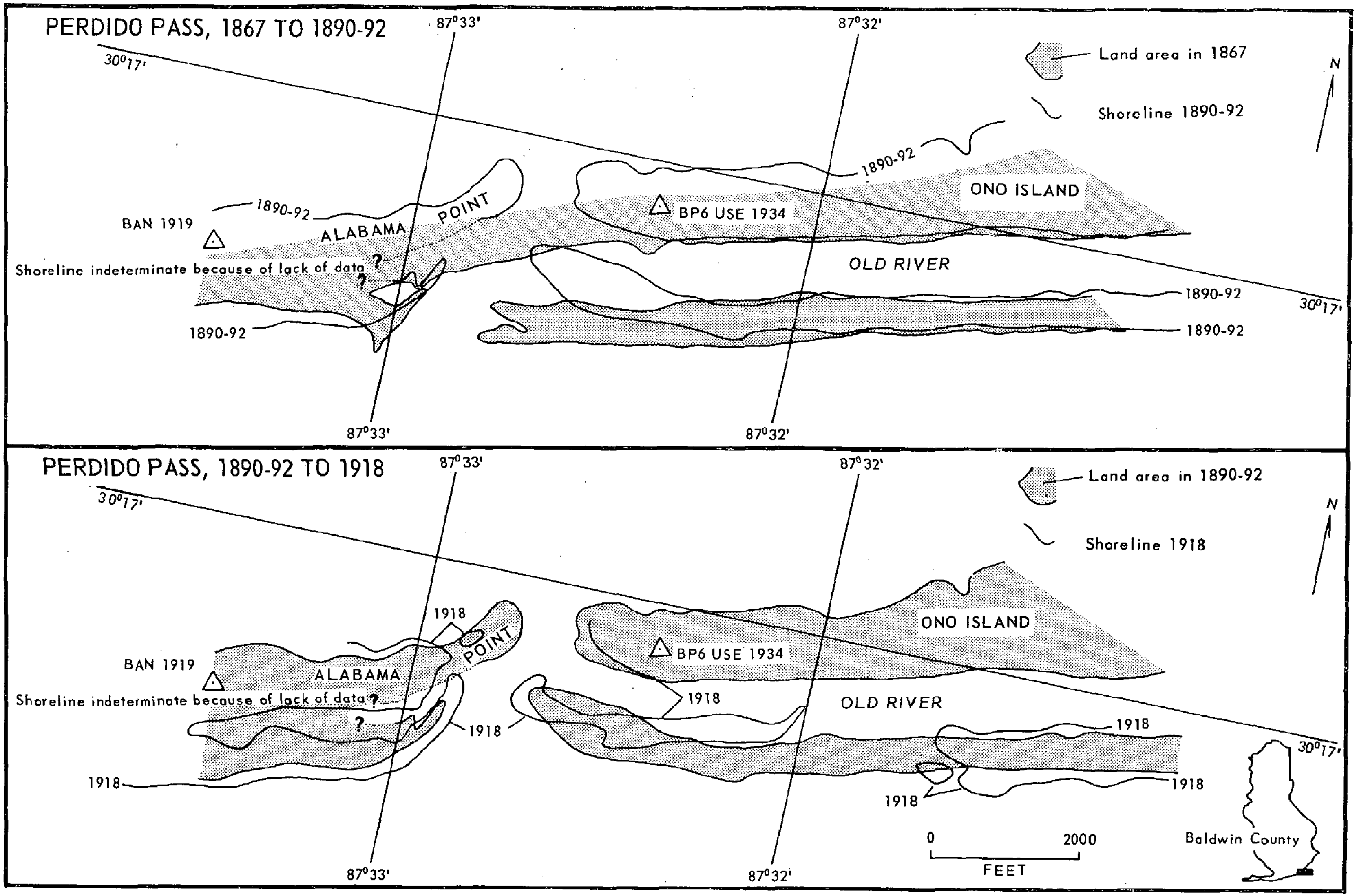

Figure 54. --Shoreline changes in Perdido Pass, 1867 to 1890-92, and 1890-92 to 1918.

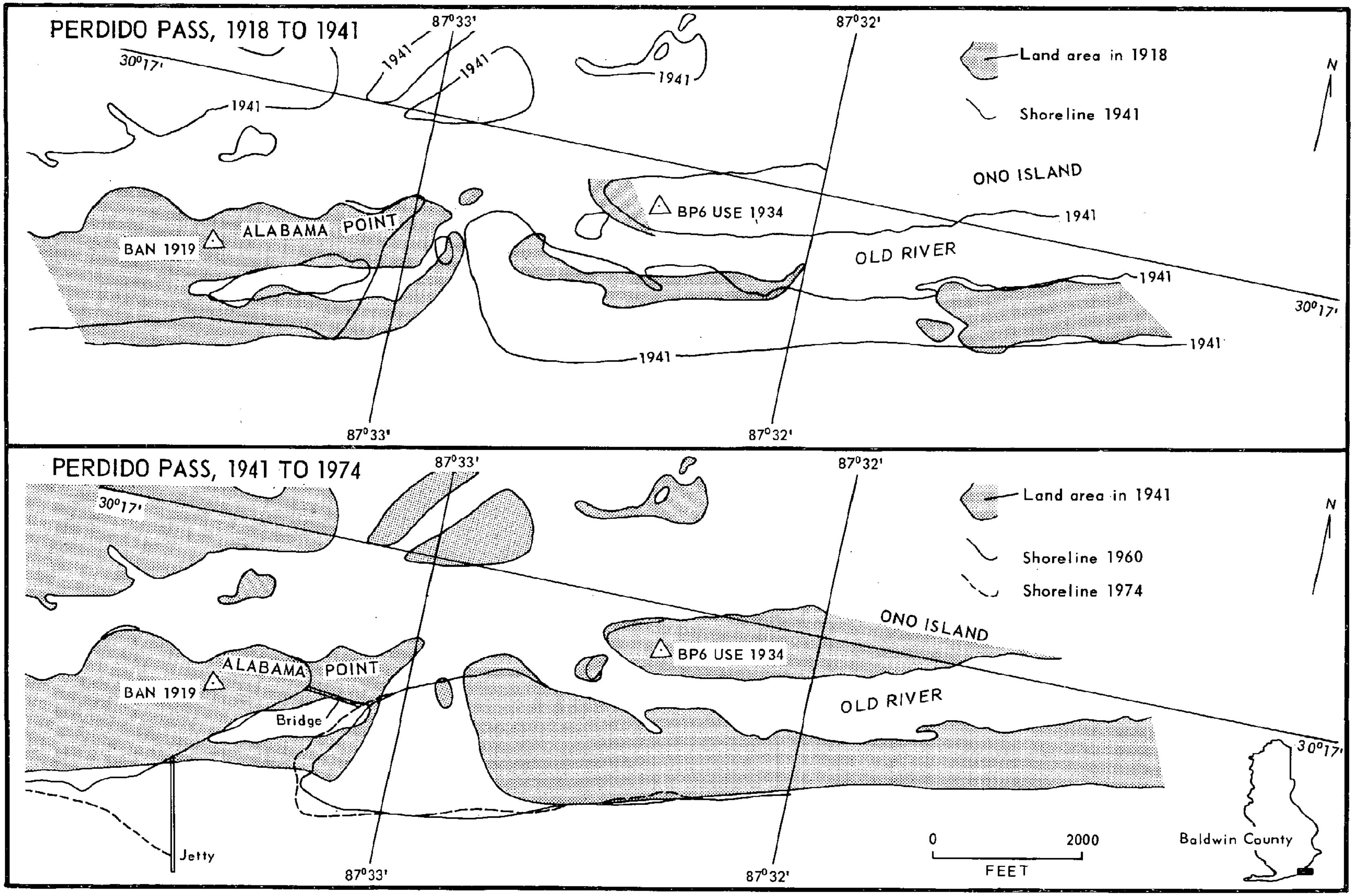

Figure 55. --Shoreline changes in Perdido Pass, 1918 to 1941, and 1941 to 1974.

