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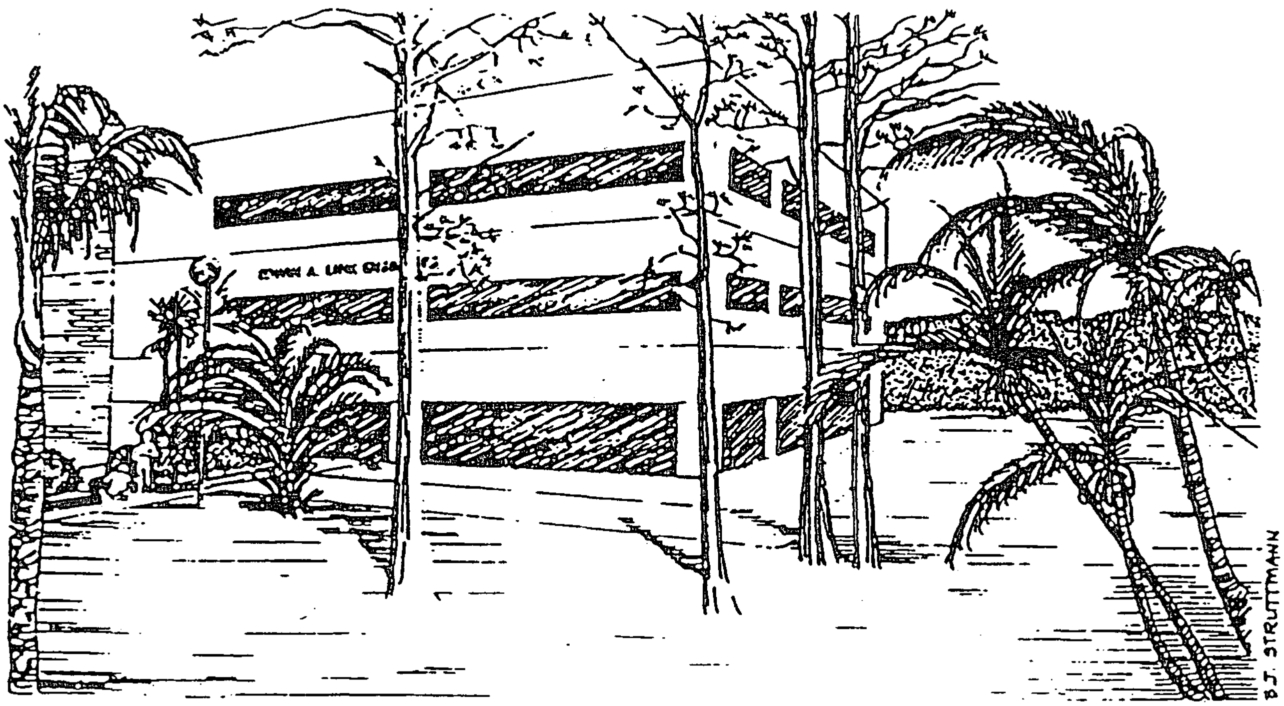
Final Report to the St. Johns River Water Management District

DESIGN AND OPERATION OF A MUCK SEDIMENT SURVEY



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The success of our muck survey is the result of the combined efforts of many people other than the authors of this document. Our warmest thanks go to Joel Steward, John Higman and Dean Vanderbleek of the St. Johns Water Management District. Their interest in the study and tireless efforts with us in the field were very much appreciated.

Our field effort ran smoothly thanks to the skills and long hours of Richard Gurlick, Master of the FIT Research Vessel DELPHINUS. We greatly appreciate the many hours given in the field by Tania Bacchus and Maryann Civil; their talents and spirit were important to making long days on the lagoon enjoyable and successful.

EXECUTIVE SUMMARY

Inputs of fine-grained, organic-rich sediment to estuaries such as the Indian River Lagoon, Florida, can have an adverse effect on water quality and benthic habitats. This sediment, sometimes referred to as muck, is not the natural bottom along most of the Indian River Lagoon. Muck can be easily resuspended to increase turbidity in the water and decrease the growth of seagrasses. Muck sediments also have a high oxygen demand and can contribute to oxygen depletion in the water column. When the normal sediment of the lagoon is covered with muck, habitats for benthic organisms are often changed and inputs of contaminants can increase.

Although some preliminary surveys in the Indian River Lagoon have been previously carried out, no comprehensive data set on muck distribution was available. During our 1989 muck survey, more than 600 discrete sediment cores were collected and hundreds of additional observations were made along the lagoon from New Smyrna Beach to St. Lucie Inlet.

Muck sediments were found throughout the Indian River Lagoon in layers as thick as 2 meters. A series of MUCKMAPS have been developed to show the distribution and thickness of muck layers and are included in the GIS data base at the St. Johns River Water Management District. Overall, less than 10% of the combined areas of the Mosquito, Indian River and Banana River Lagoons are covered with muck. Muck sediments are most abundant in the central Indian River Lagoon in proximity to developed areas such as Titusville, Cocoa and Melbourne. Large deposits are also found in the Vero Beach area. In the lagoon proper, muck tends to accumulate in the Intracoastal Waterway (ICW), in channels connecting the ICW to marinas or creeks, and in deeper pockets of water adjacent to developed areas. We estimate that about 40% of the ICW is

coated with muck, sometimes as thick as 1 meter. In many areas, a lot of muck is retained in adjacent creeks such as Crane Creek, Turkey Creek and Manatee Pocket. An in-depth study of Manatee Pocket showed muck thicknesses of 1 to 2 meters throughout the cove. Thus, winding tributaries along much of the lagoon have served as traps for incoming fine-grained, organic-rich sediment.

The typical muck sediment in the Indian River Lagoon contains 8-15% organic matter and 30-50% aluminosilicate silts and clays, with the remainder being sand and shell material. Muck deposits from the central lagoon (Titusville to Palm Bay) averaged about 6% more organic matter and 10% more silt/clay than deposits from the northern and southern portions of the lagoon. This difference is most likely related to increased nutrient inputs, more soil runoff and poorer flushing along the Titusville to Palm Bay stretch of the lagoon.

Muck sediment accumulation rates at locations where such measurements were possible ranged from about 0.2 to 1 cm/y. However, the age of onset of muck inputs is more variable. For example, near Melbourne, muck accumulations are 20-30 years old and are contaminated with mercury and lead. In Manatee Pocket, muck accumulation has occurred for more than 100 years. However, only sediments deposited since 1950 are contaminated with mercury, lead, copper and cadmium.

The 1989 Muck study and the MUCKMAPS produced provide a first order presentation of the distribution of fine-grained, organic-rich sediments throughout the Indian River Lagoon. Fortunately, the spatial occurrence of muck deposits is limited at present. However, available data show these deposits to be contaminated with heavy metals and suggest that they adversely effect local water quality and seagrass habitats.

INTRODUCTION

Large inputs of fine-grained, organic-rich sediments to coastal estuaries are a growing global concern. These deposits, sometimes referred to as muck, are composed of fine-grained silts, clays and biogenic detritus. The biogenic fraction of the muck gives the sediment a black color and is an indicator of high plant productivity in the system, most often spurred by sewage nutrients and fertilizer runoff. In contrast, the silt/clay portion of the muck gives a measure of poor soil retention along the shoreline or in upland areas during construction, farming or other activities. Muck is not the natural bottom in many estuarine areas. Where present, it is readily resuspended, thereby increasing the turbidity of the water. Increased turbidity leads to decreased growth of seagrasses and loss of habitat. Organic-rich sediments also support massive bacterial activity which, in turn, promotes decomposition of organic matter and depletion of oxygen in sediments and sometimes in the overlying water. When the normal, perhaps sandy, sediment of an estuary is covered with muck, biological community structure can be completed altered. Furthermore, muck can serve as depository for a variety of potential pollutants.

Deposits of muck sediments have been identified in portions of the Indian River Lagoon, Florida (Trefry et al., 1987). The largest deposits were found in the creeks adjacent to the lagoon such as Crane Creek and Turkey Creek in the Melbourne area. In the lagoon proper, muck deposits were greatest in the deeper areas of the lagoon, including the Intracoastal Waterway, especially in proximity to tributary sources. The preliminary muck studies (Trefry et al., 1987) surveyed only a small portion of the entire lagoon. Thus, the primary goal of the present study was to complete a detailed reconnaissance of the Indian River Lagoon System from New Smyrna Beach to St. Lucie Inlet (Figure 1) identifying the spatial and vertical distribution of fine-grained, organic-rich sediments. A secondary goal was to identify any general differences in the composition of muck along the lagoon.

During 1989, 635 distinct sediment cores were collected from the lagoon along with a much larger number of direct observations of muck versus sand distribution in shallow water areas. From this data base we have been able to prepare a broad picture of muck sediment deposits in the Indian River Lagoon and to compare the composition and sources of these deposits throughout the system.

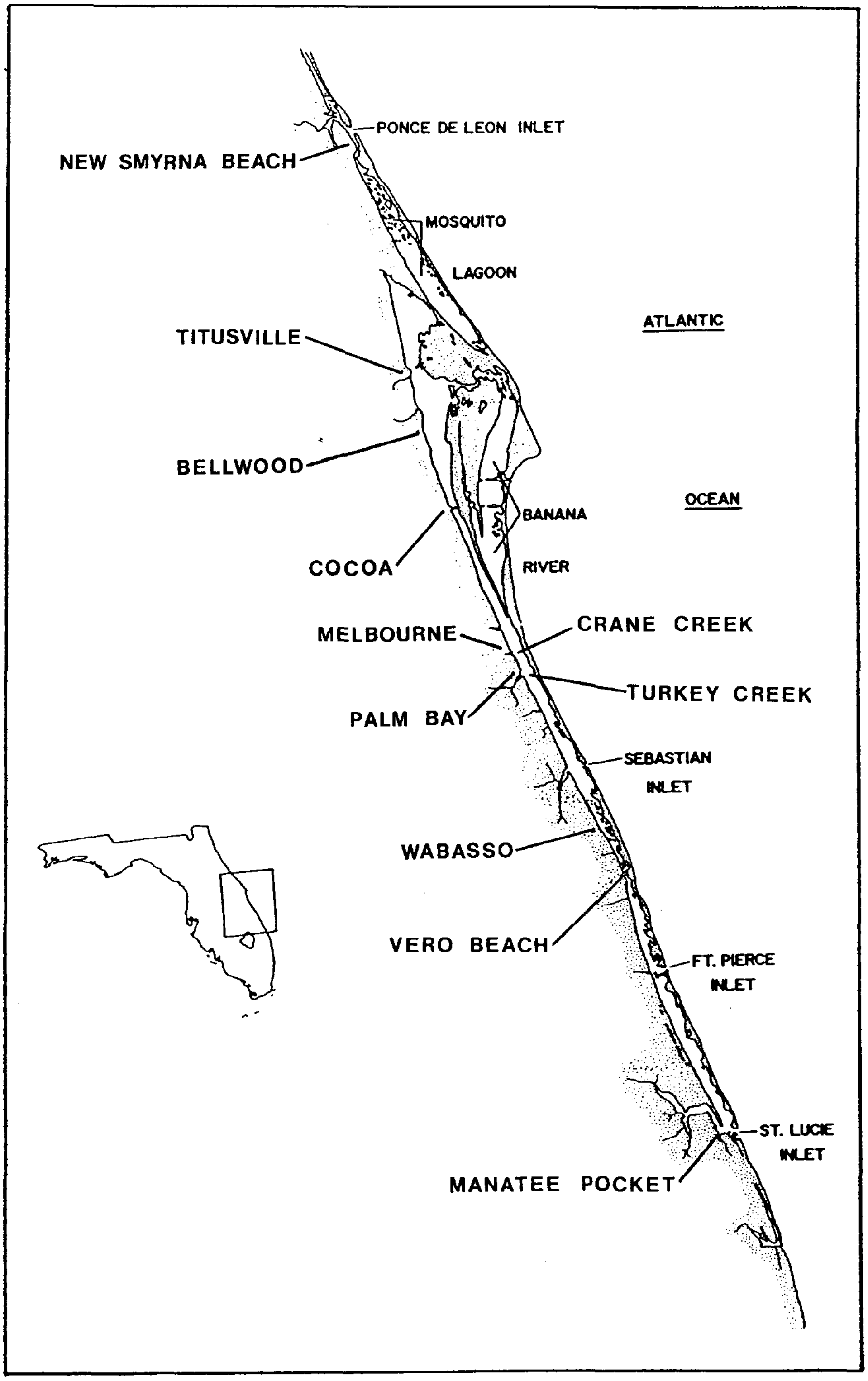


Figure 1. Map showing the Indian River Lagoon System on the east coast of Florida.

METHODS

Sampling

Most of the sediment samples for this study were collected using a hand-held corer, deployed from either the 20 m-long Research Vessel DELPHINUS or from a small boat. The coring device consisted of a 4-cm diameter polyvinyl chloride (PVC) tube connected to a second tube at the top to form a handle and an overall T-shape configuration. A one-way valve was fitted along the upper end of the main barrel of the system to help retain the sediment. Several lengths of PVC tubes were available to enable convenient sampling in water depths from less than 1 m to 6 m. A liner of cellulose-acetate-butyrate (CAB) was secured inside the PVC tube for each sample. Fortunately, a core catcher was not needed and we were able to obtain relatively undisturbed samples. The coring device was deployed by slowly easing it through the water and down into the sediment until hard bottom (sand/shell) was penetrated. The corer was then lifted back to the surface, retained in an upright position, and the liner was capped, removed and labelled. The overlying water was drawn from each core top while the sample was still in a vertical position. Samples were then stored for generally less than 1 hour before subsampling.

Subsectioning was carried out aboard the DELPHINUS by carefully extruding the core into a 3-m long PVC tray. Sediment lithology was described for each core, noting the presence of muck, sand, shell-hash, clay and other distinguishing features. During shipboard examination of these cores, a preliminary depth of the muck layer was assigned based on color and texture of the sediment. This field decision was later re-evaluated from laboratory analyses. Subsamples from key intervals throughout the core were placed in sealed plastic vials for return to the laboratory. At selected sites, large portions of the sand, shell hash, clay or muck were saved in plastic bags or glass jars.

At selected sites where a hard, sandy or gravelly sediment surface was encountered, samples were collected using a Smith-McIntyre grab sampler. Sub-cores from the grab were collected using a CAB tube. This sample was sub-sectioned in the same way as described above.

In addition to collecting samples, many observations of the composition of the floor of the lagoon were made by probing or by direct inspection from a small boat. These observations were noted as 'sand' or 'shell' or 'hard bottom' and provided the detail necessary to prepare the MUCKMAPS. Whenever a small boat encountered a fine-grained deposit, a sample was taken for laboratory analysis to confirm the presence of muck.

Laboratory Analyses

Sediment water content was determined based on samples placed in pre-weighed plastic vials. The samples were freeze-dried for 48 hours and reweighed to determine the mass of water lost. Previous experiments had shown us that % water values determined by freeze drying were the same as those obtained following heating at 105°C (Trefry, unpublished data).

Aliquots of the freeze-dried samples were then weighed into glass beakers and heated for at least 12 hours at 550°C to determine Loss On Ignition (LOI). The decrease in mass during high-temperature heating is the % LOI. This loss results primarily from combustion of organic matter, but also includes in some instances vaporization of tightly bound water in clays. The relationship between LOI and organic matter content is considered in the next section. The LOI values serve as a rapid, first cut identification of muck deposits.

Total organic carbon and nitrogen were determined on selected samples using a Carlo-Erba NA1500 nitrogen/carbon/sulfur analyzer. Ten-milligram samples of freeze-dried sediment were placed in silver cups, acidified with HCl to drive off the inorganic carbon and then dried under a heat lamp. The C and N content was then determined following combustion at 1000°C in the Carlo-Erba system. Analytical precision was determined from replicate analysis of selected samples. Accuracy was assessed by analyzing standardized estuarine sediment (MESS-1) provided by the National Research Council of Canada (NRC).

Concentrations of total Al and Si were determined by atomic absorption spectrophotometry (AAS) following complete digestion of the sediment in sealed tubes using a HNO_3-HF mixture. The sealed tube is required to avoid volatilization and loss of Si as SiF_4. The AAS analyses were carried out using a Perkin-Elmer Model 4000 instrument equipped with deuterium and tungsten background correction. A nitrous oxide-acetylene flame was used for analysis of both elements. Analysis of replicate lagoon samples and a standard reference material (SRM #1646, an estuarine sediment) issued by the National Institute of Standards and Technology (NIST) were included to obtain precision and accuracy, respectively.

The $CaCO_3$ content of selected samples was determined using the carbonate bomb technique of Schink et al. (1978). In this gasometric method, the pressure of CO_2 released from sediment carbonate following addition of 6 N HCl is measured. Pure $CaCO_3$ was used to standardize the method and determine accuracy. Precision was determined by analysis of replicates and was found to be consistently better than 5% ([standard deviation/mean] X 100%).

Sedimentation rates and age determinations were made using Pb-210 and Cs-137 geochronologies. The gamma activities of Pb-210 at 46.5 KeV and Cs-137 at 661.6 KeV were determined using a Princeton Gamma-Tech intrinsic germanium detector. Counting efficiencies and accuracy were determined by analyzing (1) SRM 4350B, a NIST sediment sample calibrated for environmental radioactivity and (2) muck samples from Manatee Pocket that were spiked with Pb-210 and Cs-137.

Table 1. Analytical results for Al, Si, organic carbon and organic nitrogen in standardized estuarine sediment (SRM No. 1646 and MESS-1). Standards were obtained from the National Institute of Standards and Technology (NIST) and the National Research Council of Canada (NRC), respectively.