The migration of the present inlet in the future is unlikely; however, past evidence suggests that a severe disturbance, such as a direct blow from a hurricane with its high tides and high current velocities, could again create one or more passes similar to those shown for 1918 (fig. 54).

LAND/WATER INTERFACE ANALYSIS

Measurement of Alabama Shoreline Length

Three different shoreline length measurements are currently used for the State of Alabama. Appendix E of the National Shoreline Study prepared by the U.S. Army Corps of Engineers lists the estuary shoreline length as 491.2 km (305.3 mi.), while the Alabama Department of Conservation states that the correct length is 577.5 km (358.9 mi.). N.O.A.A. has published a value of 976.7 km (607 mi.) for the length of tidal shoreline in Alabama. The Geological Survey of Alabama measured the shoreline and obtained a figure of 811.3 km (504.2 mi.), using an opisometer on large-scale maps. These measurements are based on traditional map analysis techniques and the difference between them manifests the difficulty encountered in such measurements, including the definition of the parameter being measured. Problems arise with subjective interpretation and the physical limitations of opisometry (map-wheel operation).

The earth imagery acquired by the two NASA satellites, Landsat I and II, is a new source of information applicable to the problem in a format highly appropriate for automatic processing with digital computers. With data being collected periodically, repetitive analysis is feasible on at least an annual basis. This is particularly important in areas of dynamic geomorphology such as the upper reaches of Mobile Bay and the barrier islands. In addition, imagery may normally be obtained a short time after the occurrence of hurricanes, which cause rapid and substantial changes to occur in coastal areas.

Automatic processing of satellite imagery makes possible a rapid analysis of the large volume of data representing an area such as the coastal region of Alabama while simultaneously reducing the influence of human error on the analysis. Measurements based on the satellite data are not as subject to interpretation errors because they are based principally on objective analyses of quantitative data, as opposed to the subjective analysis of qualitative data representative of traditional techniques. The repetitive analysis provides the opportunity to readily identify any inconsistencies that might appear so that they can be resolved in a timely manner, while at the same time facilitating change detection.

Because of the experimental nature of the automatic shoreline detection and measurement technique and the pilot aspect of this application, the resources dedicated to the Alabama shoreline measurement project were necessarily restricted. To analyze the entire Alabama shoreline would require, given the available data, the processing of three computer-compatible tapes through the entire shoreline measurement system (which is outlined in appendix C). To improve confidence in the measurements, it was decided to analyze imagery from two dates covering the Alabama coastal area from the Mississippi state line east to longitude 87°42', near Foley. This excludes the

Perdido Bay area and requires only two computer-compatible tapes for each date. The shoreline segment east of Foley is being analyzed as a follow-on project. The inland boundary of the measured area was determined by estimating the extent of tidal influence. Measurement of simple features in the Landsat images have agreed to within 8 percent of measurements of the same features on standard maps made with an opisometer.

Data from December 28, 1972, and from December 5, 1973, were analyzed (figs. 56 and 57). Winter dates were chosen to minimize the effects of vegetation, which might obscure true shoreline or be floating in the marsh areas. Aerial photography acquired in February, 1973, (NASA Earth Resources Aircraft Project Flight No. 73-023) was compared with the computer land/water category classification. There was some difficulty in detecting the narrow water courses in the marsh areas north and west of Mobile Bay, which demonstrates an effect of sensor resolution on the portrayal of the scene. The detection of small streams at the coast was more complete in the 1972 data and may be the result of any of a number of factors including atmospheric conditions, vegetation state, and sensor performance. It is also likely that the streams were swollen at the time the 1972 data was collected. Discharge data for the Mobile River indicated a flow approximately one third greater in December of 1972 than in December, 1973. While the drainage areas for the streams in question are different

prepared by
NASA/JSC EARTH RESOURCES LABORATORY
NATIONAL SPACE TECHNOLOGY LABORATORIES
BAY ST. LOUIS, MISSISSIPPI

Figure 56.--Shoreline map showing limits of measured area from Landsat imagery dated December 28, 1972.

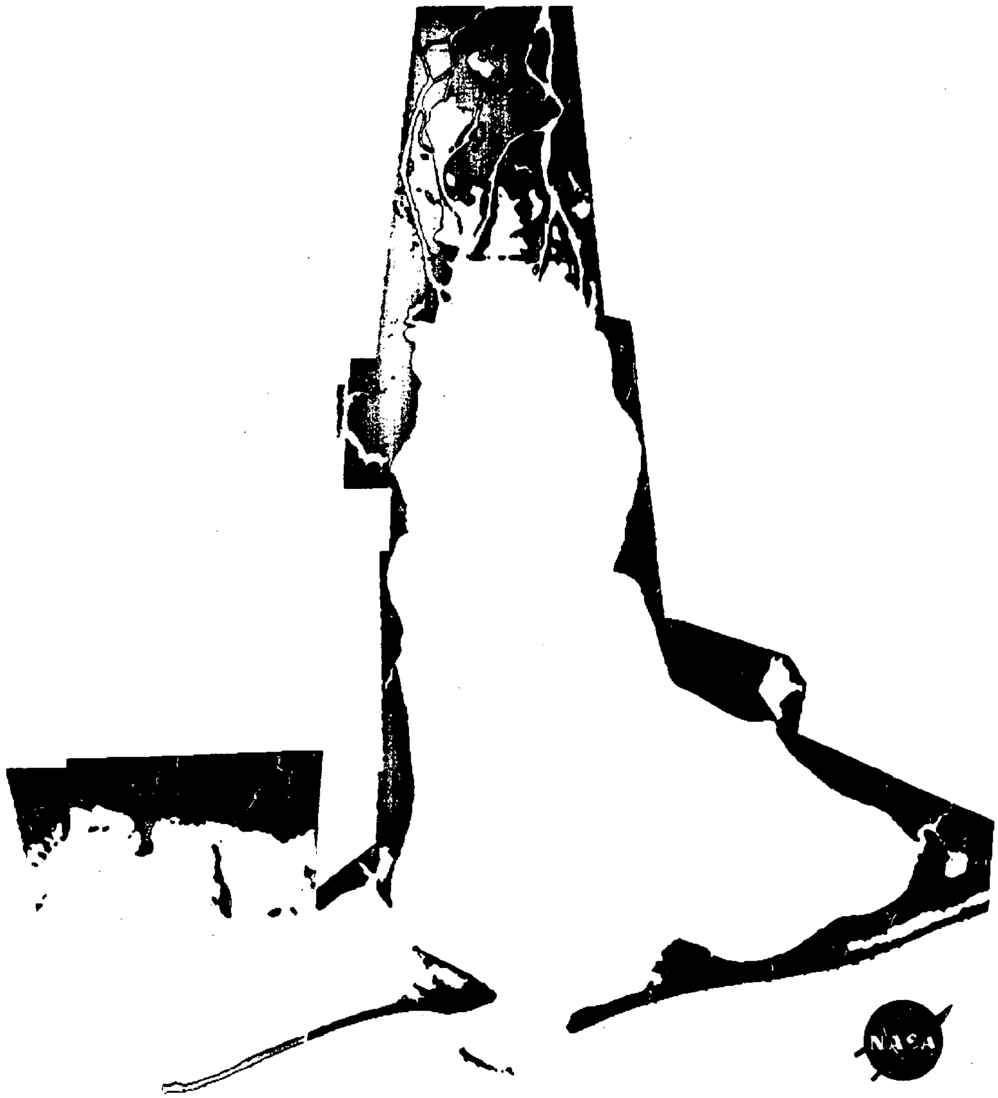

Figure 57.--Shoreline map showing limits of measured area from Landsat imagery dated December 5, 1973.

from the Mobile River basin, the Mobile River conditions were indicative of the entire area. Differences in the final shoreline measurement are due principally to the difference in detection of the small streams and marsh land/water features. The tidal level was almost identical at the time of each image, so sea level change may be ignored. The edge of the screened pattern on the figures shows the inland boundary of the study area.

The 1972 imagery yielded a land/water interface length in the coastal area of Alabama of 1,122.3 km (697.5 mi.), while the 1973 imagery was found to have a shoreline length of 878.5 km (546.0 mi.). The analysis of Landsat data considers every detail of the shoreline that is detected at the resolution of the sensor, which is about 79.2 m (260 ft) in the north-south direction and 58.8 m (193 ft) in the east-west direction. While the same detail may in fact be present in the maps on which the previously published values are based, errors can easily be made in attempting to follow intricate shoreline features with an opisometer. This type of error would tend to decrease the measurement because of the straightening of the shoreline that would thus be effected.

Deviation between the two satellite-based measurements may be the result of differences in defining the areas upon which the analysis was performed, small errors in the factors for scaling and geometric correction of the imagery, or variations in the classification of land and water features in the scene. The fourth factor includes actual geographic changes and misclassifications. This factor is apparent in the marsh areas which are much more broken in the 1972 image and probably indicates a temporary or periodic change in actual surface conditions.

The two shoreline length measurements derived from the Landsat data represent two distinct conditions. The 1973 data are representative of normal river and stream conditions while the 1972 data represent the condition associated with high discharge conditions. A Landsat-based measurement of the Alabama shoreline from the Mississippi state line to 87°42' longitude is 878.5 km (546 mi.) under normal conditions.

As stated above, NASA did not measure the entire shoreline of Alabama, since the coastal area east of 87°42', near Florida, was omitted. The Geological Survey of Alabama has derived an estimate of the total shoreline based on application of a ratio* obtained through conventional opisometer techniques. If the total length of Alabama's shoreline were measured using the NASA land/water interface technique, it would measure approximately 1,313 km (816 mi.).

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* The ratio used is defined as $\frac{\text{opisometer partial}}{\text{opisometer total}} = \frac{\text{NASA-derived partial}}{x}$

where x = total measurement of shoreline by NASA technique

therefore $\frac{680.6 \text{ km}}{811.3 \text{ km}} = \frac{1{,}000.4 \text{ km}^{**}}{x}$

and x = 1,313.1 km or 816 mi.

** mean of NASA's 1972 and 1973 partial measurements

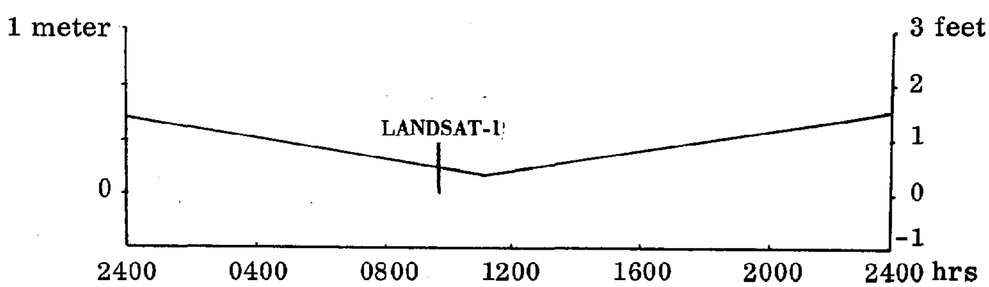
APPENDICES

APPENDIX A

Landsat Imagery and Hydrologic Characteristics

Landsat-1 1050-15560

September 11, 1972

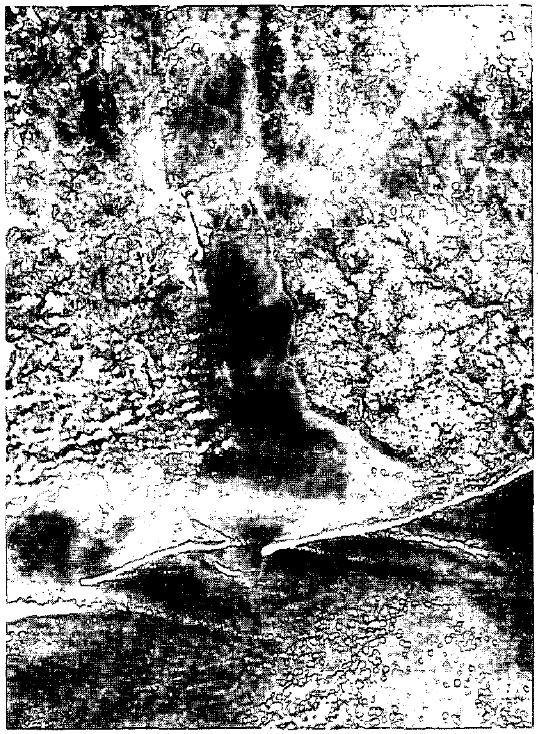


MAXIMUM CURRENT

Time	Velocity (kts)
0532 ----------------	0.9 ebb
1855 ----------------	0.9 flood

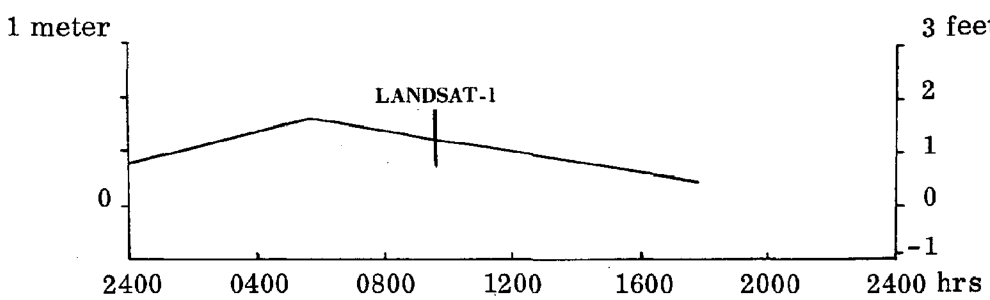
DISCHARGE CHARACTERISTICS FOR THE ALABAMA-TOMBIGBEE

Total discharge for September 1972-----------15,879.7 m^3/s (560,787 cfs)
September 11, 1972, discharge----------------479.6 m^3/s (16,938 cfs)
Mean discharge for September 1972-----------529.4 m^3/s (18,697 cfs)



Landsat-1 1086-15562

October 17, 1972



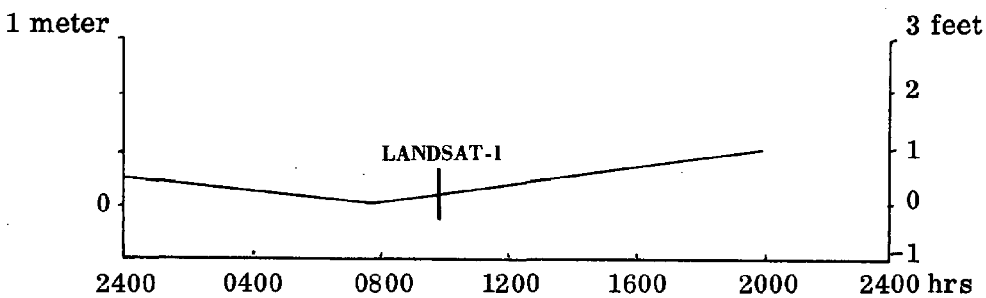
MAXIMUM CURRENT

Time	Velocity (kts)
1212	1.4 ebb
2357	1.0 flood

DISCHARGE CHARACTERISTICS FOR THE ALABAMA-TOMBIGBEE

Total discharge for October 1972--------------11,401.5 m^3/s (402,641 cfs)
October 17, 1972, discharge------------------292.7 m^3/s (10,336 cfs)
Mean discharge for October 1972--------------367.7 m^3/s (12,988 cfs)