Element	Standard	Certified Concentration	Experimental Concentration
Al	SRM 1646	6.25 ± 0.20 %	6.21 ± 0.07 % (N = 9)
Si	SRM 1646	31%	31.0 ± 0.3 % (N = 9)
C	MESS-1	2.99 ± 0.09	3.01 ± 0.05 % (N = 12)
N	MESS-1	Not available	0.20 ± 0.01 % (N = 12)

RESULTS AND DISCUSSION

What is Muck?

To identify the presence and thickness of muck deposits in the Indian River Lagoon, we first needed a working definition of muck. Our working definition of muck for this project, from Trefry et al. (1987), is as follows:

> "Muck is black, fine-grained sediment with a high water content, composed of partly decomposed organic matter and a considerable amount of admixed silt and clay material."

A set of boundaries can be established for each of the criteria listed in the definition. Muck from the Indian River Lagoon is black (Munsell soil chart color 5Y 3/2, Munsell Book of Color, Munsell Color Co., Inc., Baltimore, Maryland), has a water content greater than 50% of the total weight, contains greater than 10% of the dry weight as organic matter and greater than 60% of the dry weight as silt plus clay.

To carry on a broad-based survey, we used organic matter content as a key to the presence or absence of muck. Our goal was to do quick, simple measurements to identify muck in many samples. Loss on Ignition (LOI) is one of the easiest ways to determine organic matter content. Percent LOI and organic carbon show a good linear relationship for samples collected during the 1989 muck survey in the Indian River Lagoon (Figure 2). This relationship suggests that we can use values for LOI as a first cut means of identifying sediments. For this study, sediment with greater than 10% LOI were classified as muck.

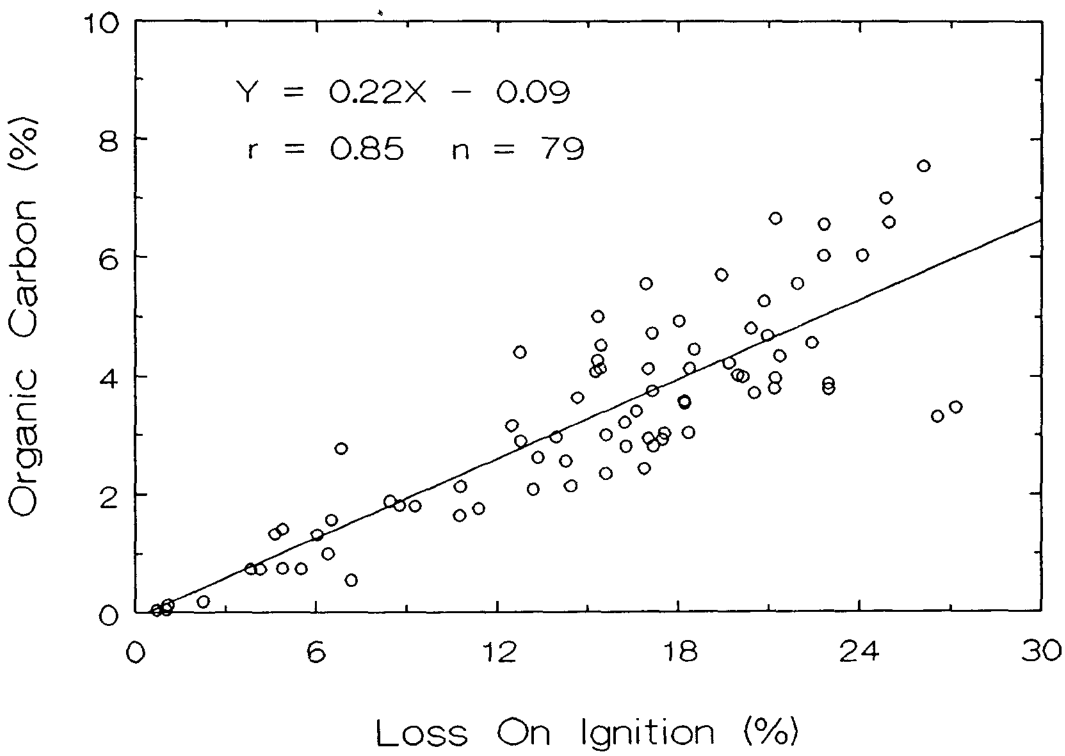


Figure 2. Scatter plot showing concentrations of organic carbon versus Loss On Ignition for sediments from the Indian River Lagoon.

Muck Sediment Distribution

Muck sediments are found throughout the Indian River Lagoon (IRL) to varying depths in the sediment column. The MUCKMAPS to be described show a region by region distribution of muck sediments throughout the lagoon (Figures 3-9). Actual sediment sampling sites are marked with solid circles. Selected station numbers are included to provide a point of reference. In addition to notations on the maps, a key to matching station numbers with locations is presented in Table 2. Overall, stations numbers increase from north to south; however, use of multiple vessels and retracing of some areas complicate numbering patterns in some areas. Numerous additional observations of surficial sediments were also made. When no muck layer was found, a sample was not collected and no number was assigned. Instead, the observations of 'no muck' were marked on a field map and incorporated into the final maps.

The regional muck distribution will be considered below. Our survey covered most of the lagoon and the trends presented show a reliable, general overview. However, in many areas the distribution of muck is patchy. Isolated occurrences of muck can be found in deep basins and at the mouths of small canals throughout the lagoon. Thin layers of flocculant material also may be found in seagrass beds. However, the substrate in seagrass bed is generally sand and we have not considered sea grass beds in any of the muck sediment areas identified.

In addition to the muck distribution maps, we have also created a series of histograms showing the thickness of muck layers for the numbered stations (Figures 10 and 11, pages 27 and 28). This data set is somewhat skewed to showing muck-bearing sites because more observations of 'no muck' at

Table 2. Station numbers and areas included on each of the MUCKMAPS (Figures 3-9) plus a legend for colors used on each map. Overall, stations numbers increase from north to south; however, use of multiple vessels and retracing of some areas complicates the number patterns in some regions.
NOTE: Duplication of station numbers results from overlap in the MUCKMAPS.

Figure	Station Numbers	Location
3	1 - 33	Indian River Lagoon from New Smyrna Beach through Mosquito Lagoon to Haulover Canal.
4	34 - 52; 55 - 62; 70 - 72; 75; 76	Indian River Lagoon from Turnbull Creek to Haulover Canal, north of Titusville.
5	34 - 61; 53 - 56; 61 - 68; 76 - 80; 82 - 206; 211; 292 - 342; 345; 349 - 351	Indian River Lagoon from Titusville through Cocoa to Palm Shores.
6	217 - 267; 269 - 289	Banana River Lagoon
7	342 - 344; 347; 348; 353 - 360; 363 - 404; 406 - 423; 425 - 466; 518 - 525; 527; 531; 532	Indian River Lagoon from Palm Shores to Sebastian Inlet.
8	526; 528 - 530; 533 - 623; 628 - 631; 635 - 640	Indian River Lagoon from Wabasso through Vero Beach to Fort Pierce.
9	624-627; 632-634; 640-700	Indian River Lagoon from Fort Pierce to St. Lucie Inlet.

<u>Legend for Colors on MUCKMAPS</u>

No color	<0.2 cm	**Orange**	10 - 30 cm
Green	0.2 - 5 cm	**Red**	>30 cm
Yellow	5 - 10 cm		

unnumbered sites were made than appear in Figures 10 and 11. Both the MUCKMAPS (Figures 3-9) and histograms (Figures 10 and 11) will be used to describe the regional distribution of muck sediments. The shaded areas denote the presence of muck and are often restricted in size or limited exclusively to the Intracoastal Waterway. This presentation is consistent with our observations. The color coding for the maps is as follows:

Legend for Colors on MUCKMAPS

No color	<0.2 cm	**Green**	0.2 - 5 cm	**Yellow**	5 - 10 cm
Orange	10 - 30 cm	**Red**	>30 cm		

New Smyrna Beach to Mosquito Lagoon (Figure 3)

No muck was found in this segment from the bridge in New Smyrna Beach (Station 1) to Oak Hill (Station 22), located in the northern end of Mosquito Lagoon (Figures 3 and 10). This portion of the lagoon is narrow, with Ponce Inlet situated just to the northern end of New Smyrna Beach. We speculate that good flow in this area either moves fine-grained sediment out of the inlet or pushes it south along the narrow channel into Mosquito Lagoon. During excursions to the east in this area towards station 13 and south to Turtle Mound we generally encountered sand and shell deposits.

The broad, shallow waters of Mosquito Lagoon are essentially free of muck sediment. Three patches of muck were found in the Intracoastal Waterway (Figures 3), mostly toward the northern end of Mosquito Lagoon. These deposits may result from southward transport of muck from Oak Hill and New

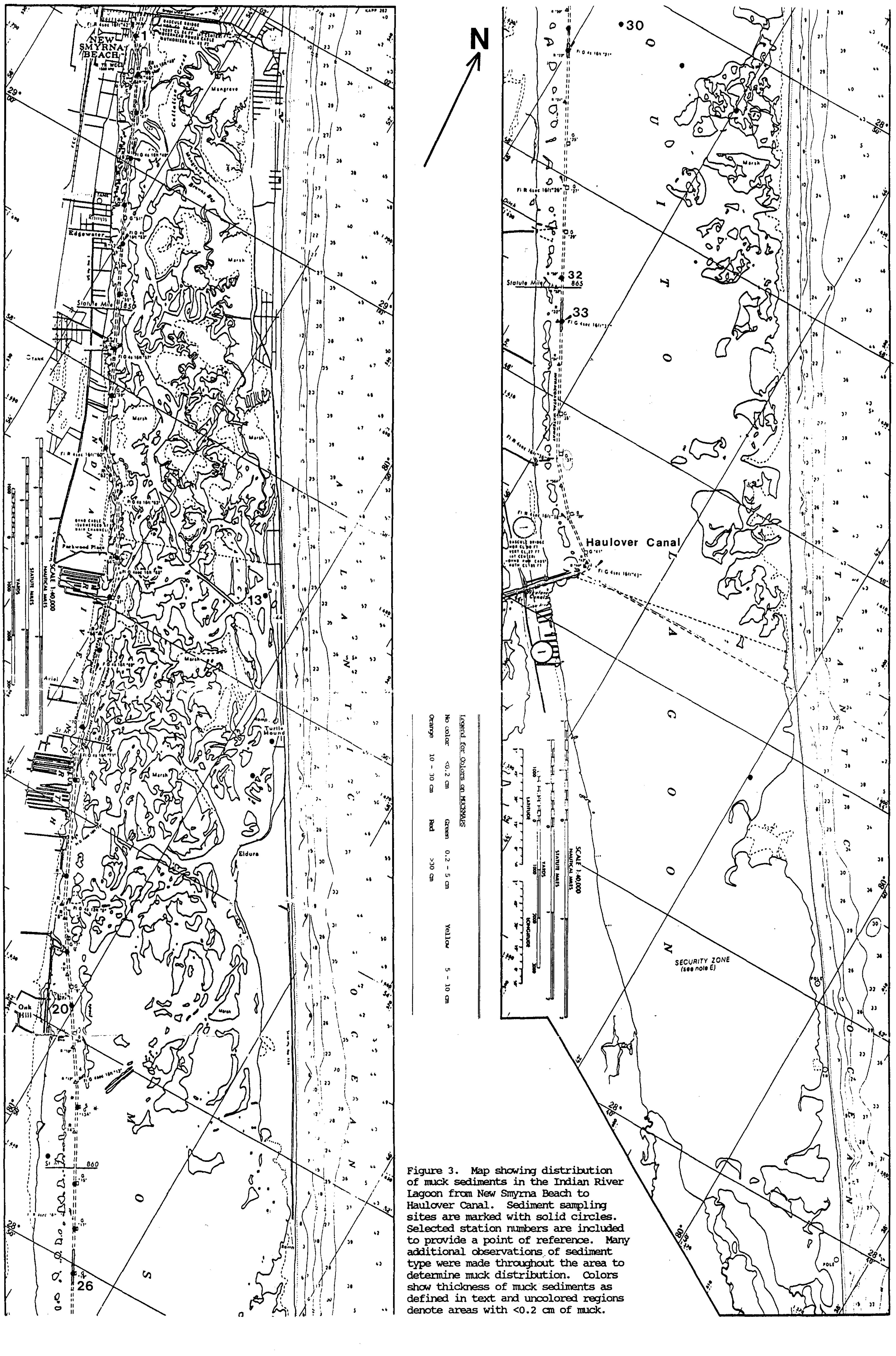


Figure 3. Map showing distribution of muck sediments in the Indian River Lagoon from New Smyrna Beach to Haulover Canal. Sediment sampling sites are marked with solid circles. Selected station numbers are included to provide a point of reference. Many additional observations of sediment type were made throughout the area to determine muck distribution. Colors show thickness of muck sediments as defined in text and uncolored regions denote areas with <0.2 cm of muck.

Smyrna Beach. No muck was found at the eastern end of Haulover Canal or in the canal itself.

Indian River Lagoon: Turnbull Creek to Haulover Canal, Titusville (Figure 4)

The northern portion of the Indian River Lagoon from Turnbull Creek to just north of Haulover Canal is characterized by sandy sediments with lush sea grass coverage (Figure 4). Even at the mouth of the creek (station 50), no muck deposits were found. A few pockets of finer-grained sediments were found along the west coast of this area; however, these minor deposits did not meet the criteria to be considered muck.

In contrast, the Intracoastal Waterway (ICW) just west of Haulover Canal is full o muck-capped sediment. The canal is quite shallow in several areas; however, ı uch of this is sand that has filled the channel and been covered with muck. Muck layers of 10-40 cm in thickness seem to be restricted to the channel, as confirmed by taking samples in and out of the channel at several locations. The channel serves as a trap for fine-grained sediment moving around this northern portion of the IRL.

Indian River Lagoon: Titusville through Cocoa to Palm Shores (Figure 5)

From Haulover Canal to Hwy 402 in Titusville, muck depths ranging from 10-30 cm (orange on Figure 5) and greater than 30 cm (red on Figure 5) are restricted to the ICW (e.g. stations 62, 63, 66 and 67, Figure 10). A marina located on the west shore, just north of Hwy 402, contained some muck (0.2-5 cm, green on Figure 5). No muck was found just north of Hwy 402 in Titusville (station 91) or in the channel north of the bridge. However, in the ICW south of Titusville, between Hwys 402 and 405 muck depths were generally greater

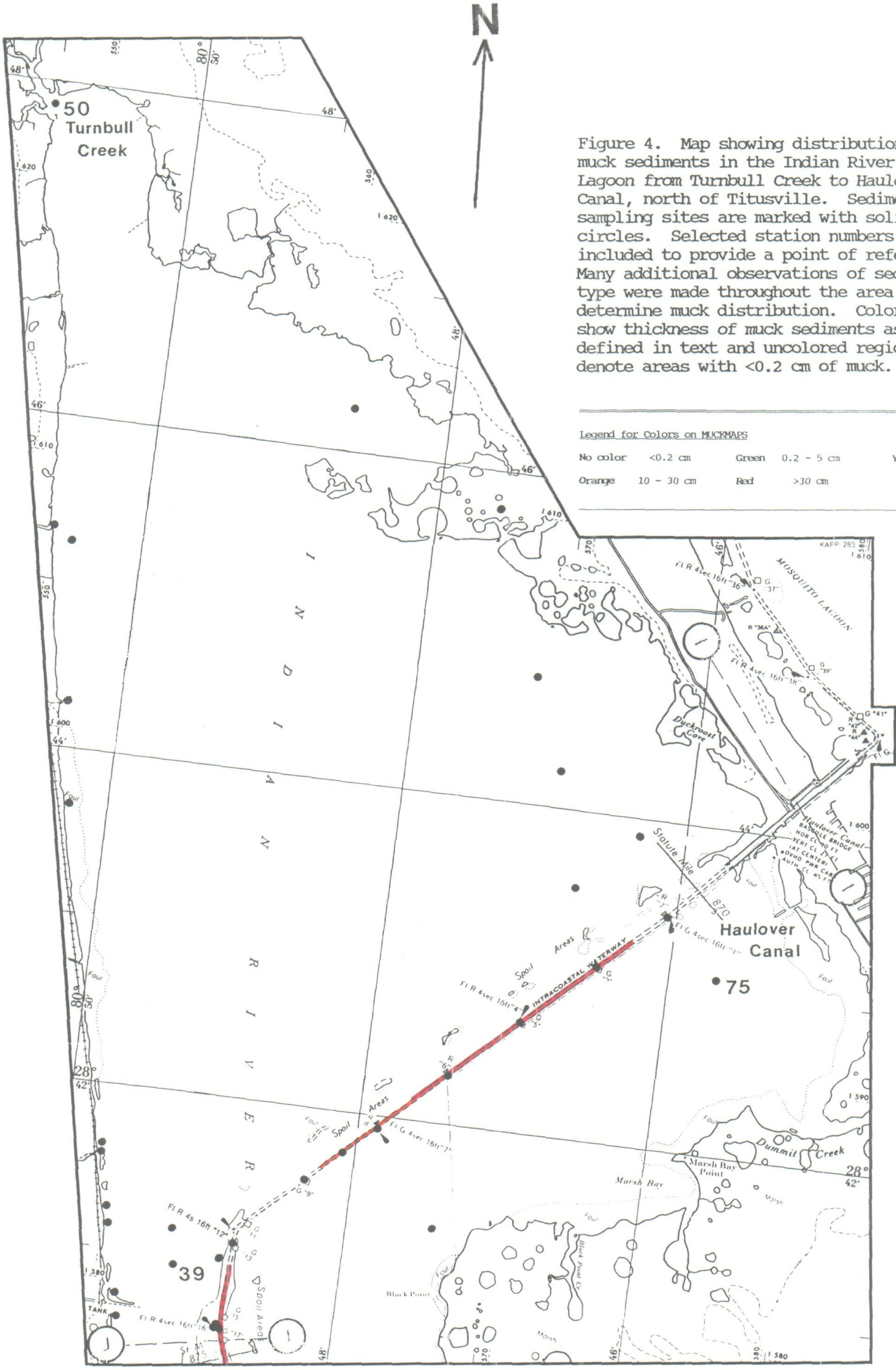
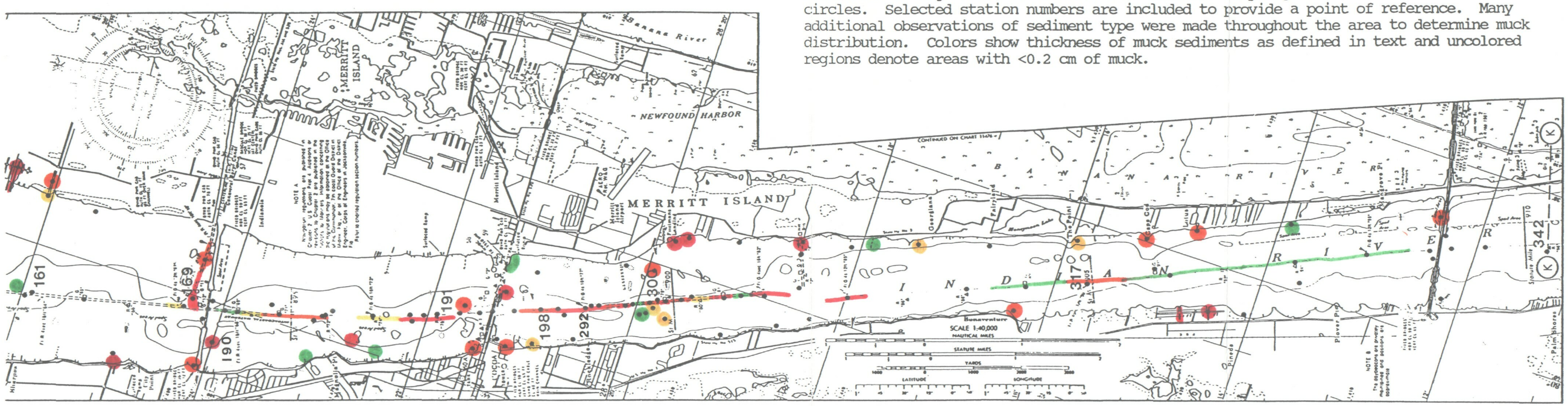


Figure 4. Map showing distribution of muck sediments in the Indian River Lagoon from Turnbull Creek to Haulover Canal, north of Titusville. Sediment sampling sites are marked with solid circles. Selected station numbers are included to provide a point of reference. Many additional observations of sediment type were made throughout the area to determine muck distribution. Colors show thickness of muck sediments as defined in text and uncolored regions denote areas with <0.2 cm of muck.

Legend for Colors on MUCKMAPS

No color	<0.2 cm	Green	0.2 - 5 cm	Yellow	5 - 10 cm
Orange	10 - 30 cm	Red	>30 cm		

Figure 5. Map showing distribution of muck sediments in the Indian River Lagoon from Titusville through Cocoa to Palm Shores. Sediment sampling sites are marked with solid circles. Selected station numbers are included to provide a point of reference. Many additional observations of sediment type were made throughout the area to determine muck distribution. Colors show thickness of muck sediments as defined in text and uncolored regions denote areas with <0.2 cm of muck.



Legend for Colors on MUCKMAPS

No color	<0.2 cm	Green	0.2 - 5 cm	Yellow	5 - 10 cm
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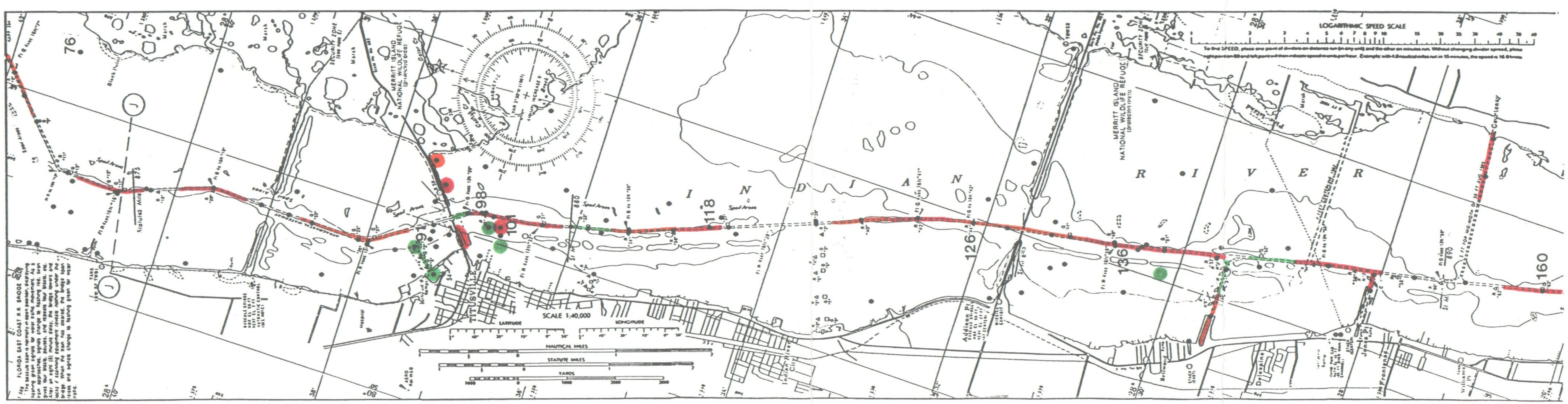


than 10 cm with greater than 40 cm at stations 98, 99 and 104 (Figure 10). Just south of the Hwy 402 bridge, muck sediments were also found outside the ICW; however, along most of the ICW in this area, the fine-grained, organic-rich sediment is confined to the channel.

The ICW, between Hwys 405 and 528, has several stretches with muck sediments greater than 10 cm. These appear to be linked with muck-bearing canals, especially those leading from a power plant on the west shore south of Bellwood, a channel from Courtenay on the east shore and from the Canaveral Barge Canal (station 169). The deeper channels are consistently key sites for muck deposition.

From Hwy 528 to 520, the ICW has variable amounts of muck ranging from 0.2-5 cm to greater than 30 cm. The deepest muck segment in the ICW are found just north of Hwy 520, near Cocoa. Various muck pockets were also found outside the channel in this section of the IRL, most notably a greater than 60-cm layer at station 190 (Figure 10) just south of Hwy 528 (Figure 5).

Continuing south of Hwy 520, muck depths in the ICW generally decrease from greater than 30 cm near Cocoa to less than 5 cm north of the Pineda Causeway. Muck deposits of 13 cm to greater than 60 cm (orange and red on Figure 5) south of Hwy 520 near Cocoa (stations 198, 201 and 202, Figure 10) most likely result from development in that area. This section of the lagoon is also characterized by abundant patches of muck deposits on both the east and west shore. Deposition of muck on the east shore may be influenced by the presence of cuspate spits. These spits, or sand ridges that project into the lagoon from the shoreline, are formed by currents. The region between two spits represents a low energy environment where fine-grained sediments can settle out. On the west shore, the presence of muck can be attributed to canals feeding into the lagoon (Pineda area) or fine-grained sediment being trapped behind a causeway such as that south of Hwy 520.

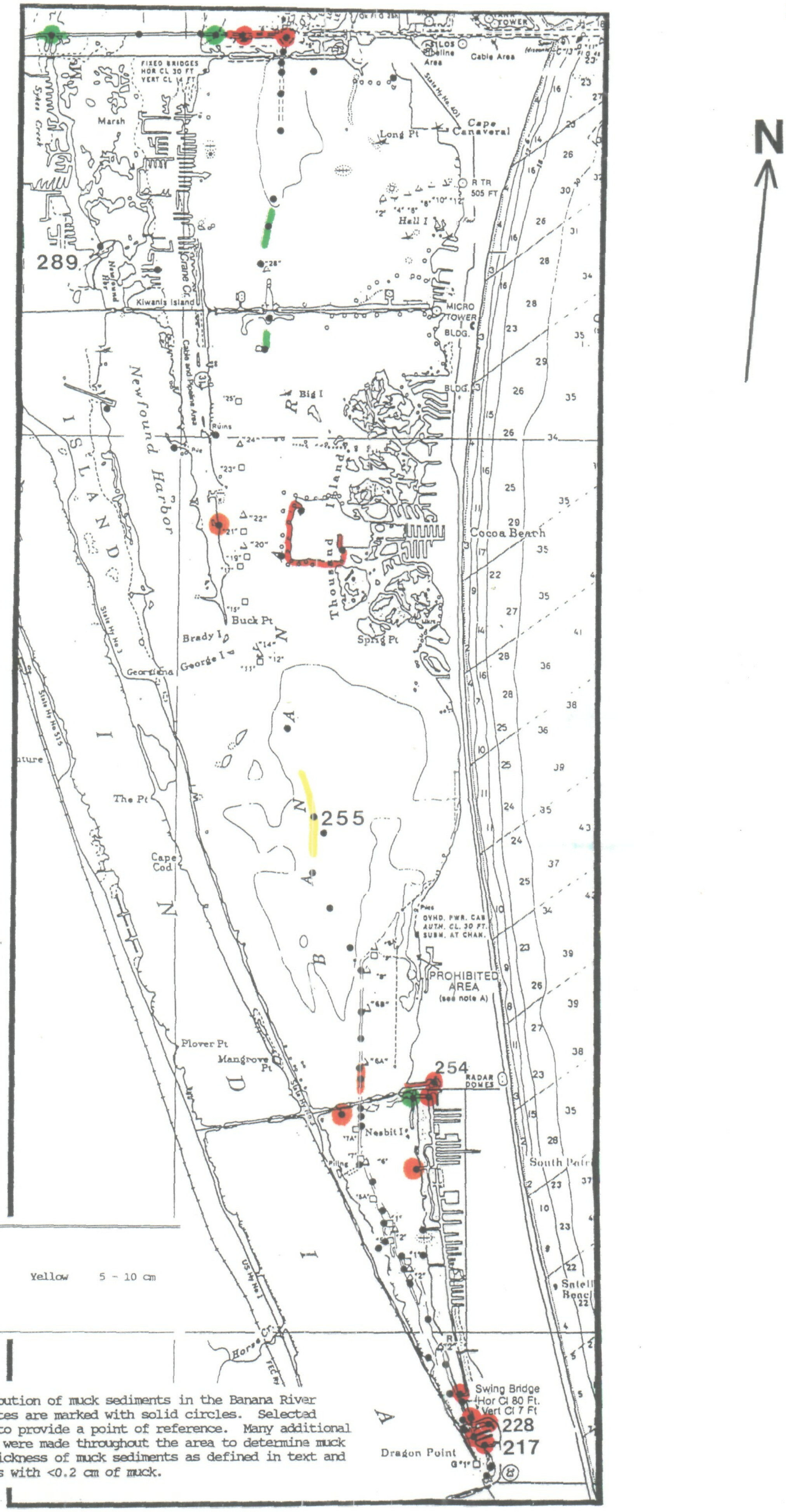
Banana River (Figure 6)

Muck deposits are thickest in the southern portion of the Banana River near its juncture with the IRL. In this area, muck depths greater than 30 cm are found in canals on the east shore such as the 83-cm thick layer of muck at station 217 (Figures 6 and 10). Canals both north and south of the Pineda Causeway also had thick deposits as did the entrance to the Canaveral Barge Canal from the Banana River and in the immediate periphery of Thousand Island. Muck deposits around these islands most likely are the result of fine-grained sediment transport from canals in the Cocoa Beach area. Canals in the Cocoa Beach area are located east of the Thousand Islands area. In the main channel of the Banana River, some small segments containing 0.2-30 cm of muck are found; however, most of the area is muck free.

Indian River Lagoon: Palm Shores to Sebastian Inlet (Figure 7)

The ICW from Palm Shores to the Eau Gallie Causeway contains a pocket with 10-30 cm of muck at station 342 and then one long segment with muck deposits less than 5 cm. Additional muck deposits are found in Horse Creek (less than 5 cm) and a marina in Sherwood Park (greater than 30 cm). The entrance to the Banana River in this segment of this IRL has less than 5 cm of muck except for a marina located just north of the causeway, which has sediments covered with 30 cm of muck. As described previously (Figure 6), the southernmost portion of the Banana River has a significant muck burden.

Muck covers almost the entire length of the ICW between the Eau Gallie



Legend for Colors on MUCKMAPS

No color	<0.2 cm	Green	0.2 - 5 cm	Yellow	5 - 10 cm
Orange	10 - 30 cm	Red	>30 cm		

Figure 6. Map showing distribution of muck sediments in the Banana River Lagoon. Sediment sampling sites are marked with solid circles. Selected station numbers are included to provide a point of reference. Many additional observations of sediment type were made throughout the area to determine muck distribution. Colors show thickness of muck sediments as defined in text and uncolored regions denote areas with <0.2 cm of muck.

Figure 7. Map showing distribution of muck sediments in the Indian River Lagoon from Palm Shores to Sebastian Inlet. Sediment sampling sites are marked with solid circles. Selected station numbers are included to provide a point of reference. Many additional observations of sediment type were made throughout the area to determine muck distribution. Colors show thickness of muck sediments as defined in text and uncolored regions denote areas with <0.2 cm of muck.

and Melbourne Causeways. Depths of muck in this area range from less than 5 cm (green on Figure 7) to greater than 30 cm (red on Figure 7) and extend outside the channel. Sources of muck found in the ICW include Eau Gallie Harbor (10-30 cm) and a marina located midway between the two causeways. On the eastern side of the ICW, south of the Eau Gallie Causeway (station 365), and again north of the Melbourne Causeway (station 355), more than 80 cm of muck were found (Figure 11), suggesting that fine-grained material is trapped around these effective "sand bars".

A large fraction of the ICW between Melbourne and Sebastian is covered with muck ranging in depth from less than 5 cm to greater than 30 cm. In addition, a few muck deposits were found on the eastern shore of the IRL, generally in low energy regimes between spits of land emerging from the shore. The ICW from Micco to Sebastian is covered with muck containing up to 60 cm at stations 448 and 519 (Figure 11). The most likely source for these inputs is Sebastian Creek, which was found to contain from 10 to well over 30 cm of muck near the mouth.

Indian River Lagoon: Wabasso through Vero Beach to Fort Pierce (Figure 8)

A segment of the ICW north of Wabasso had several areas with greater than 30 cm of muck. From Wabasso to Vero Beach, no muck was found in the ICW. On the east and west shores along this stretch of the IRL, only a few muck deposits were encountered. These deposits include Hobart Landing with 10-30 cm of muck (orange on Figure 8), the marina and bridge located north of Wabasso with greater than 30 cm of muck (red on Figure 8) and the southern extreme of Johns Island Creek.

In contrast to the area north of Vero Beach, about 75% of the ICW between

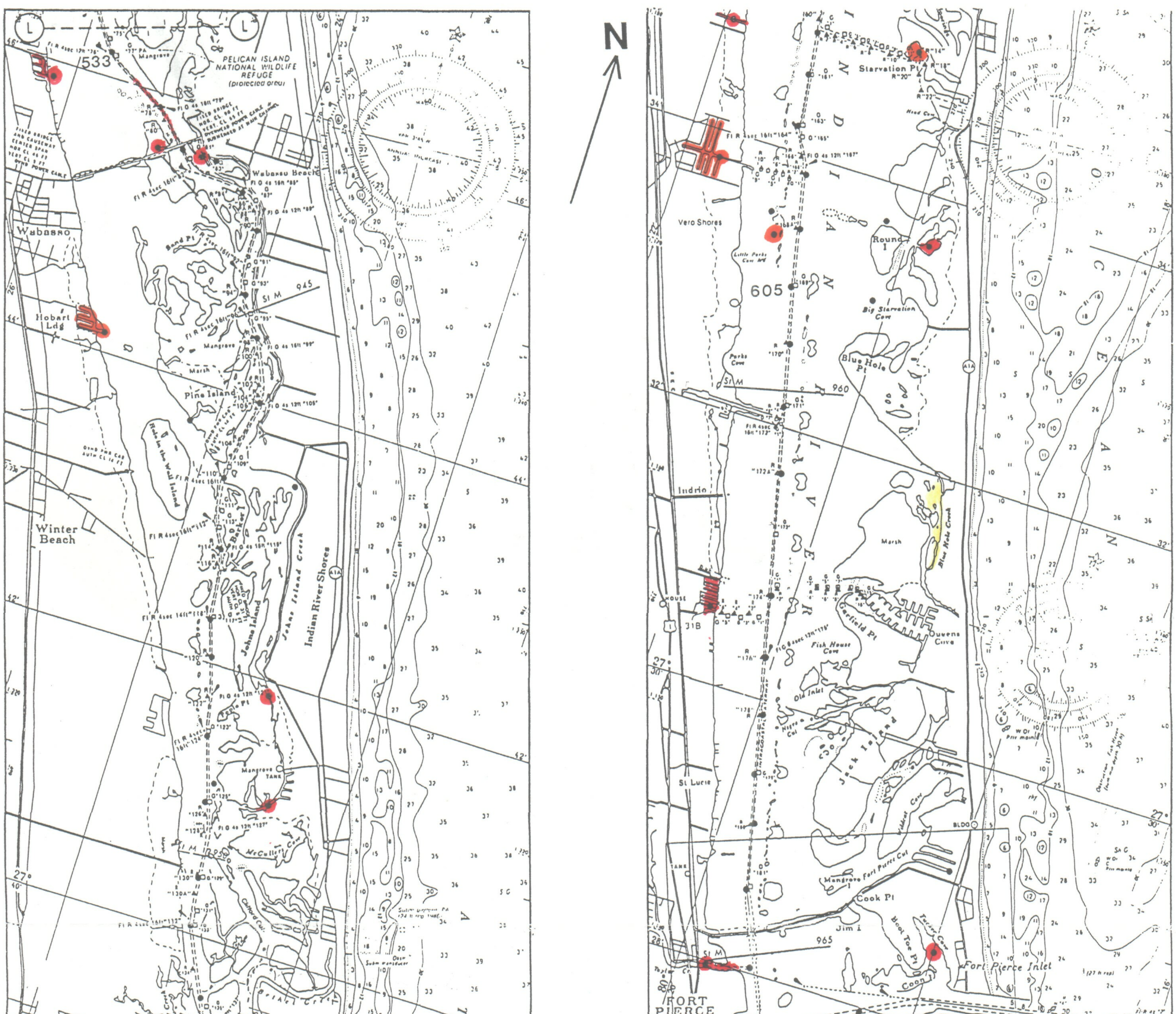


Figure 8. Map showing distribution of muck sediments in the Indian River Lagoon from Wabasso through Vero Beach to Fort Pierce. Sediment sampling sites are marked with solid circles. Selected station numbers are included to provide a point of reference. Many additional observations of sediment type were made throughout the area to determine muck distribution. Colors show thickness of muck sediments as defined in text and uncolored regions denote areas with <0.2 cm of muck.