Landsat-1 1158-15564
December 28, 1972

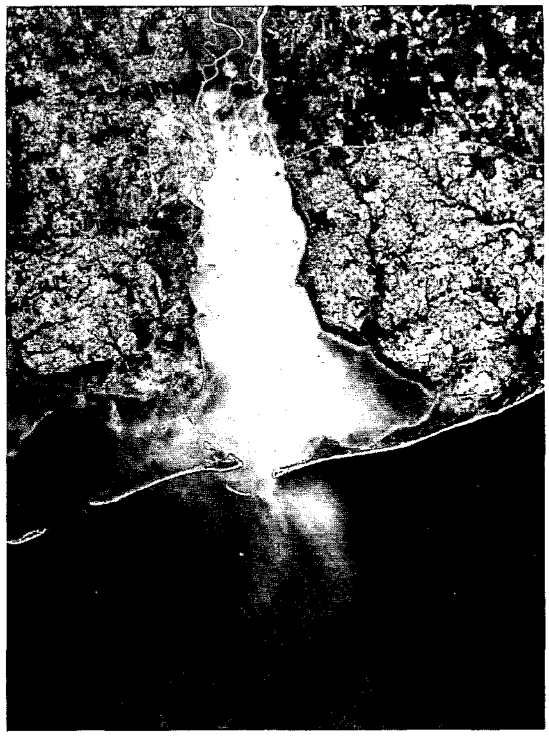


MAXIMUM CURRENT

Time	Velocity (kts)
0102	0.5 ebb
1406	0.8 flood

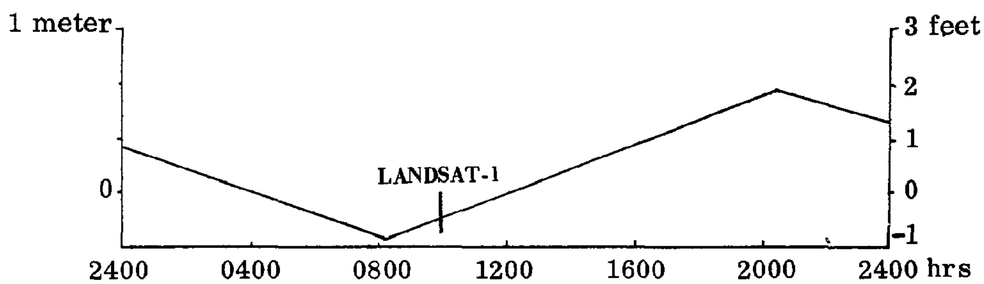
DISCHARGE CHARACTERISTICS FOR THE ALABAMA-TOMBIGBEE

Total discharge for December 1972----------------82,673.8 m^3/s (2,919,602 cfs)
December 28, 1972, discharge--------------------2,814.8 m^3/s (99,403 cfs)
Mean discharge for December 1972----------------2,666.6 m^3/s (94,170 cfs)



Landsat-1 1176-15562

January 15, 1973



MAXIMUM CURRENT

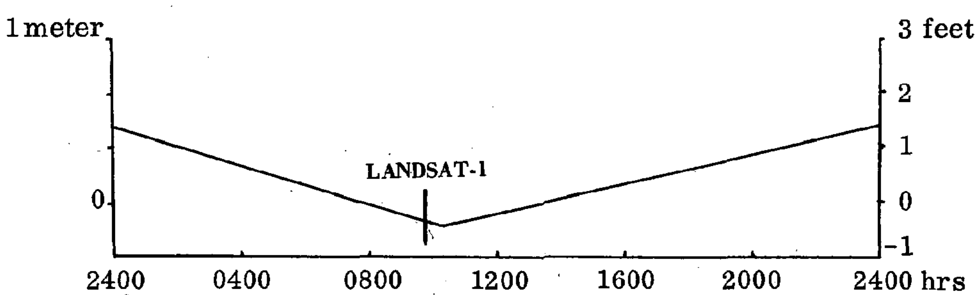
Time	Velocity (kts)
0136	2.6 ebb
1415	2.6 flood

DISCHARGE CHARACTERISTICS FOR THE ALABAMA-TOMBIGBEE

Total discharge for January 1973-----------194,678 m^3/s (6,875,010 cfs)
January 15, 1973, discharge---------------5,678 m^3/s (200,518 cfs)
Mean discharge for January 1973----------4,785 m^3/s (168,985 cfs)

Landsat-1 1194-15564

February 2, 1973



MAXIMUM CURRENT

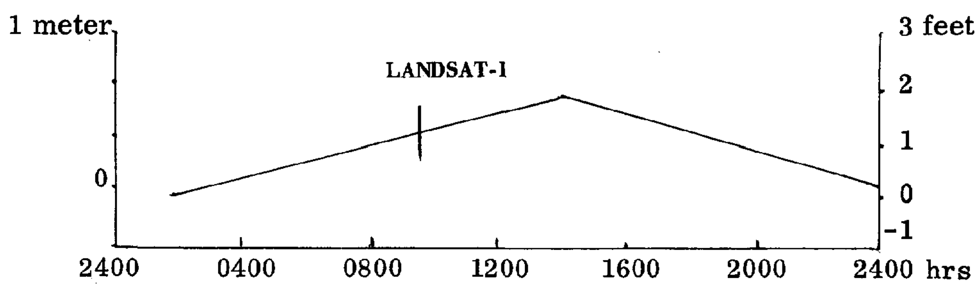
Time	Velocity (kts)
0429	2.1 ebb
1730	1.9 flood

DISCHARGE CHARACTERISTICS FOR THE ALABAMA-TOMBIGBEE

Total discharge for February 1973----------157,794.2 m^3/s (5,572,457 cfs)
February 2, 1973, discharge--------------3,614.6 m^3/s (127,651 cfs)
Mean discharge for February 1973---------3,434.4 m^3/s (121,285 cfs)

Landsat-1 1302-15565

May 21, 1973



MAXIMUM CURRENT

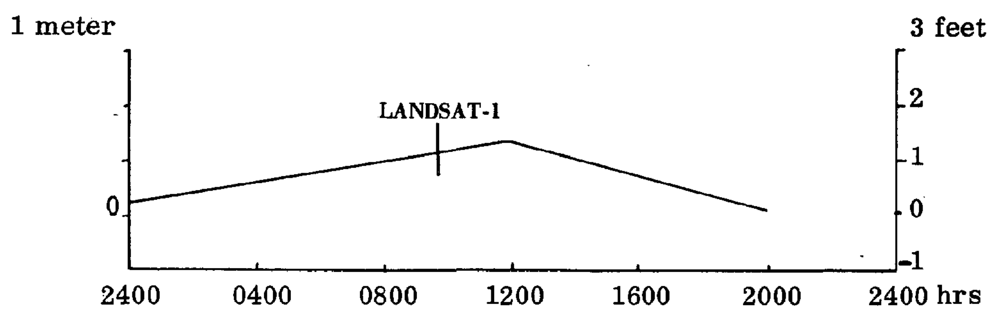
Time	Velocity (kts)
0720	2.0 flood
1936	2.0 ebb

DISCHARGE CHARACTERISTICS FOR THE ALABAMA-TOMBIGBEE

Total discharge for May 1973--------------------123,518 m^3/s (4,361,534 cfs)
May 21, 1975 discharge-------------------------1,903 m^3/s (67,196 cfs)
Mean discharge for May 1973--------------------39,881.6 m^3/s (140,594 cfs)