Vero Beach and Crawford Point contains 10 to greater than 100 cm of muck (Figure 11, stations 554-595). Once again, the increase in muck deposition in this region is most likely related to development, this time in Vero Beach. Canals located on both the east and west shore of the IRL between Vero Beach and Fort Pierce are characterized by deposits containing 10-30 cm (orange on Figure 8) and greater than 30 cm (red on Figure 8) of muck. Additional muck sediments in this segment of the IRL were found in Riomar (greater than 30 cm), Dark Point (59.5 cm, station 574), Prang Island and Porpoise Point (greater than 40 cm, stations 575-576), Starvation Point (10-30 cm), east of Round Island (64.5 cm, station 597) and Blue Hole Creek (5-10 cm).

At Fort Pierce, muck deposition is limited to Taylor Creek and Tucker Cove (greater than 30 cm muck) and a small area north of Causeway Island (less than 5 cm). Overall, no muck deposits were recorded in the ICW from Crawford Point, located just south of Vero Beach to Middle Point, south of Fort Pierce. Active water flow in the area of Fort Pierce Inlet plays an important role in the limited muck deposits found in the immediate area of Fort Pierce.

Indian River Lagoon: Fort Pierce to St. Lucie Inlet (Figure 9)

In the ICW between Fort Pierce and St. Lucie Inlet, four patches with greater than 10 cm of muck and one patch with less than 5 cm were found. On the west shore, sediment capped with muck ranging from 10 to more than 30 cm are restricted to canals and marinas. In contrast, on the east shore of the IRL, muck is introduced to the lagoon via both the Little Mud and Big Mud Creeks (station 651, Figure 11). The presence of cuspate spits on Hutchinson Island that create various coves also appear to trap muck. Examples of this process are found in Joe's Cove and east of Nettles Island. The Bascule

Legend for Colors on MUCKMAPS

No color	<0.2 cm	Green	0.2 - 5 cm	Yellow	5 - 10 cm
Orange	10 - 30 cm	Red	>30 cm		

Figure 9. Map showing distribution of muck sediments in the Indian River Lagoon from Fort Pierce to St. Lucie Inlet. Sediment sampling sites are marked with solid circles. Selected station numbers are included to provide a point of reference. Many additional observations of sediment type were made throughout the area to determine muck distribution. Colors show thickness of muck sediments as defined in text and uncolored regions denote areas with <0.2 cm of muck.

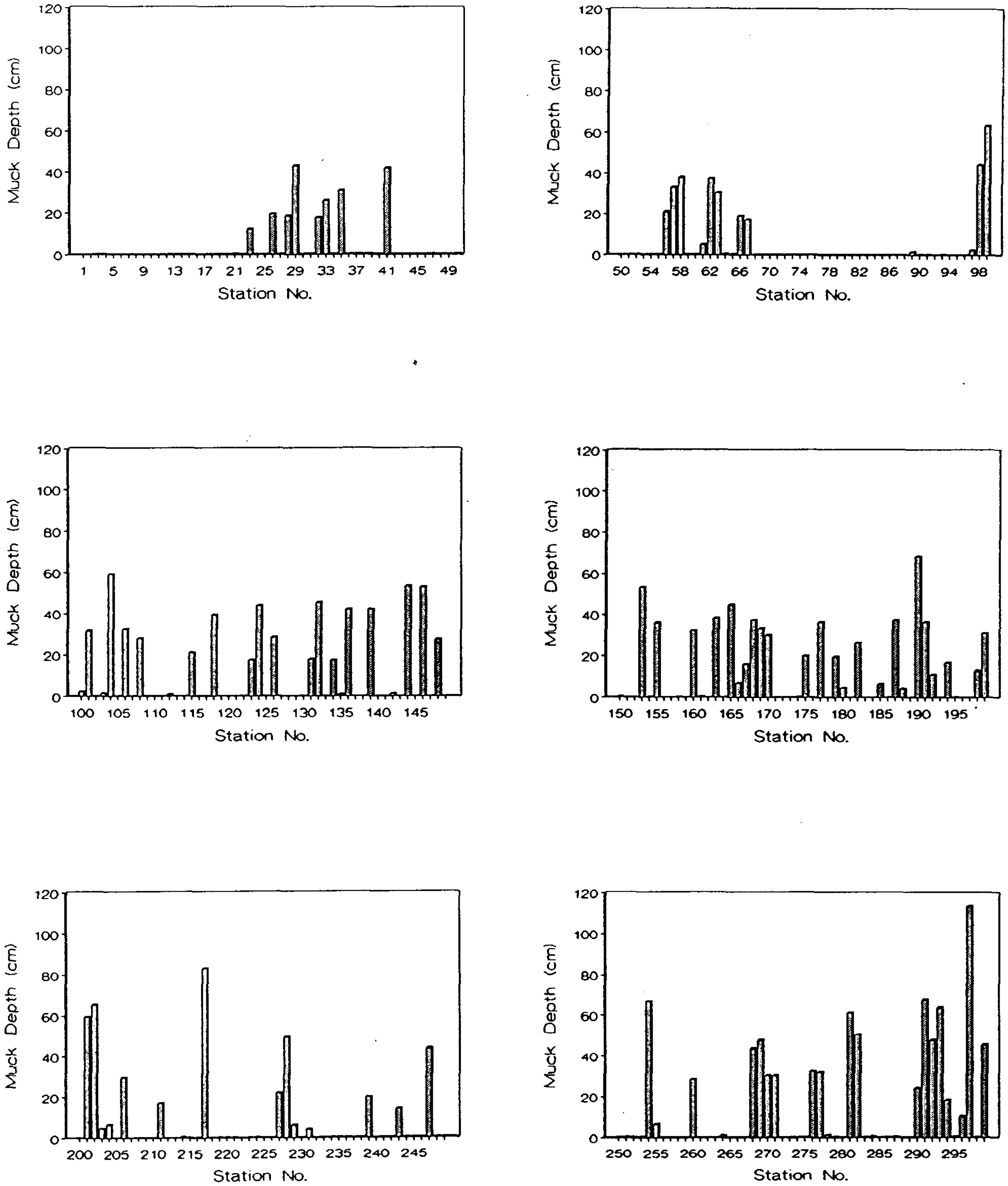


Figure 10. Muck sediment thicknesses for stations 1 to 299.

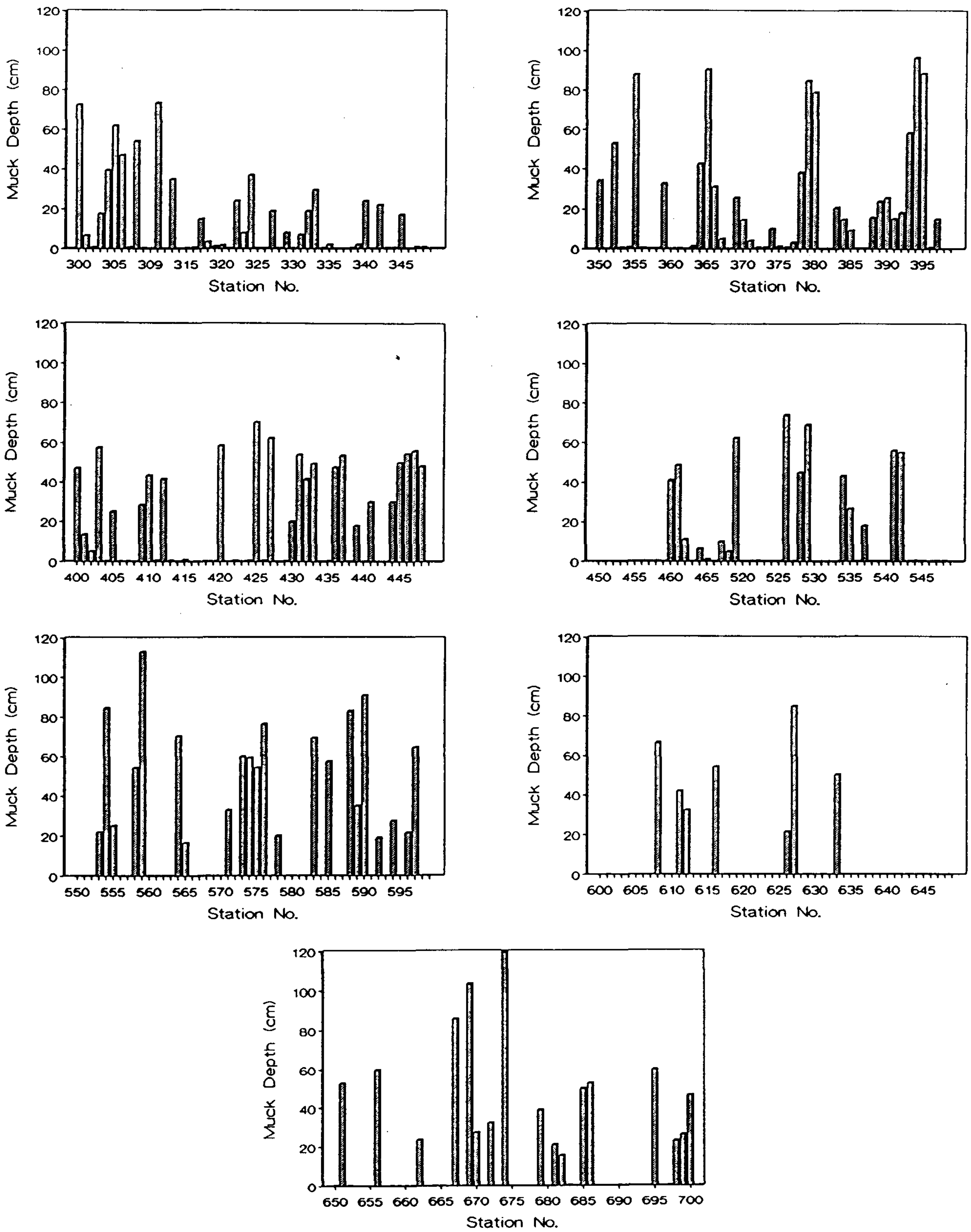


Figure 11. Muck sediment thicknesses for stations 300 to 700.

Bridge forms a barrier north of Jensen Beach and has trapped more than 100 cm of muck on the north and south sides (stations 669 and 674, Figure 11). No obvious link between muck in canals and creeks and that found in the ICW is apparent in this stretch of the lagoon.

Manatee Pocket

In addition to the main portions of the Indian River Lagoon, we focused on Manatee Pocket, an off-lagoon creek, to identify the potential muck reservoir that these systems may represent. Fine-grained, organic-rich, muck-like sediments were found virtually throughout Manatee Pocket (Figure 12). The shape and bathymetry of the pocket effectively traps much of the fine-grained material carried into it by the numerous creeks and canals. Muck depths for the 21 sites in the pocket averaged 84 cm with a range of less than 0.2 cm to 198 cm. The largest muck deposits were generally found in the center of the pocket at deeper water depths where settling and deposition are more favored. No muck was found in the area immediately outside Manatee Pocket in the St. Lucie Estuary.

Sufficient data were collected during a companion project (Trefry et al., 1990) to estimate the total muck burden of Manatee Pocket. To do this we divided Manatee Pocket into 63 blocks, where full blocks were 1 in^2 on a map with 1 inch = 250 feet. The muck thickness data from our work and that of McNulty and McNulty (1987) were used to determine muck depths in each block, or subsections within a block (Trefry et al., 1990). The muck depths were then multiplied by the appropriate area to calculate a muck volume for each block. The total volume of wet muck for Manatee Pocket is 340,000 m^3. This is a similar volume to the 270,000 m^3 of muck estimated for the Hillsborough

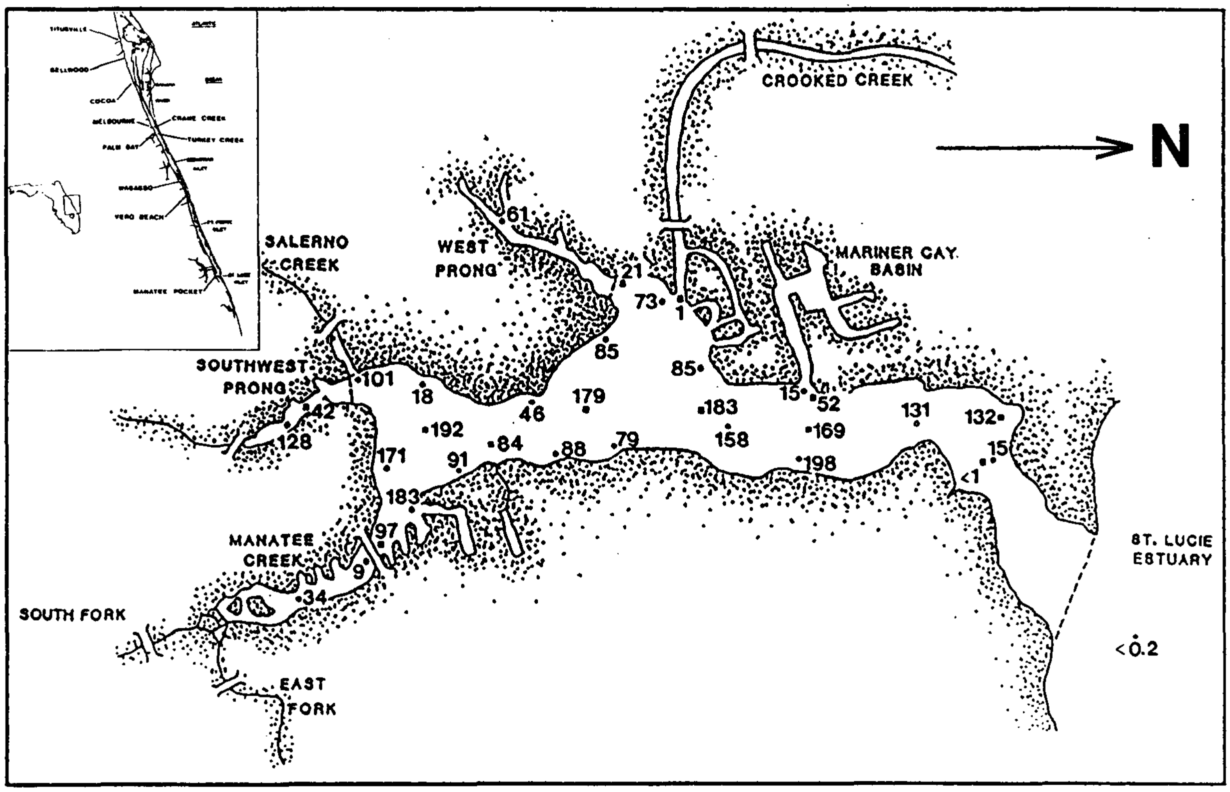


Figure 12. Map of Manatee Pocket showing muck depths in centimeters with inset map showing location of Manatee Pocket along southeast coast of Florida.

River and adjacent river mouth basin in Tampa, Florida (Trefry et al., 1989). The muck (plus admixed layers) averages about 60% water by weight or 80% water by volume. Therefore the volume of dry sediment is estimated at 68,000 m^3.

Even a cursory review of the MUCKMAPS (Figures 3-9) shows that less than 10% of the Indian River Lagoon is presently coated with fine-grained, organic-rich sediments. The primary sources of fine-grained sediment are from erosion of upland soils, as demonstrated for Turkey Creek (Trefry et al., 1989). As a result, much of the muck being carried toward the Indian River Lagoon is still trapped in the creeks and tributaries of the lagoon. The muck burden of Manatee Pocket alone is very large.

Within the IRL, the ICW is a primary depositional site. This occurs because it is deeper than the adjacent lagoon waters and thus particles are somewhat less likely to be transported elsewhere. In contrast to the lagoon overall, we estimate that 40% of the ICW contains muck. Finally, the occurrence of muck is clearly greatest in the area from Titusville to Palm Bay and around Vero Beach where development has been most extensive and where water movement and flushing are most restricted. Patchy deposition of muck in other areas is directly related to localized activity.

Muck Sediment Composition

In addition to mapping the distribution of muck sediments in the Indian River Lagoon, we also are interested in knowing (1) whether differences in muck composition occur from site to site along the Indian River Lagoon and (2) whether differences in muck composition can be used to show variations in organic matter and soil inputs to the lagoon. The following four components make up the bulk of the sediment in the Indian River Lagoon: (1) clays and other aluminosilicates, (2) organic matter, (3) quartz sand and (4) calcium carbonate. Of course, a whole spectrum of variations in the mix of these components is observed. When clays and organic matter dominate a sediment sample, the deposit takes on a muck-like quality. According to our operational definition, muck is greater than 50% water by weight, with more than 10% of the dry weight as organic matter and more than 60% of the dry weight as silt plus clay.

Sediment composition has been determined for selected sites throughout the IRL. Our goal in this effort was to study a representative subset of samples that traversed the entire lagoon and show compositional differences among different muck deposits and, to a lesser degree, among non-muck sediments. Percent Loss on Ignition data (Figure 13) provide an initial screening mechanism. About 60% of the stations identified in Figure 13 have % LOI values above 10% and thus we classified them as muck. As shown in Figure 2 (page 11), % LOI is positively correlated with organic carbon. Very low % LOI values for sites 1-20 and selected other locations throughout the lagoon, provide a useful contrast of muck versus non-muck sediments.

Figure 14 shows the Loss on Ignition and organic carbon data and Table 3 lists the organic carbon values for key sites along the Indian River Lagoon.

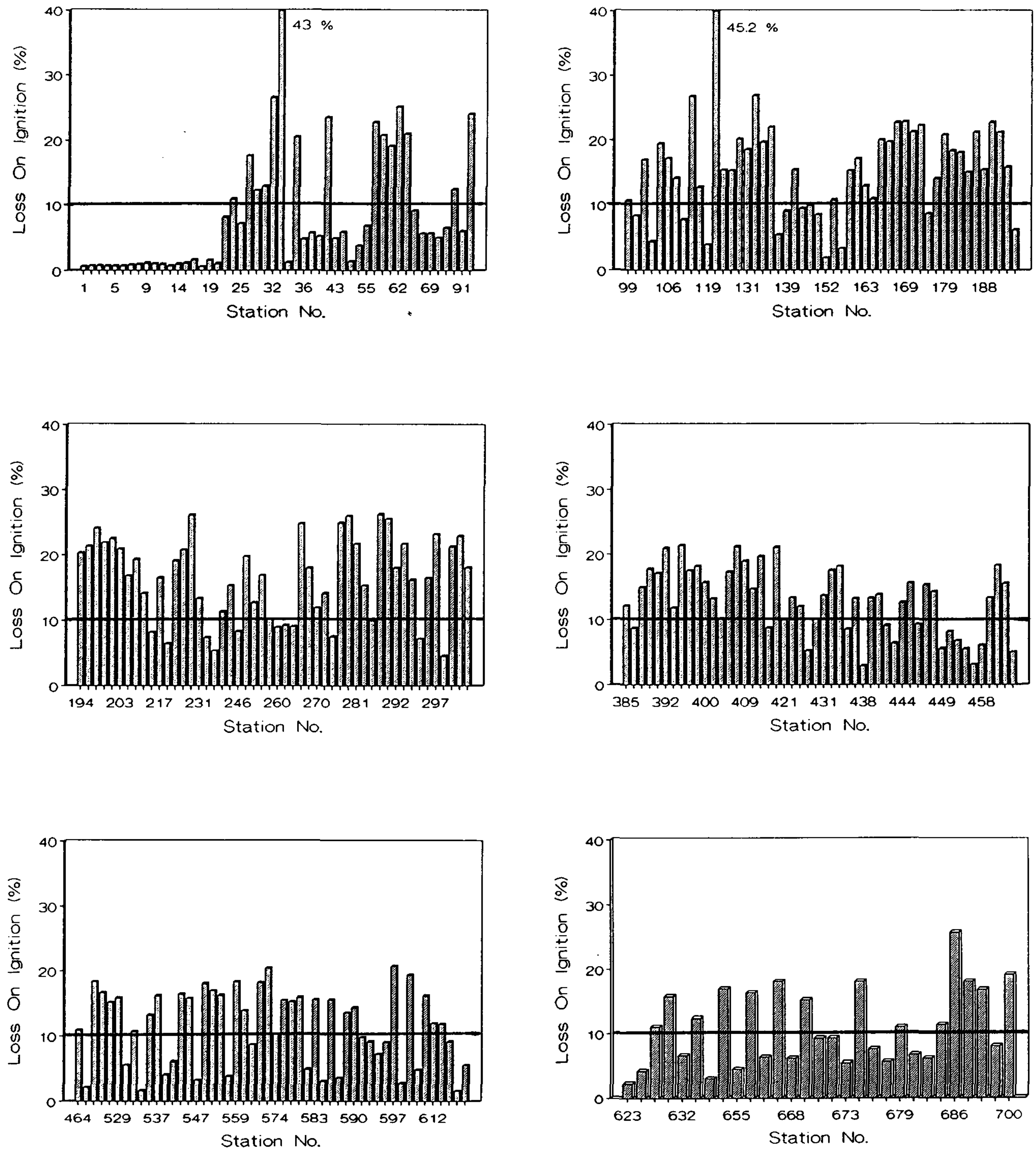


Figure 13. Histograms showing percent Loss on Ignition (LOI) in Indian River Lagoon sediments from stations 1-700. Solid line identifies 10% LOI. Sediments with greater than 10% LOI are characterized as muck.

The two parameters mirror one another well and show that the most organic-rich deposits are in the Cocoa area (stations 169, 191, 198, 300 and 317; Figures 14 and 5, Table 3) as well as near Melbourne and Palm Bay (stations 350, 364 and 412; Figures 14 and 7, Table 3). These sites have well over 20% LOI and more than 4% organic carbon and thus are generally more organic rich than other muck deposits to the north or south. This mid-portion of the lagoon is the most highly developed and least well flushed. Numerous causeways also help to restrict water flow and trap muck sediments.

Nutrient inputs from sewage runoff in the Cocoa and Melbourne areas were high for many years prior to recent reductions in discharge of treated sewage. The abundant organic matter in these sediments promotes large-scale bacterial activity and leads to production of hydrogen sulfide, ammonia, dissolved phosphate and methane in the sediment interstitial water (Gu et al., 1987). These chemical regeneration processes are most active in organic-rich muck sediments.

In contrast, the organic carbon content is below 1% in sandy sediments south of New Smyrna Beach (stations 1-30), near Sebastian Inlet and south toward Wabasso (e.g. station 533, Table 3 and Figure 8), in the Fort Pierce Inlet area (station 623, Table 3 and Figure 8) and near St. Lucie Inlet. Each of these areas is well flushed with little fine-grained sediment. Montgomery et al. (1983) showed that interstitial water levels and release of nitrogen and phosphorus from sandy sediments in seagrass beds was low relative to the muck sediments described above.

Organic nitrogen concentrations follow the same spatial trends observed for organic carbon, with high values in the mid-lagoon areas around Cocoa Beach and Melbourne and low values in the sandy sediments north of Mosquito

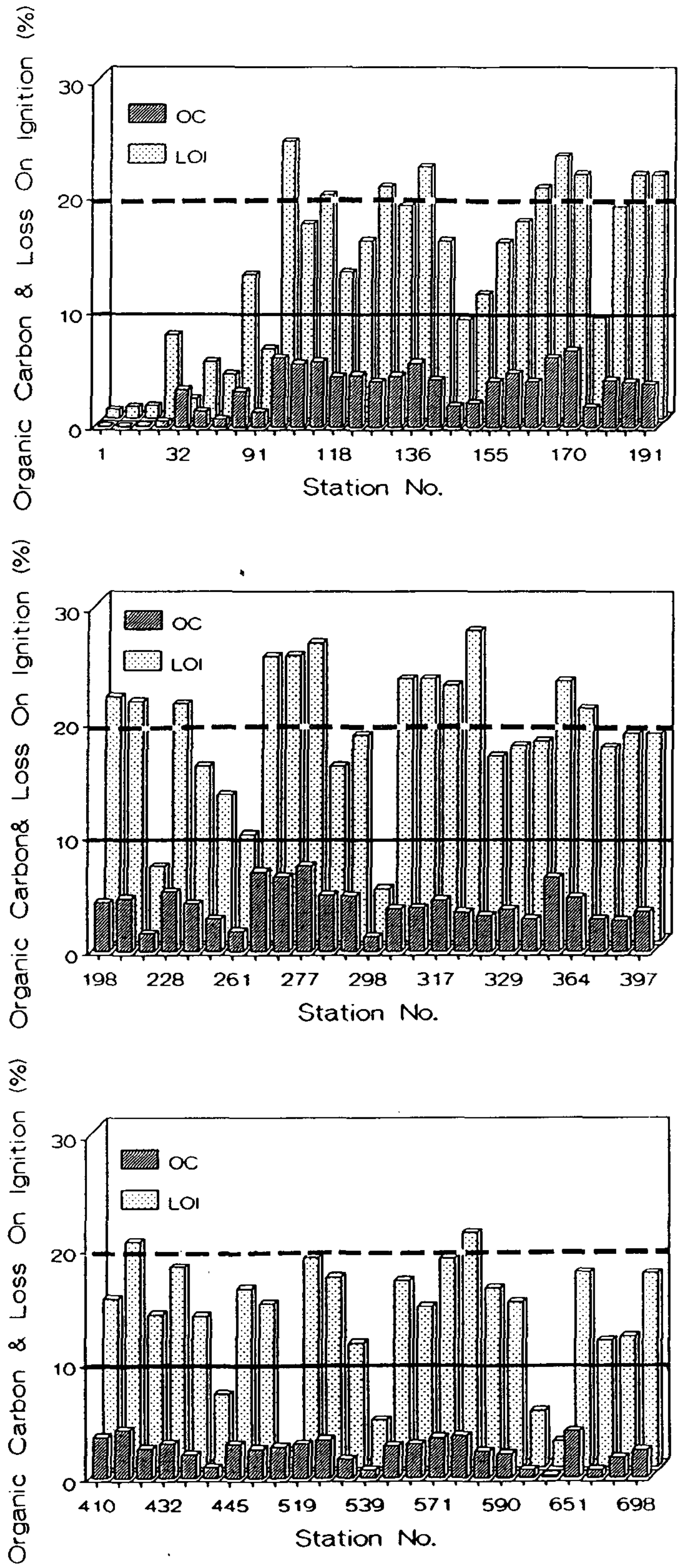


Figure 14. Histograms showing percent organic carbon and Loss On Ignition (LOI) in sediments from selected stations in the Indian River Lagoon. Solid line identifies 10% LOI, the minimum level for muck sediments. The dashed line identifies 20% LOI for very organic-rich sediments.

Table 3. Concentrations of Al, Si, organic C, organic N, $CaCO_3$ and the organic C/N ratio for selected samples from the Indian River Lagoon.

Station No.	Al	Si	$CaCO_3$	C	N	C/N
	(%)					
1	0.61	23.50	0.6	0.04	<0.01	8.20
8	0.47	24.90	0.7	0.05	<0.01	9.60
20	0.37	20.92	13.2	0.13	0.03	3.82
25	1.90	20.56	51.9	0.54	0.14	3.86
32	3.68	24.21	8.0	3.31	0.43	7.70
43	1.15	24.83	0.3	1.41	0.17	8.29
54	1.07	22.31	19.6	0.73	0.07	10.00
89	4.16	22.49	8.1	3.16	0.33	9.58
91	1.50	24.35	--	1.32	0.17	7.76
98	4.32	17.59	12.6	6.03	0.69	8.74
101	3.53	19.17	19.4	5.55	0.73	7.60
104	2.31	17.38	33.4	5.70	0.68	8.38
118	2.17	22.38	11.0	4.40	0.62	7.10
123	2.63	21.72	12.0	4.52	0.60	7.53
126	4.02	16.91	32.9	3.99	0.45	8.87
131	2.95	21.14	22.8	4.45	0.57	7.81
136	3.96	15.73	28.7	5.56	0.57	9.75
144	2.84	17.90	21.1	4.12	0.53	7.77
149	1.80	18.08	32.0	1.88	0.22	8.54
153	2.45	18.20	32.4	2.13	0.21	10.14
155	3.91	17.36	22.9	4.07	0.45	9.04
160	4.18	15.62	14.5	4.72	0.52	9.08
166	4.06	19.23	22.1	4.02	0.46	8.74
169	4.85	16.93	13.7	6.02	0.61	9.87
170	5.05	17.40	7.2	6.64	0.73	9.10
176	1.87	20.80	34.2	1.81	0.21	8.62
180	3.90	17.53	24.2	4.13	0.48	8.60
187	4.47	16.73	17.7	3.97	0.46	8.63
191	4.11	15.76	31.7	3.79	0.44	8.61
198	4.28	16.54	13.3	4.34	0.45	9.64
203	3.83	16.46	19.7	4.68	0.50	9.36
222	1.29	16.11	36.3	1.57	0.20	7.85
228	3.76	16.90	2.5	5.26	0.56	9.39
243	2.92	19.21	13.7	4.26	0.45	9.47
253	2.10	12.56	38.0	2.90	0.33	8.79
261	1.88	24.29	11.6	1.80	0.21	8.57
268	4.18	14.83	11.2	6.99	0.87	8.03
276	4.02	15.98	13.1	6.58	0.79	8.33
277	4.55	15.71	8.9	7.54	0.88	8.57

Table 3. (Continued)

Station No.	Al	Si	$CaCO_3$	C	N	C/N
	(%)					
282	2.10	22.43	12.0	5.00	0.51	9.80
292	3.38	13.22	42.1	4.93	0.35	14.09
298	1.16	18.29	1.0	1.33	0.14	9.50
300	4.09	15.26	37.7	3.78	0.41	9.22
306	2.89	15.28	21.6	3.87	0.46	8.41
317	2.72	17.03	16.8	4.56	0.53	8.60
320	2.29	12.37	--	3.47	0.42	8.26
323	2.25	21.02	22.7	3.21	0.40	8.02
329	3.00	23.91	12.8	3.74	0.46	8.13
342	2.53	21.16	30.7	2.93	0.36	8.14
350	4.00	15.61	5.0	6.55	0.66	9.92
364	2.45	19.13	5.2	4.80	0.58	8.28
374	1.79	17.95	28.8	2.94	0.39	7.54
397	2.36	20.56	12.0	3.58	0.45	7.96
410	3.32	16.32	25.4	3.63	0.47	7.72
412	2.56	18.46	3.0	4.22	0.54	7.82
425	2.72	25.41	8.9	2.62	0.36	7.28
432	2.62	21.53	12.4	3.03	0.41	7.39
437	2.52	26.04	6.5	2.08	0.28	7.43
443	1.13	26.92	17.3	0.99	0.16	6.19
445	2.17	20.52	10.9	3.00	0.40	7.50
448	2.74	23.51	8.3	2.56	0.36	7.11
519	4.44	18.65	1.3	3.04	0.41	7.42
526	2.82	21.73	8.6	3.40	0.42	8.10
533	1.98	24.76	15.3	1.64	0.22	7.46
539	2.28	37.87	5.8	0.73	0.10	7.30
555	3.93	22.01	11.6	2.81	0.36	7.81
564	3.46	25.96	8.4	2.97	0.36	8.25
571	3.23	19.35	11.9	3.54	0.45	7.87
573	3.40	18.47	13.4	3.71	0.50	7.42
585	3.49	22.58	14.0	2.35	0.31	7.58
590	2.97	23.65	14.4	2.14	0.30	7.13
610	2.31	31.75	12.7	0.74	0.11	6.73
623	1.00	29.90	22.9	0.19	0.05	3.96
651	3.92	21.20	7.3	4.12	0.61	6.75
673	1.28	27.28	14.1	0.73	0.11	6.64
685	2.30	25.82	16.8	1.76	0.21	8.38
698	2.16	19.46	18.1	2.43	0.28	8.68

Lagoon, near the various inlets, and south of Fort Pierce (Figure 15). The sediment nitrogen values covary well with organic carbon concentrations ($r^2 = 0.96$) throughout the IRL. The overall C/N ratio is 8.4 ± 1.1 (Figure 16). This value is slightly higher than C/N values of about 6 for plankton and suggests that significant N release has occurred in muck sediments, leaving them more C-rich and N-poor than the starting organic matter. Muck sediments are clearly a major reservoir for nitrogen in the Indian River Lagoon.