Landsat-1 1428-15550

September 24, 1973



MAXIMUM CURRENT

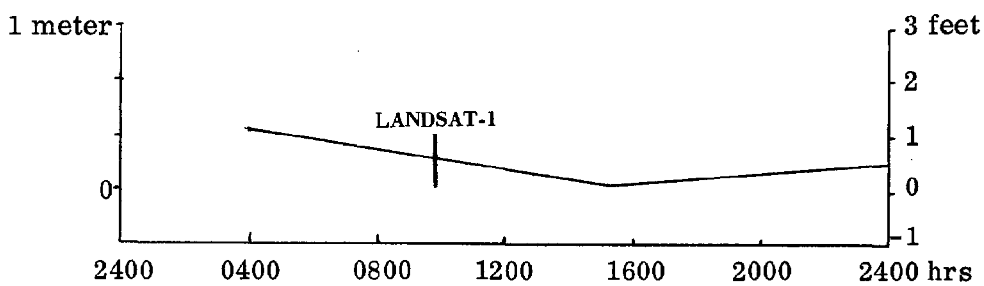
Time	Velocity (kts)
0407	1.1 flood
1443	0.9 ebb

DISCHARGE CHARACTERISTICS FOR THE ALABAMA-TOMBIGBEE

Total discharge for September 1973------------17,227 m^3/s (608,365 cfs)
September 24, 1973, discharge----------------500 m^3/s (17,687 cfs)
Mean discharge for September 1973------------536.6 m^3/s (18,953 cfs)

Landsat-1 1482-15541

November 17, 1973



MAXIMUM CURRENT

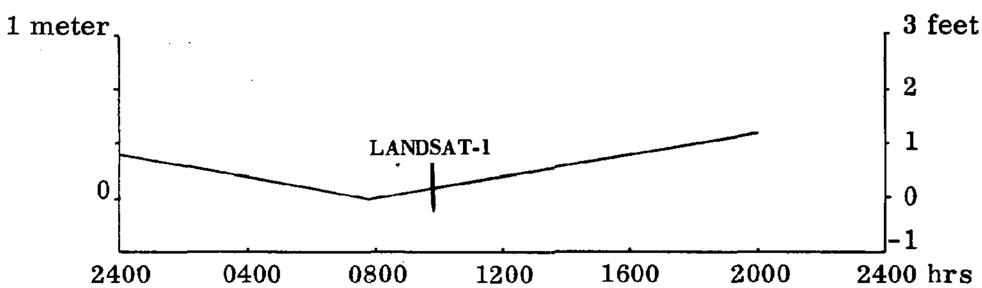
Time	Velocity (kts)
0924------------------	1.5 ebb
2148------------------	1.0 flood

DISCHARGE CHARACTERISTICS FOR THE ALABAMA-TOMBIGBEE

Total discharge for November 1973-------------26,012.7 m^3/s (918,633 cfs)
November 17, 1973, discharge-----------------642.3 m^3/s (22,684 cfs)
Mean discharge for November 1973-------------810.5 m^3/s (28,623 cfs)

Landsat-1 1500-15535

December 5, 1973



MAXIMUM CURRENT

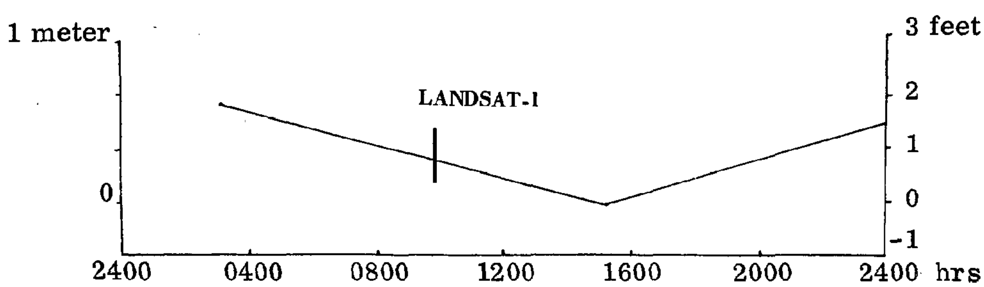
Time	Velocity (kts)
0146	0.7 ebb
1430	0.8 flood

DISCHARGE CHARACTERISTICS FOR THE ALABAMA-TOMBIGBEE

Total discharge for December 1973------------73,054 m^3/s (2,579,885 cfs)
December 5, 1973, discharge----------------2,220.9 m^3/s (78,431 cfs)
Mean discharge for December 1973-----------2,666.6 m^3/s (94,171 cfs)

Landsat-1 1806-15451

October 7, 1974



MAXIMUM CURRENT

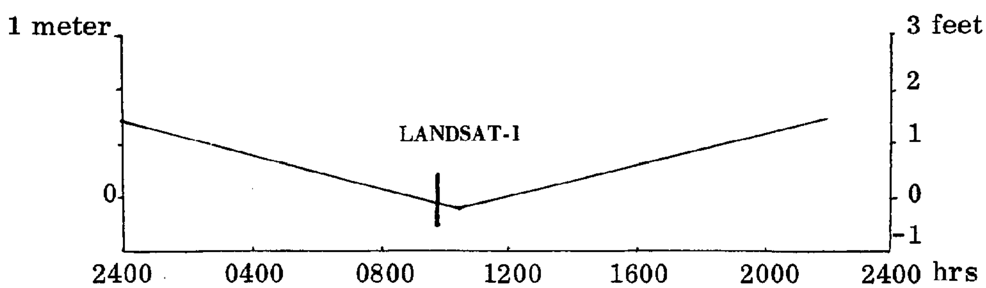
Time	Velocity (kts)
0849	2.1 ebb
2111	2.1 flood

DISCHARGE CHARACTERISTICS FOR THE ALABAMA-TOMBIGBEE

No data available

Landsat-1 1842-15441

November 12, 1974



MAXIMUM CURRENT

Time	Velocity (kts)
0241	1.6 ebb
1553	1.7 flood

DISCHARGE CHARACTERISTICS FOR THE ALABAMA-TOMBIGBEE

No data available

APPENDIX B

Source Material and Hydrologic Data

Table 1. --Selected photographic coverage available for Mobile Bay

Type of acquisition platform	Data type, format	Date of photography
Landsat-1	Prints-transparencies, B&W and a few color composites Scale: 1:3,369,000 to 1:250,000	9-11-72 9-29-72 10-17-72 12-28-72 1-15-73 2- 2-73 5-21-73 9-24-73 10-30-73 11-17-73 12- 5-73 6-21-74 9-19-74 10- 7-74 11-12-74
Skylab 3	B&W, color, and color IR prints or transparencies Scale: 1:2,850,000 to 1:250,000	8- 5-73
Skylab 4	B&W, color, and color IR prints or transparencies Scale: 1:2,850,000 to 1:250,000	1-21-74
U-2 aircraft	Color IR Scale: 1:130,000	9-24-72
U-2	Color IR Scale: 1:130,000	2-22-73
U-2	Color IR Scale: 1:130,000	10-17-74
RB-57 F aircraft	Color IR (post-hurricane Camille, quite a few clouds) Scale: 1:130,000	8-19-69
Low-altitude aircraft	B&W photos and photo mosaics Scale: 1:20,000 and 1:63,360	1938, 1940, 1949, 1950, 1955, 1960, 1966

Table 2.--Monthly discharge averages for the Alabama River (1931-1965) and Tombigbee River (1929-1960)*

Monthly	M^3/s	ft^3/s
October	566.1	19,989.7
November	835.1	29,489.2
December	1,600.0	56,496.0
January	2,646.6	93,453.8
February	3,349.0	118,256.4
March	3,824.5	135,044.7
April	3,563.9	125,842.7
May	1,736.6	61,321.7
June	914.2	32,281.9
July	914.8	32,303.3
August	744.4	26,285.6
September	579.5	20,462.7

NOTE: In order to obtain the full discharge into Mobile Bay, the figures for the combined rivers were multiplied by 1.07.