Our focus in this section until now has been on organic matter in the sediments. However, most of the sediment components in the IRL are inorganic aluminosilicates (clays), silicates (quartz) and carbonates (Table 3). The Al content of the selected IRL sediments varied from 0.37 to 5.05% with an average of 2.8 ± 1.1%. These sediment Al concentrations are lower than reported values of 8.2% Al for average continental crust (Taylor, 1967). Higher Al values (above 4%) are found in the central portion of the lagoon from station 160, north of Cocoa, through station 350 in the Melbourne area (Figure 17). The upland soils in this region contain higher levels of aluminosilicates (D'Arcy, 1987) and have been heavily eroded by development. In our previous muck study (Trefry et al., 1987), we found as much as 6% Al in muck sediments south of the Melbourne Causeway. During a year-long study of sediment transport from Turkey Creek to the IRL (Trefry et al., 1989), we observed that the Al content of suspended sediment ranged from 3-5% during non-storm flow and increased to 7-9% during runoff from large storms. An increase in the aluminosilicate content of the suspended matter during storm flow results from erosion of sub-surface soils which have a much lower organic matter component. The muck sediments in the Melbourne area represent a mixture of non-storm and storm-derived material. A lower aluminosilicate

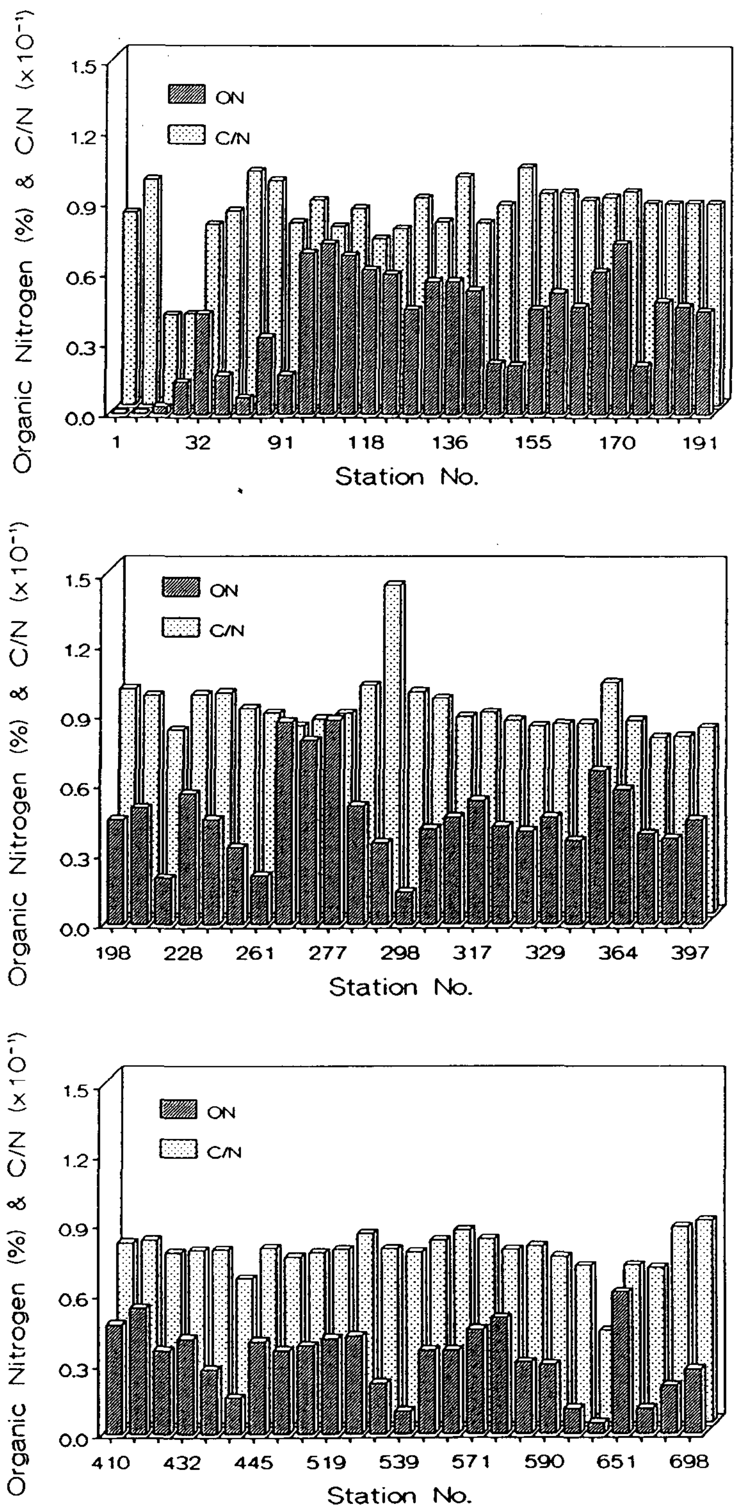


Figure 15. Histograms showing percent organic nitrogen and the organic C/N ratio in sediments from selected stations in the Indian River Lagoon.

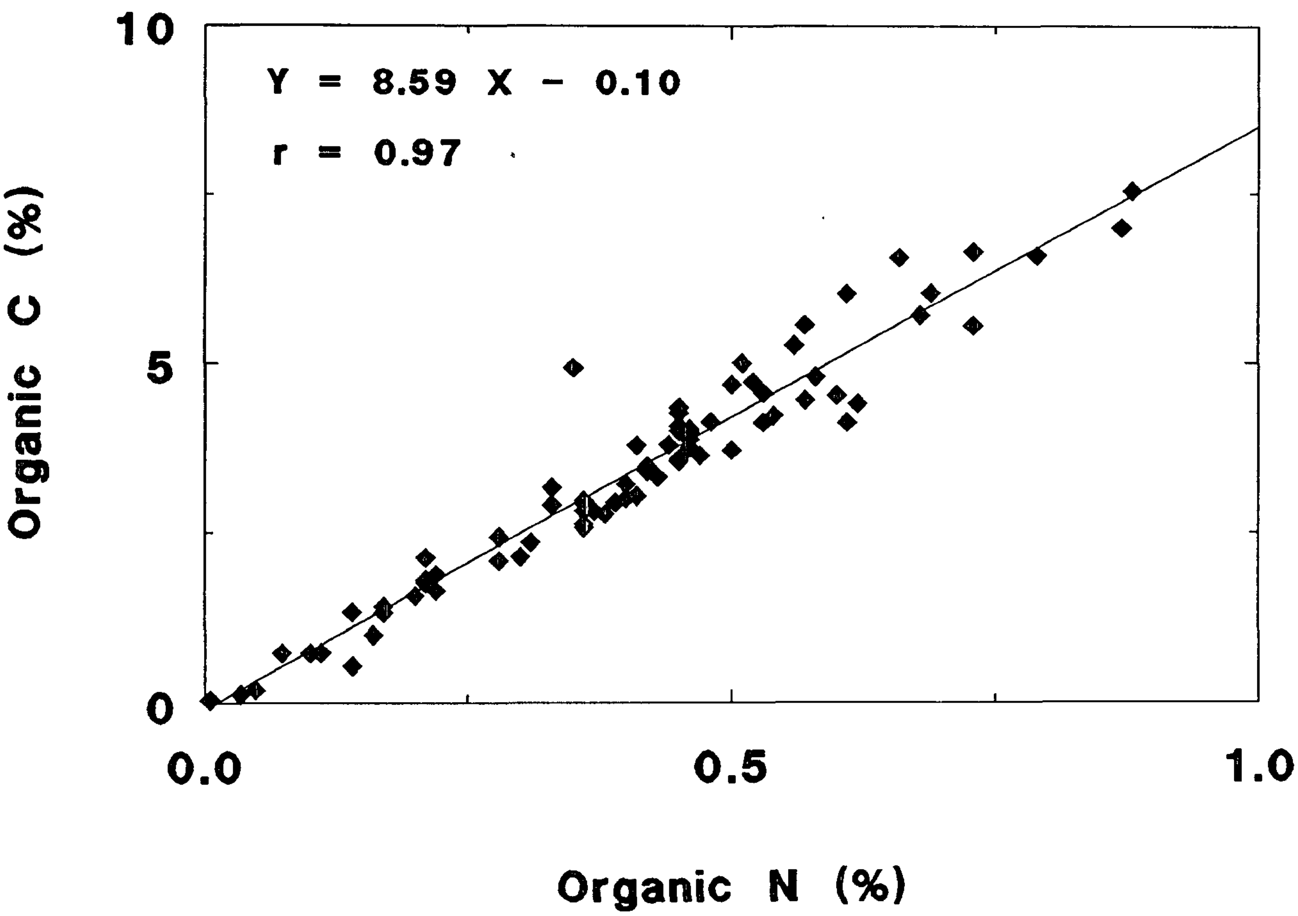


Figure 16. Scatter plot showing concentrations of organic carbon versus organic nitrogen for Indian River Lagoon sediments.

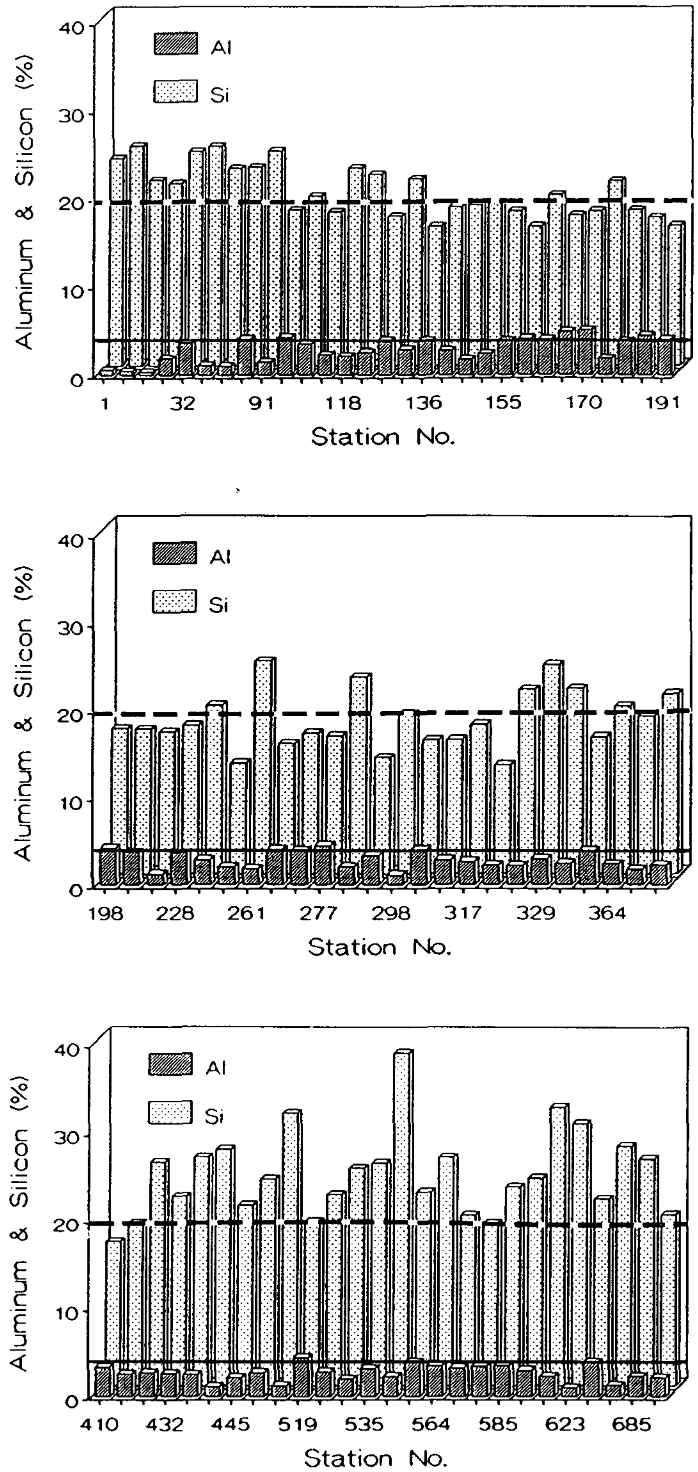


Figure 17. Histograms showing percent aluminum and silicon in sediments from selected sites in the Indian River Lagoon. Solid line at 4% identifies typical aluminum concentrations for muck sediments. Dashed line at 20% identifies average silicon values for lagoon sediments.

component in sediments from the northern and southern areas is the combined result of less upland development and less available clay material.

The silicon content of the selected sediment samples was less variable (range 12.4-37.9%; mean 20.3 ± 4.5%; Table 3) than found for Al or organic carbon. No obvious trends in Si concentrations are shown in Figure 17. In general, the lower Si values are found for sediments with high carbonate or organic content and highest Si levels are observed for sediments dominated by quartz sand. Pure quartz sand has 46.7% Si. Much of the quartz sand found in lagoonal sediments was deposited thousands of years ago and resides on what are now relict beaches. Together, silicates and aluminosilicates are the most common component of IRL sediments as will be detailed below.

Sediment carbonates are the shell remains from a variety of estuarine organisms. Expressed as % $CaCO_3$, the sediments of the IRL contain less than 1 to more than 50% carbonate (Table 3). Sediment carbonates are less abundant south of Palm Bay with an average of 11 ± 5% than in the Palm Bay to Titusville portion of the lagoon where sediments contain 20 ± 11% carbonate. Overall, carbonate distribution is quite patchy and variable from site to site.

Taken collectively, the data for carbonate, organic carbon, aluminum and silicon can be used to determine a composite composition for the various muck and non-muck sediments from the Indian River Lagoon. The following calculations and assumptions are made to complete this composite:

1. The % carbonate is determined directly from the gasometric method for $CaCO_3$ used in this study.
2. The organic matter content is set equal to 2.5 times the organic carbon content, assuming that organic matter contains 40% C.

3. The % aluminosilicate is set equal to 12 times the Al concentration, assuming that average continental crust contains 8.2% Al.
4. The silicate content is calculated by

   % Silicate = [Total Si - 2(Al)] x 2.14

   where the amount of Si associated with aluminosilicates is equal to twice the Al concentration and the % silicate is expressed as SiO_2 (Si x 2.14).
5. The remaining percentage required to attain 100% is referred to as % other and is equal to [100 - (the sum of the other 4 components)]. This fraction might include heavy minerals, excess iron oxides and other metal oxides or sulfides not included in the aluminosilicate fraction.

The calculated composition data are compiled in Table 4. The mean value for % other of 11 ± 11% shows that, on average, about 90% of the composition of the sediment could be described using the general assumptions described above. Deviations in the Al/Si ratio of aluminosilicates and the presence of feldspars, heavy minerals and other minerals may account for the higher % other fraction in some samples. Despite these difficulties, we are able to provide a comparative picture of the composition of muck deposits from Mosquito Lagoon through the Indian River Lagoon to St. Lucie Inlet.

Data for a large variety of muck and non-muck samples (Table 4), show a wide range of values for each of the sediment components along the entire lagoon. This diversity is consistent with the patchwork nature of IRL sediments. For the purposes of this study, we will focus on differences in the composition of muck deposits along the length of the lagoon studied.

Table 4. Percent composition of selected samples from the Indian River Lagoon

Station No.	Carbonate	Organic Matter	Alumino-silicates	Silicates	Other
	(%)				
1	0.6	0.10	7.32	46.79	45.19
8	0.7	0.13	5.64	50.32	43.22
20	13.2	0.33	4.44	42.38	39.66
25	46.7	1.21	20.50	31.64	--
32	8.0	8.28	44.16	35.39	4.18
43	0.3	3.53	13.80	47.31	35.06
54	19.6	1.83	12.84	42.36	23.38
89	8.1	7.90	49.92	29.76	4.32
98	12.6	15.08	51.84	18.80	1.69
101	19.2	13.73	41.91	25.16	--
104	32.7	13.95	27.13	26.23	--
118	11.0	11.00	26.04	37.88	14.08
123	12.0	11.30	31.56	34.57	10.57
126	30.0	9.09	43.96	16.97	--
131	22.5	10.98	34.94	31.58	--
136	26.9	13.05	44.61	15.40	--
144	21.1	10.30	34.08	25.66	8.86
149	32.0	4.70	21.60	30.41	11.29
153	32.4	5.33	29.40	27.93	4.94
155	22.9	10.17	46.91	20.03	--
160	14.5	11.80	50.16	15.25	8.29
166	21.2	9.64	46.76	22.39	--
169	13.4	14.74	56.98	14.87	--
170	7.2	16.60	60.60	15.33	0.27
176	34.2	4.53	22.44	35.83	3.01
180	23.8	10.15	45.99	20.08	--
187	17.7	9.93	53.64	16.36	2.38
191	29.8	8.91	46.38	14.89	--
198	13.3	10.85	51.36	16.76	7.73
203	19.7	11.70	45.96	18.48	4.16
222	36.3	3.93	15.48	28.41	15.88
228	2.5	13.15	45.12	19.70	19.53
243	13.7	10.65	35.04	28.08	12.53
253	38.0	7.25	25.20	17.56	11.99
261	11.6	4.50	22.56	43.11	18.23
268	11.2	17.48	50.16	13.59	7.58
276	13.1	16.45	48.24	16.67	5.54
277	8.9	18.85	54.60	13.88	3.77

Table 4 (continued)

Station No.	Carbonate	Organic Matter	Alumino-silicates	Silicates	Other
	(%)				
282	12.0	12.50	25.20	38.28	12.02
292	38.8	11.35	37.36	12.50	--
298	1.0	3.33	13.92	33.54	48.22
300	33.9	8.51	44.18	13.38	--
306	21.6	9.68	34.68	19.95	14.10
317	16.8	11.40	32.64	24.34	14.82
323	22.7	8.03	27.00	34.69	7.58
329	12.8	9.35	36.00	37.61	4.24
342	30.0	7.17	29.71	33.08	--
350	5.0	16.38	48.00	15.98	14.64
364	5.2	12.00	29.40	29.88	23.52
374	28.8	7.35	21.48	30.18	12.19
397	12.0	8.95	28.32	33.26	17.47
410	25.4	9.08	39.84	20.33	5.36
412	3.0	10.55	30.72	28.01	27.72
425	8.9	6.55	32.64	41.94	9.97
432	12.4	7.58	31.44	34.21	14.38
437	6.5	5.20	30.24	44.10	13.96
443	17.3	2.48	13.56	51.79	14.88
445	10.9	7.50	26.04	33.98	21.58
448	8.3	6.40	32.88	37.86	14.56
519	1.3	7.60	53.28	20.52	17.30
526	8.6	8.50	33.84	33.79	15.27
533	15.3	4.10	23.76	43.68	13.16
539	5.4	1.71	25.63	67.22	--
555	11.6	7.03	47.16	29.72	4.50
564	8.4	7.43	41.52	39.98	2.67
571	11.9	8.85	38.76	27.07	13.42
573	13.4	9.28	40.80	24.51	12.02
585	14.0	5.88	41.88	32.76	5.49
590	14.4	5.35	35.64	37.19	7.42
610	12.7	1.85	27.72	56.97	0.76
623	22.9	0.48	12.00	58.59	6.03
651	7.3	10.30	47.04	28.06	7.30
673	14.1	1.83	15.36	51.91	16.80
685	16.8	4.40	27.60	44.56	6.64
698	18.1	6.08	25.92	31.79	18.11

For ease of comparison, composition data from eight representative muck sediments along the lagoon are presented in pie diagrams (Figures 18-20). Each diagram shows the percentage of organic matter, carbonate, aluminosilicate, silicate and other components. The organic matter content of these muck samples increases from Mosquito Lagoon to the Titusville-Cocoa-Melbourne stretch of the lagoon and then decreases again from Sebastian to Jensen Beach. Muck deposits from the northern and southern portions of the IRL (Stations 32, 445, 590 and 698; Figures 18-20) average 6.8% organic matter relative to 12.2% in the central lagoon (Stations 98, 228, 292 and 397).