* Source: U.S. Geological Survey, Surface Water Records, 1929-1960.

Table 3.--Suspended sediment (12-year monthly average), Tombigbee and Alabama River systems from 1952 to 1963

(Compiled from unpublished data, U.S. Corps of Engineers, Mobile District)

	Tombigbee River		Alabama River		Combined	
Month	M. tons	Sh. tons	M. tons	Sh. tons	M. tons	Sh. tons
January	304,454	(335,661)	218,502	(240,899)	522,956	(576,560)
February	470,903	(519,171)	349,988	(385,863)	820,892	(905,034)
March	506,559	(558,482)	429,001	(472,974)	935,560	(1,031,456)
April	343,529	(378,742)	397,015	(437,710)	740,545	(816,452)
May	164,647	(181,524)	187,768	(207,015)	352,416	(388,539)
June	43,766	(48,253)	102,116	(112,583)	145,882	(160,836)
July	65,272	(71,963)	79,899	(88,089)	145,171	(160,052)
August	11,163	(12,308)	38,657	(42,620)	49,821	(54,928)
September	12,511	(13,794)	44,640	(49,216)	57,151	(63,010)
October	16,934	(18,670)	40,408	(44,550)	57,342	(63,220)
November	59,436	(65,529)	47,137	(51,969)	106,574	(117,498)
December	173,324	(191,090)	169,315	(186,670)	342,639	(377,760)
Annual totals	2,172,503	(2,395,187)	2,104,446	(2,320,158)	4,276,949	(4,715,345)

1. Based on daily suspended sediment data.
2. Station near Leroy, Ala.
3. Station at Claiborne, Ala.

(After Ryan 1969)

Table 4.--Yearly discharge averages into Mobile Bay by the Alabama-Tombigbee Rivers (1931-1974)

Year	M^3/s	ft^3/s
1931	1,052.7	37,171.8
1932	1,837.3	64,874.1
1933	2,630.9	92,897.4
1934	1,066.9	37,674.7
1935	1,767.5	62,413.1
1936	1,985.1	70,095.7
1937	1,922.7	67,891.5
1938	1,850.6	65,344.9
1939	1,835.4	64,809.9
1940	1,636.3	57,780.0
1941	1,066.3	37,653.3
1942	1,342.7	47,411.7
1943	1,623.6	57,330.6
1944	2,012.4	71,058.7
1945	1,606.9	56,742.1
1946	2,580.3	91,110.5
1947	2,158.8	76,226.8
1948	1,964.2	69,357.4

Table 4.--Yearly discharge averages into Mobile Bay by the Alabama-Tombigbee Rivers (1931-1974)--Continued

Year	M^3/s	ft^3/s
1949	3,050.2	107,706.2
1950	1,684.5	59,481.3
1951	1,744.2	61,589.2
1952	1,484.8	52,430.0
1953	1,716.3	60,604.8
1954	1,097.5	38,755.4
1955	1,257.8	44,415.7
1956	1,326.9	46,855.3
1957	1,517.8	53,596.3
1958	2,116.9	76,515.7
1959	1,345.4	47,508.0
1960	1,630.9	57,587.4
1961	2,245.4	79,287.0
1962	2,517.5	88,895.6
1963	1,360.0	48,021.6
1964	2,323.9	82,058.3
1965	1,736.6	61,321.7
1966	1,514.5	53,478.6

Table 4.--Yearly discharge averages into Mobile Bay by the Alabama-Tombigbee Rivers--Continued

Year	M^3/s	ft^3/s
1967	1,259.0	44,458.5
1968	1,969.3	69,539.3
1969	1,500.2	52,975.7
1970	1,456,0	51,413.5
1971	1,994.2	70,416.7
1972	1,760.5	62,167.0
1973	2,726.6	96,278.6
1974	2,278.7	80,464.0

Table 5.-- Selected charts and maps available for the Alabama coastal area

U.S.G.S. 7½' Quadrangles	Publication Date
Mobile	1953-1967
Hollingers Island	1953-1967
Bellefontaine	1956
Little Dauphin Island	1958
Heron Bay	1958
Isle aux Herbes	1958
Kreole	1958
Grand Bay S. W.	1958
Grand Bay	1967
Coden	1956
Petit Bois Island	1958
Fort Morgan N. W.	1958
Fort Morgan	1958
Bridgehead	1953-1967
Daphne	1953-1967
Point Clear	1956
Lillian	1970
W. Pensacola	1970
Perdido Bay	1970
U.S.G.S. 15' Quadrangles	
Weeks Bay	1941
Grand Bay	1958
Foley	1941

Table 5.--Selected charts and maps available for the Alabama coastal area--Continued

U.S.G.S. 1:250,000	National Topographic Maps
Pensacola, Fla.; Ala.	1957-1970
Mobile, Ala.; Miss.; La.	1953-1970

U.S.G.S. 1:500,000	Base map of Alabama
	1966

National Ocean Survey Nautical Charts

Chart No.	Scale	Date
91	1:80,000	1860
187	1:80,000	1897
187	1:80,000	1916
188	1:80,000	1909
188	1:80,000	1894
189	1:80,000	1894
189	1:80,000	1909
189	1:80,000	1918
874	1:40,000	1947
1266	1:80,000	1921
1266	1:80,000	1929
1266	1:80,000	1943
1266	1:80,000	1973
1267	1:80,000	1920
1267	1:80,000	1921
1267	1:80,000	1933
1267	1:80,000	1944
11374 (Formerly 874-SC)	1:40,000	1974
11378 (Formerly 874-SC)	1:40,000	1974

Table 5.-- Selected charts and maps available for the Alabama coastal area--Continued

Miscellaneous U.S.C. & G.S. Topographic Sheets

1:40,000-Scale

3702	1917
3711	1917
3712	1918
3713	1918
3714	1918
3716	1918-1919

1:10,000-Scale

5497	1934
5498	1934
5528	1934
5529	1934
5530	1934
5531	1934
5532 Supp.	1934
5533	1934
5534	1934
5535	1934
5536	1934
5537	1934

Miscellaneous Maps

Carte de L'Isle Dauphine, ses Environs, par le S[r] DuSault, 1917

Historic Dauphin Island, by E. Wilson, 1971

APPENDIX C

Automatic Processing of Satellite Data for Shoreline Measurement

APPENDIX C

AUTOMATIC PROCESSING OF SATELLITE DATA FOR SHORELINE MEASUREMENT

The NASA satellite Landsat (formerly the Earth Resources Technology Satellite) provides imagery of the earth's surface in a format suited for automatic processing. Analysis of the light intensity in different regions of the optical spectrum allows one to discriminate land from water. Further processing makes possible the measurement of the land/water interface and generation of a thematic presentation showing the land and water and the shoreline that was measured.

Data Acquisition System

The sensor used to acquire data on Landsat is a multispectral scanner. This is a device which, at any given instant in time, views a very small area approximately 79 m (259 ft) on a side. This area is called the instantaneous field of view (IFOV) of the sensor. The IFOV is scanned along a line perpendicular to the motion of the satellite, which itself travels along a line oriented approximately north-south. The extent of the scan is about 5 degrees from nadir in either direction across the satellite ground track, and results in a coverage of 185 km (100 nautical mi.) in an east-west direction. By the time that the system completes one scan and is ready to scan again, the satellite has moved down its track and the next scan line is offset from the previous line. The data taken at this time is adjacent to the previous line of data, and juxtaposition of successive scan lines generated in this way produces the two-dimensional image.