A 10% difference in the aluminosilicate fraction of the muck deposits is also observed between the northern/southern sites (33 ± 9%) and the central lagoon locations (41 ± 10%). Thus, the Titusville to Melbourne muck is more clay and organic rich. This is most likely related to the greater amounts of nutrient and soil runoff to these sites during the past 30-40 years.

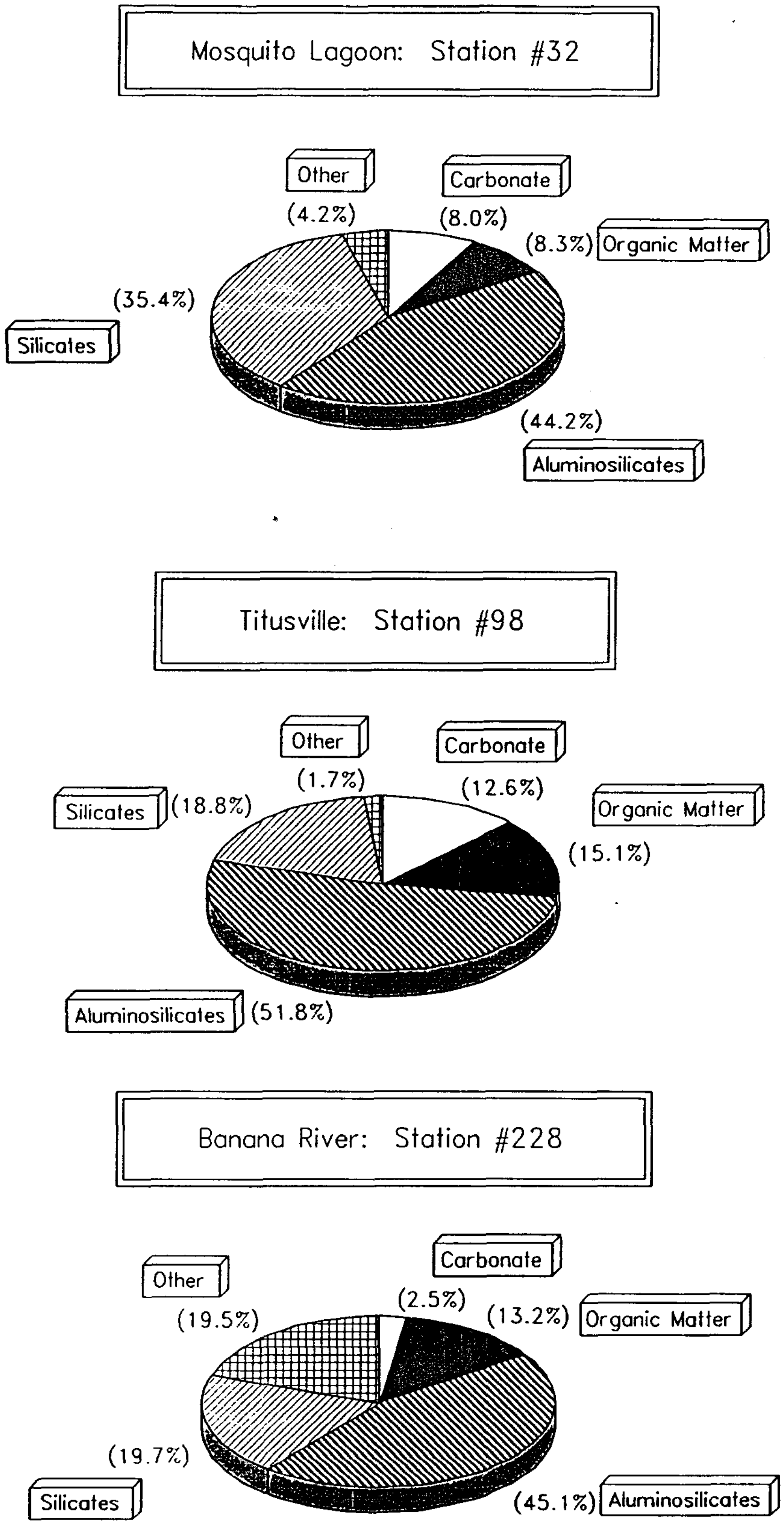


Figure 18. Pie diagrams showing percent composition of sediments from Mosquito Lagoon, Titusville and the Banana River. Locations identified on appropriate MUCKMAPS.

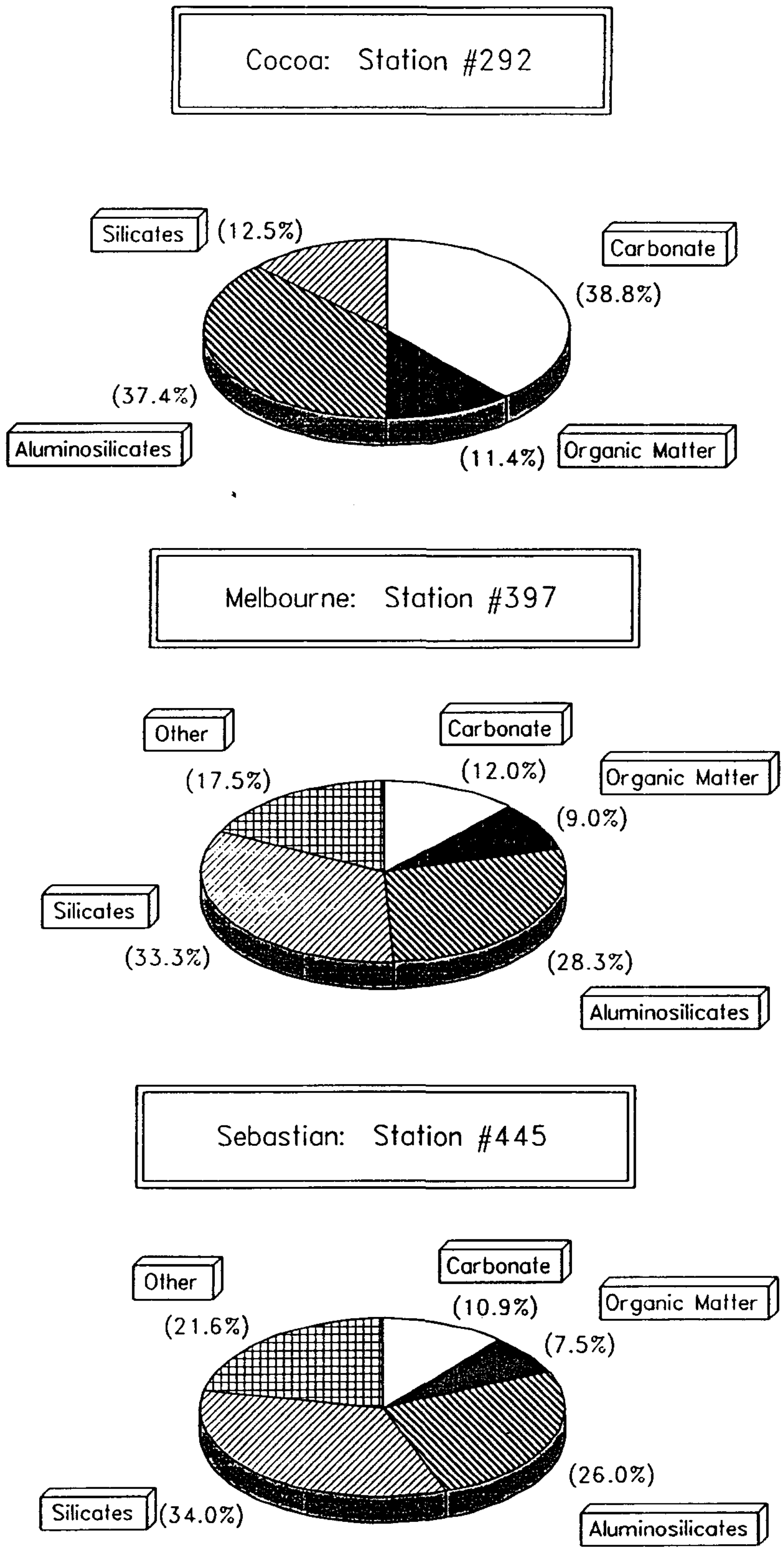
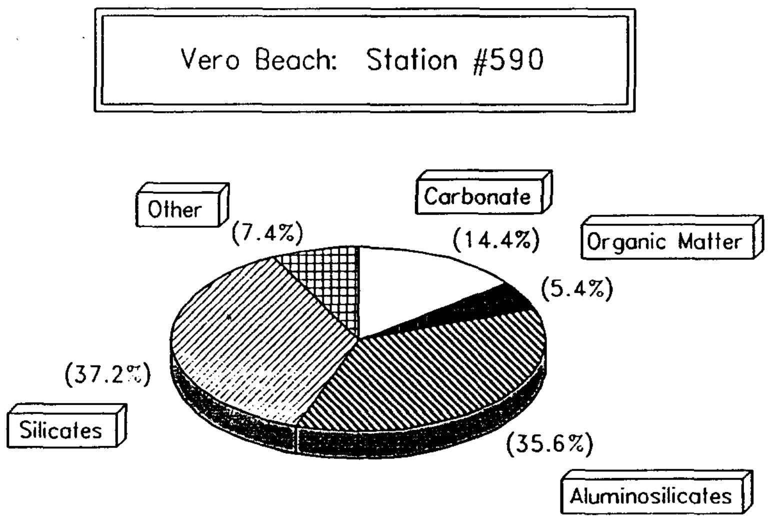


Figure 19. Pie diagrams showing percent composition of sediments from Cocoa, Melbourne and Sebastian. Locations identified on appropriate MUCKMAPS.



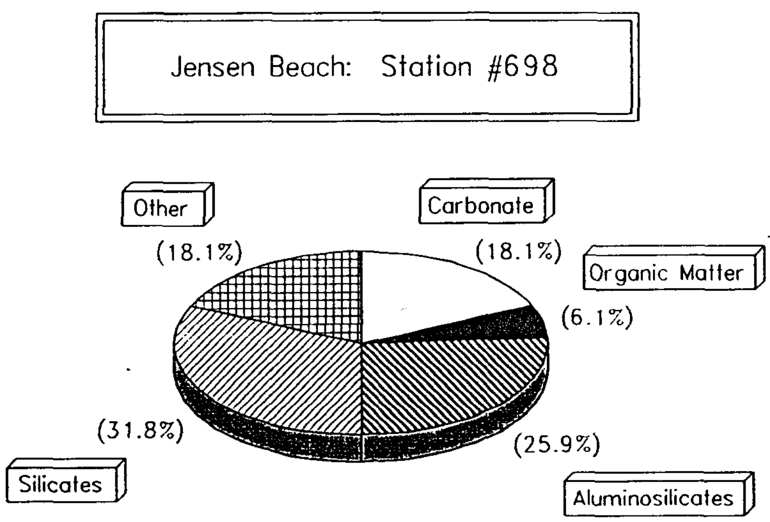


Figure 20. Pie diagrams showing percent composition of sediments from Vero Beach and Jensen Beach. Locations identified on appropriate MUCKMAPS.

Muck Deposition Rates and Contamination

Accumulation rates are often difficult to determine for sediments in shallow water regions such as the Indian River Lagoon. Non-steady state accumulation, the presence of sand layers and plant debris, as well as physical and biological mixing of the sediments can distort vertical profiles for isotopes or other indicators. Nevertheless, first-order approximations of the historical record of sediment and contaminant inputs for these areas can sometimes be made using geochronometers such as Cs-137 and Pb-210.

Cesium-137 is a man-made radionuclide first introduced into the environment during aboveground nuclear testing in the early 1950's. Nuclear testing peaked in 1963 and sometimes a corresponding maximum value in sediment Cs-137 values can be found when sediment mixing processes have not distorted it (Figure 21). No Cs-137 will be found in sediments deposited prior to 1950 unless some downward mixing of "newer" sediment has occurred. The half-life of Cs-137 is 30.7 years and thus the nuclear testing record is still preserved in sediments and provides a useful time marker.

Manatee Pocket has been a passive trap for fine-grained, organic-rich sediments for many years. Our geochronometers were somewhat successful at this site. In the center of Manatee Pocket (station E), the Cs-137 signal is undetectable below 20 cm and a clear maximum in Cs-137 activity is observed between 10 and 15 cm (Figure 21). The positioning of the 1963 maximum and the point of no detectable Cs-137 for this site in Manatee Pocket are consistent with a recent sediment accumulation rate of about 0.5 cm/y. At two other stations in Manatee Pocket (stations C and H), Cs-137 is not detected below 40 cm and thus the deeper layers were most likely deposited before 1950 (Figure 21). The 1963 maxima are not as clear for stations C and H as for station E.

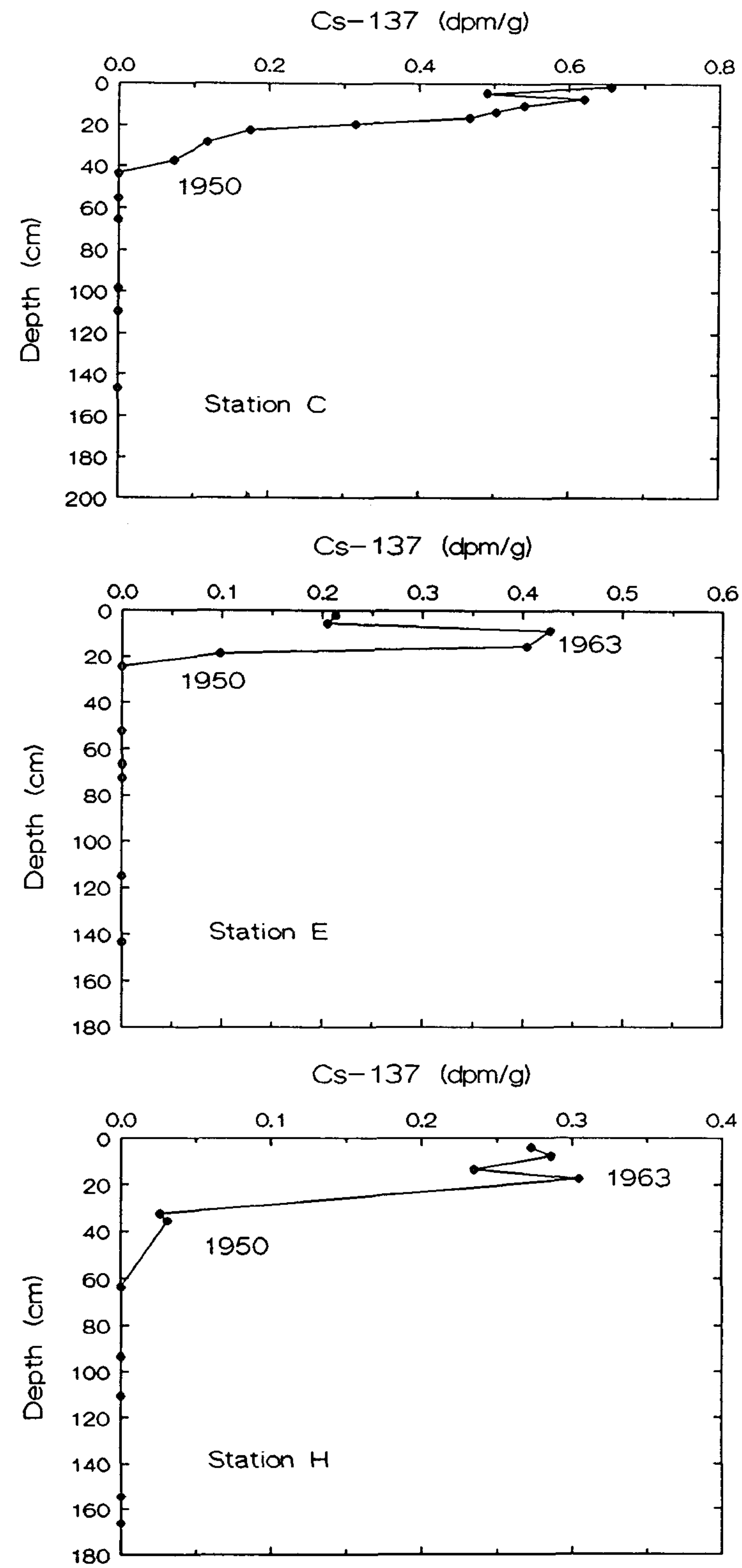


Figure 21. Vertical profiles of Cs-137 in sediments from stations C, E and H (Figure 12) in Manatee Pocket with age estimates as described in text.