As the term multispectral implies, the scanner is viewing the earth beneath in different regions of the electromagnetic spectrum. The radiation received by the scanner is broken down into green light (0.5-0.6 micrometers (μm)), red light (0.6-0.7 μm), and two bands of infrared light (0.7-0.8 and 0.8-1.1 μm). The intensity of the radiation in each of these four spectral bands is simultaneously measured and recorded for each picture element, which is defined as an individual sample point on the scan line. The picture element represents a spot on the earth with dimensions of about 79 by 58 m (259 by 190 ft).

Multispectral scanner data is well suited for earth surface studies because the data from each of the four spectral bands are readily available in a computer-compatible form for automatic processing. Spectral signature analysis can be performed directly on this data to generate images, with each picture element classified into predetermined categories. For shoreline analysis, the computer is programmed to recognize the spectral signature of water and to classify those picture elements which it recognizes to be water, and to leave all other picture elements unclassified, which set then corresponds to land.

There are problems involved with the use of this type of data for analysis of surface features, notably the geometric distortions inherent with scanner data. Corrections can be made for rotation of the earth beneath the satellite, the angular displacement of the scan direction from the exact perpendicular to the satellite ground track, and variation of the width of the picture elements along the scan line. First-order corrections for the earth rotation and for the varying picture element size were made in the shoreline length analysis described in this document, while the second problem was deemed to have a negligible effect. Better correction techniques now exist, and are being implemented, but were not available at the time this work was performed.

Procedure for Shoreline Measurement

There are nine basic steps outlined in figure C1 that are required to derive a display showing land, water, and shoreline and the length of the shoreline from the Landsat multispectral scanner data. The data are originally provided in the form of a film image of the earth scene as recorded for each of the four spectral channels. Initial examination of the film images determines the suitability of the frame of data for analysis - whether the area to be studied is completely included in the frame, whether clouds will interfere with the analysis, and so on. If the frame is suitable for analysis, the digital magnetic tapes containing the values of light intensity for each spectral band for each picture element are obtained. All subsequent work is based on these digital data.

The next step in the procedure is to determine the spectral signature of water so that the computer can be instructed to recognize water and classify it.

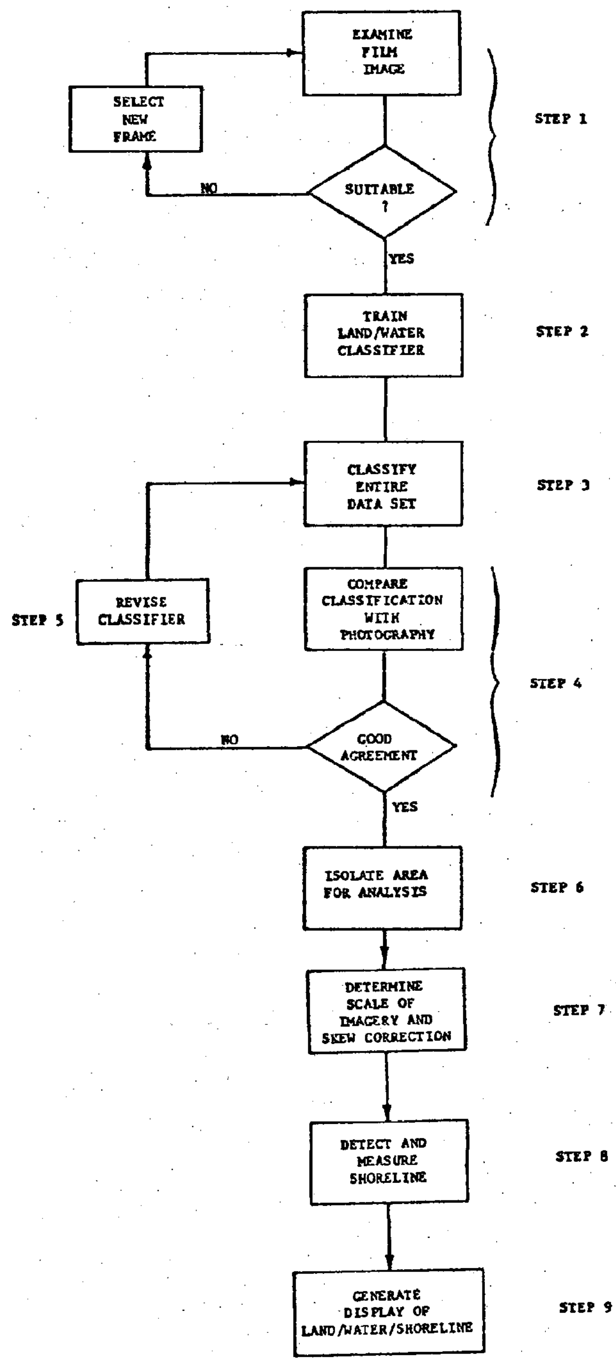


Figure C1.--Flow of processing to perform shoreline length analysis on Landsat MSS data.

Areas known to be land and areas known to be water are located in the data. Values of radiation intensity in the green and second infrared spectral bands are then extracted for each of the picture elements in these land and water areas. These areas are known as training samples because data from them are used to "train" the computer to recognize the two categories. A graph with axes representing the green-band intensity and the infrared-band intensity is developed, with data points corresponding to land features differentiated from those which correspond to water features (fig. C2). A line is then drawn through the data that best separates the two sets of points. This line defines the land/water discriminator that will then classify each picture element on the basis of intensity of green and infrared light. The second infrared band alone provides a very good definition of land and water because water strongly absorbs radiation in that spectral region, where very strong reflectance is typical of land features. The intensity of green light reflected from the area being classified serves to adjust the decision point in the infrared for varying turbidity levels of the water, which can cause problems in areas of muddy river discharges and marshes.

The third step in the procedure is to examine each data point in the frame and compare the light-intensity measurements in the green and infrared bands to the land/water decision curve. The computer tests these data and determines whether they match more closely the spectral signature of land or of water, and then classifies accordingly that picture element. From this classification process, a new

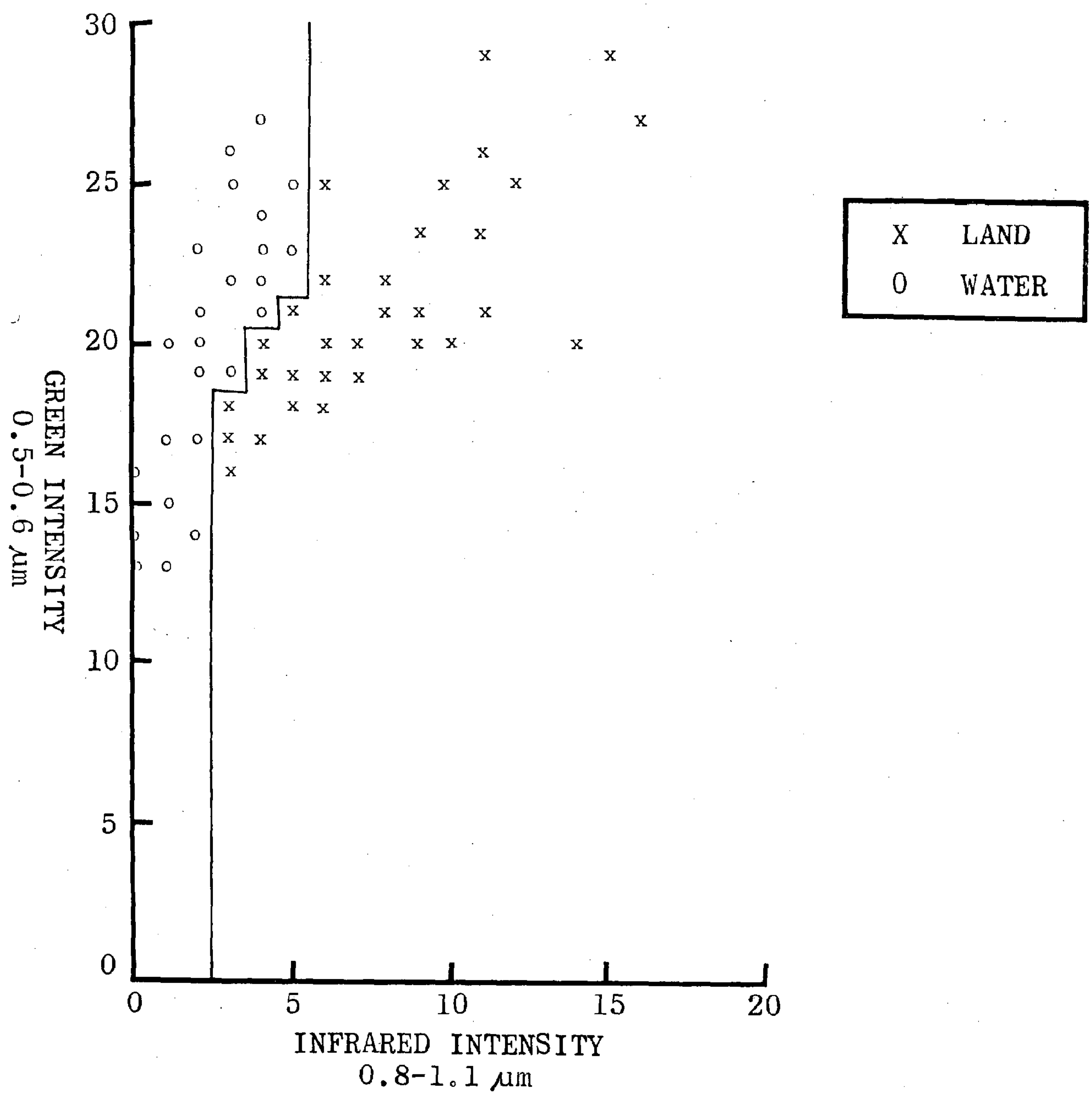


Figure C2.--Land/water discrimination using Landsat MSS data.

magnetic tape is generated that portrays each picture element with a code corresponding to either land or water. After the image is classified, it is then closely examined and compared to aerial photography of the area acquired within a reasonable time period of the satellite data acquisition. The acceptable time period is determined by the rate of change of the geography and the problems expected in the classification. Marsh areas generally are the most difficult to classify and also the most dynamic, so when marsh areas are to be classified there should be aerial photography for comparison not more than a year or two before or after the date of the satellite image. If the comparison shows that there are serious discrepancies between the classification and the visual interpretation of the photography, the land/water discriminator must be modified. The most common cause for such discrepancies is that the training samples are not representative of all regions found in the data set. After modifying the discriminator, the classification process is repeated and the results are compared to the photography. These steps are repeated until a satisfactory land/water thematic has been generated.

Because a Landsat image will typically contain not only the immediate coastal area in which one wants to measure the land/water interface, but also the inland region containing small ponds, lakes, creeks, and rivers, the coastal area must be isolated. The image is displayed and the limits of the area to be analyzed are determined. The code for each picture element outside the area of consideration is then switched from either land or water to a third code that will be recognized by subsequent computer analysis and ignored. The image is then ready for detection and measurement of the shoreline.

The satellite data must be scaled accurately for the shoreline measurement to be meaningful. Nominal values are given for the picture element dimensions, but these may vary significantly. Good results have been obtained in scaling the data by locating points identifiable in the satellite imagery on accurate maps. The distances between these points are measured on the maps, and the number of picture elements separating the points in the satellite imagery along the scan direction and perpendicular to it are determined. In addition to the simple scaling, a correction must be made for the rotation of the earth beneath the satellite, referred to as skew correction. Both the scaling and skew correction factor are determined using distances measured on the map and in terms of picture element offsets in the image. A least squares error technique is used to compute the picture element "width" and "height" and the skew correction factor, which is consistently equivalent to approximately one element offset every eleven scan lines.

With these factors determined, the shoreline may be detected and measured. A shoreline element is defined as the edge of an element of water which is adjacent to an element of land. A two element wide and two element high "window" is scanned over the classified image, and each element of shoreline is noted. There are four basic types of shoreline elements: horizontal (two water elements in one scan line, two land in the other); vertical (the first element of each scan line within the window is land and the second is water); diagonal (fig. C3); and corner (fig. C4). Each of these types has a different length, so the number of each type of shoreline element is accumulated for the entire image. After scanning the entire image, the number of each type of shoreline element is multiplied by the length for the respective type, and these products are then summed to give the total interface length.

The horizontal and vertical elements contribute one picture element width and height respectively. The diagonal contribution is the square root of the sum of the squares of the width and height, corresponding exactly to the diagonal measure of the picture element. Because sharp corners are not typical of natural scenes, the contribution of such apparent features is that of a rounded corner, the length being one half the width plus one half the height of the picture element, plus one quarter of the average of the perimeters of the ellipses that can be inscribed and circumscribed on the picture element.

The computer program that detects and measures shoreline also generates a new image of the scene. This image has been modified from that generated by the

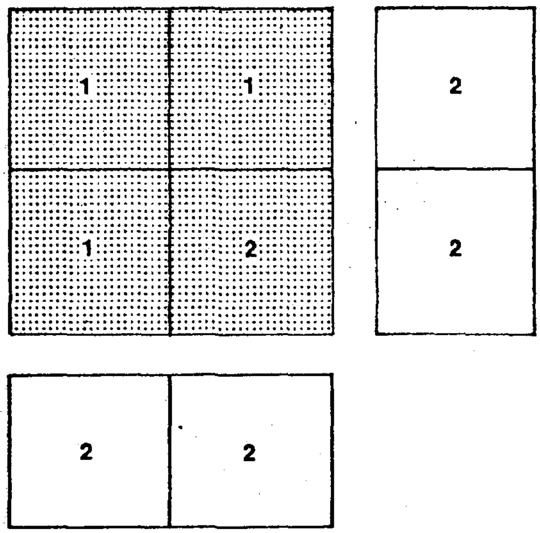


Figure C3.--One configuration of land (1) and water (2) which indicates a diagonal interface feature. Shaded area is examination window.

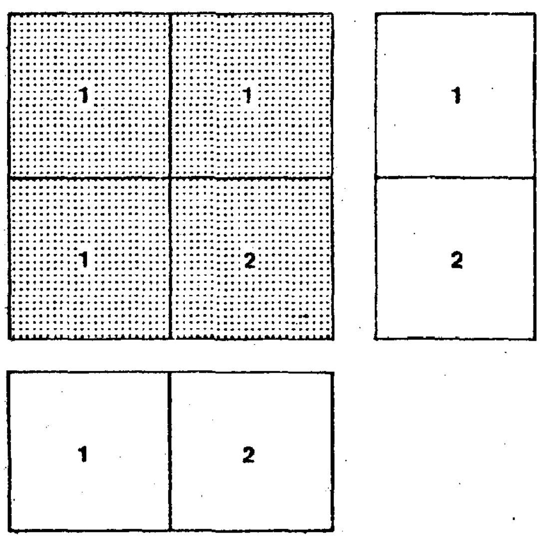


Figure C4.--One configuration of land (1) and water (2) which indicates a corner interface feature which must be rounded in the length computation.

land/water classifier to show as a fourth class every element of water found to be adjacent to an element of land. The shoreline image, as this new image is called, shows land, water, shoreline, and areas excluded from analysis.

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