However, sediment accumulationrates of about 1 cm/y are estimated for both stations.

In contrast with Cs-137, Pb-210 is a naturally occurring daughter isotope of U-238. Sediments contain supported Pb-210, formed from decay of U-238 in the sediments, as well as unsupported Pb-210 introduced to the sediments via atmospheric transport of Rn-222, a gas. The unsupported (or excess) Pb-210 is formed when Rn-222 escapes from the Earth's crust as a gas. The Rn-222 quickly decays to Pb-210 (half-life Rn-222 = 3.8 days) and this excess Pb-210 is transported to estuaries and the ocean without its parent isotopes U-238 or Ra-226. The excess Pb-210 decays away with a half-life of 22.3 years and can be traced down through an ideal sediment column over about 100 years. In the Pb-210 technique, the sediment accumulation rate is determined from the slope of the line for the natural logarithm of excess Pb-210 versus depth in the sediment. Thus, one of the assumptions for application of the Pb-210 geochronometer is that the accumulation rate of excess Pb-210 has been constant over a fixed interval of time.

Figure 22 shows plots of total Pb-210 and excess Pb-210 versus sediment depth for sediments from Manatee Pocket. At stations C and H in Manatee Pocket, a linear decrease in ln excess Pb-210 can be followed downcore until the excess Pb-210 signal has decayed away at about 100 and 60 cm, respectively. From the slopes of the decay curves, we calculate sediment accumulation rates of 0.8 cm/y for station C and 0.5 cm/y for station H. These values are slightly lower than determined from the Cs-137 profiles, suggesting that Cs-137 has been mixed down into the sediment column over time. Overall, we can assume that sediments in Manatee Pocket have accumulated at rates of a few tenths to 1 cm/y during the past 100 years. The presence of

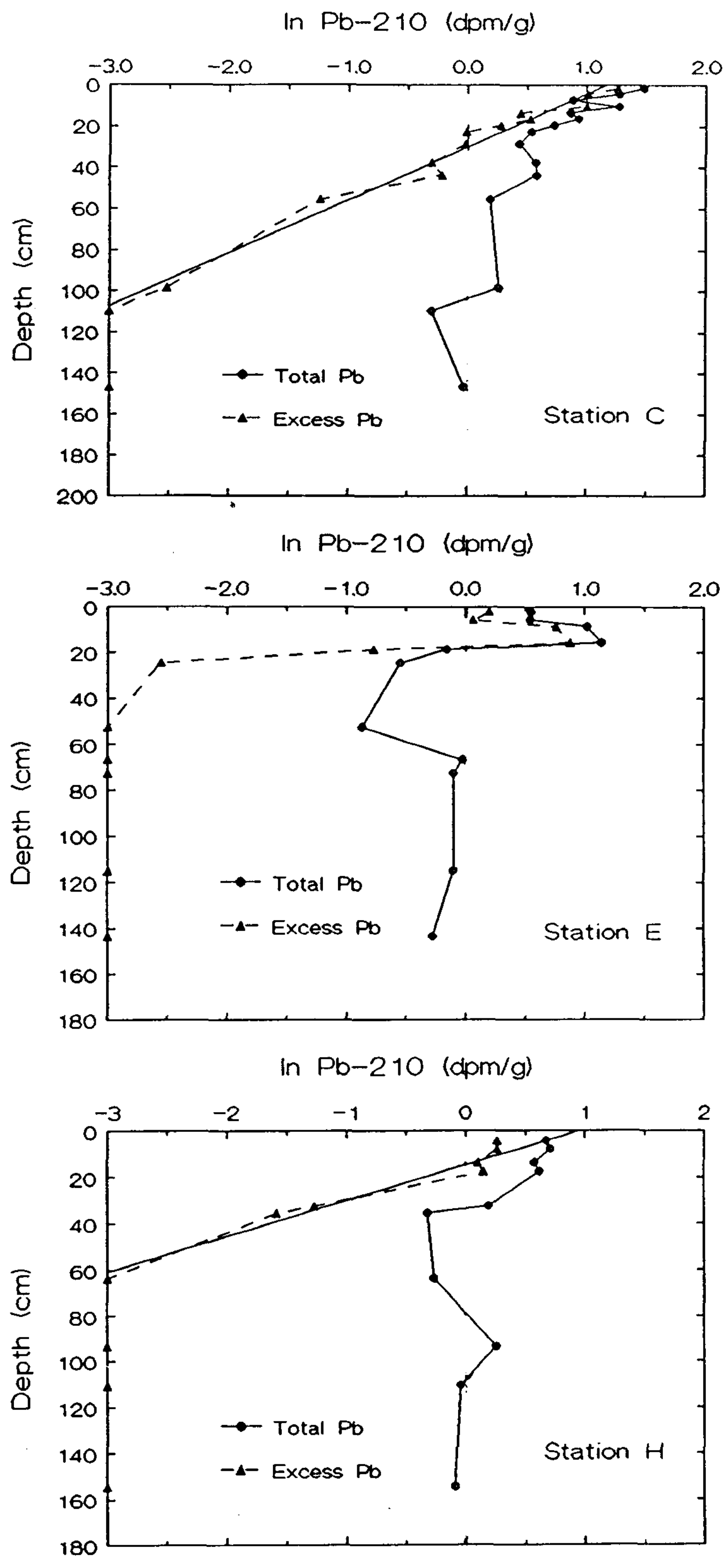


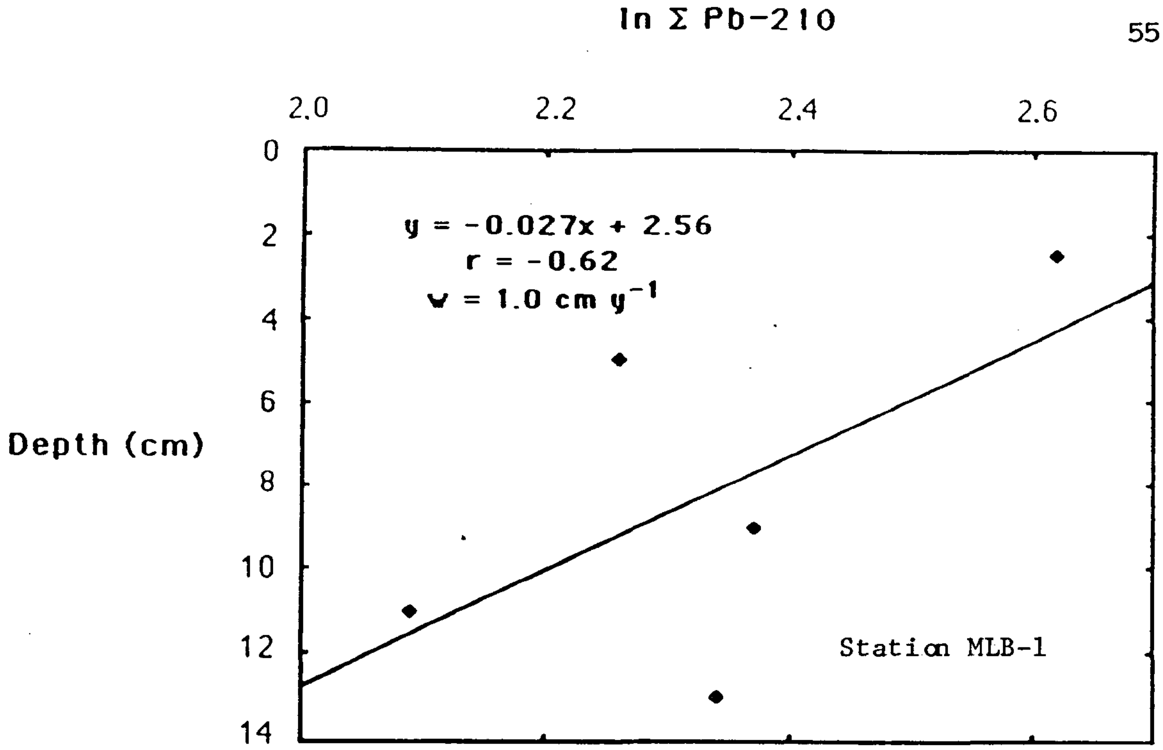
Figure 22. Vertical profiles of total and excess Pb-210 in sediments from stations C, E and H (Figure 12) in Manatee Pocket. Straight line for stations C and H gives best fit for excess Pb-210 versus depth in the sediment.

various sand and shell layers and only a short linear trend in ln excess Pb-210 for station E make calculations of accumulation rates unreliable. However, the rate would be lower than at stations C and H (i.e. less than 0.5 cm/y) which is consistent with the Cs-137 data.

We also have had some success in determining sediment accumulation rates in the Melbourne area. Lead-210 data for two sites near the mouth of Crane Creek (Figure 23, Sisler, 1986) yield sediment accumulation rates of 1 cm/y and 0.2 cm/y, respectively. At station MLB-1, the 19-cm muck layer accumulated at 1 cm/y over about a 20 year period. In contrast, the smaller 7-cm muck layer at station MLB-2 accumulated more slowly (about 0.2 cm/y). However, the age of the onset of muck accumulation is similar at about 30 years.

Thus, in the cores for which useful data were attainable, we observed muck accumulation rates of a few tenths to about 1 cm/y. At the sediment accumulation rates described above, sediments at depths greater than 100 cm in Manatee Pocket date back into the 1800's. It is speculated that the deeper muck layers represent either long-term natural runoff of organic-rich sediments or a large pulse of 'natural' sediment sometime during the mid-1800's. In contrast, the muck deposits in the Melbourne area are only 20-30 years old. As we continue our MUCK Program in 1990-1991, we will add to our data base for sediment accumulation rates in the lagoon.

Because of their fine-grained composition, muck sediments have an affinity for uptake and retention of contaminants. We present here some preliminary data on trace metal contamination of sediments from Manatee Pocket and the Melbourne area.



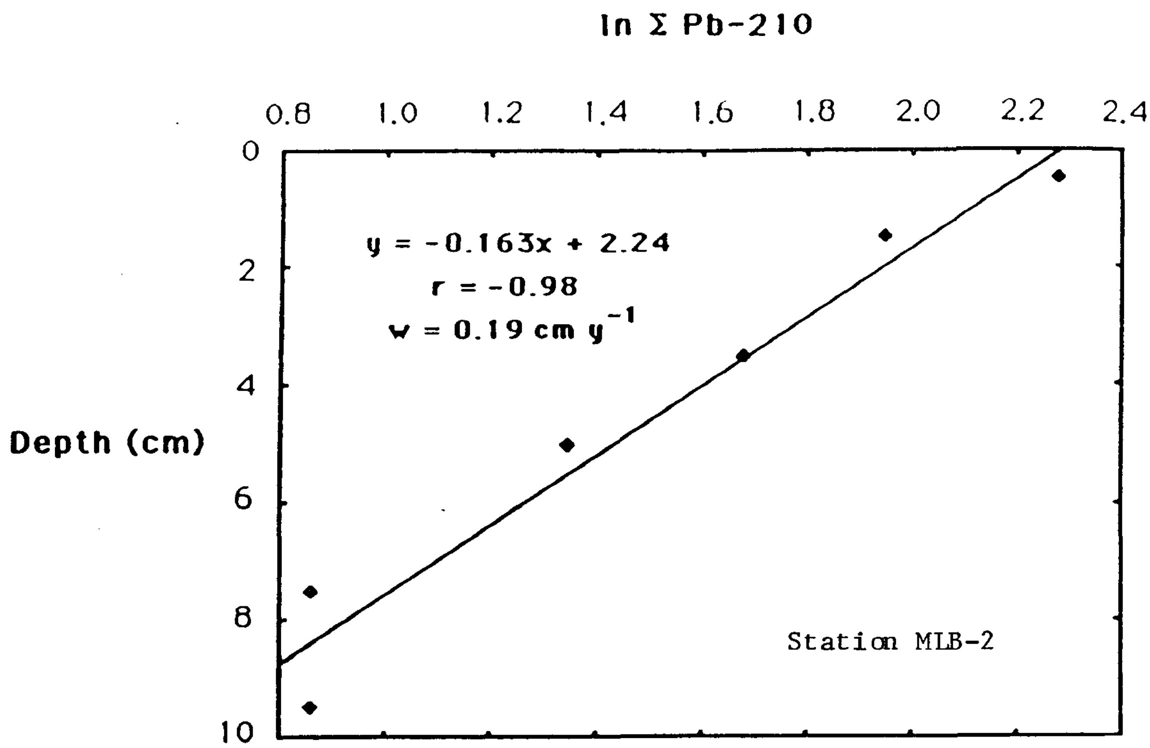
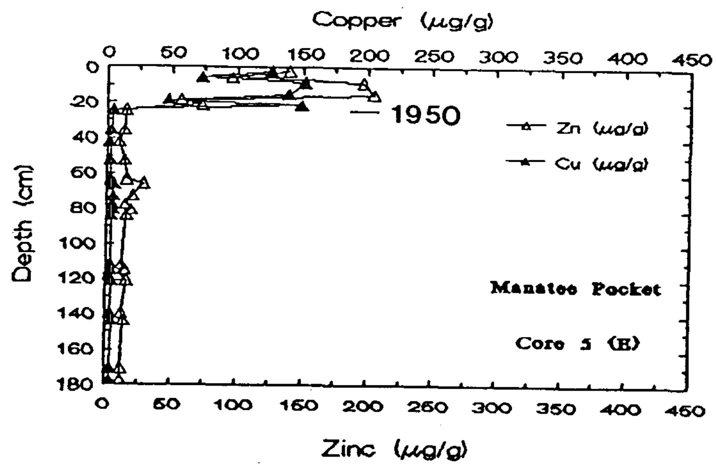


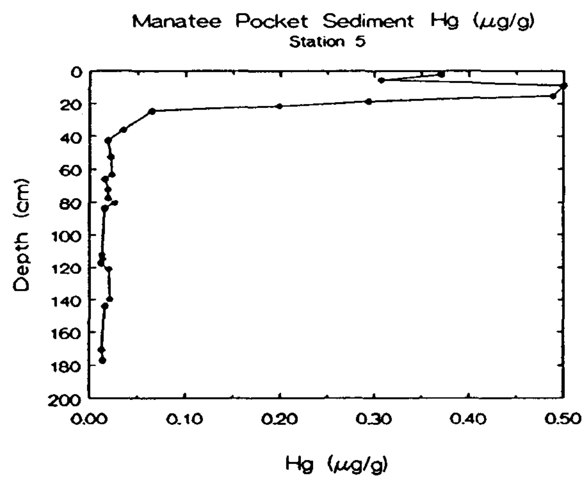
Figure 23. Vertical profiles of total Pb-210 in sediments from the Melbourne area of the Indian River Lagoon

The vertical profiles for trace metals in sediments from Manatee Pocket (Figure 24) show very high levels of copper, zinc, mercury, lead and cadmium in the top 20 cm. The top 20 cm of sediment have accumulated since 1950 and the onset of contaminant inputs has thus occurred since 1950. During the 1800's and half of the 1900's, the fine-grained, organic-rich deposits in Manatee Pocket were free from metal contaminants. However, during the past 30-40 years, excess loadings of lead, copper, mercury, cadmium and zinc have contaminated Manatee Pocket sediments.

In the Melbourne area, vertical profiles for mercury and lead in the sediments show elevated concentrations; however, the values are lower than observed for Manatee Pocket. Copper levels are close to natural concentrations. The enhanced lead and mercury inputs to the Melbourne area have occurred since the early 1960's.

Muck deposits can vary in age from more than 100 years old to less than 30 years old. However, in each case, heavy metal contamination began during the 1950-1960 period.





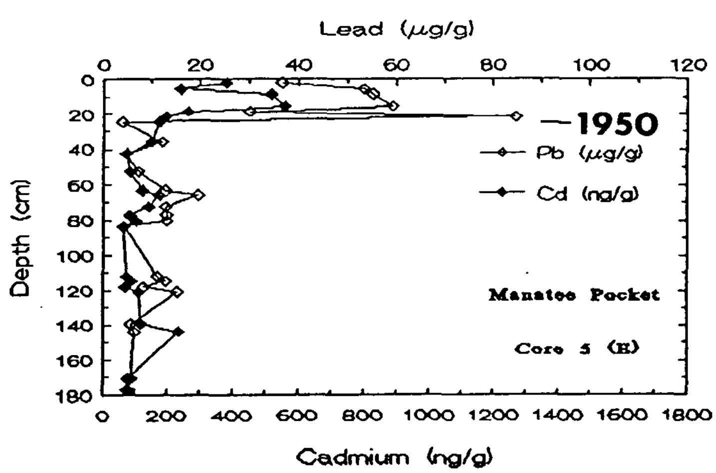


Figure 24. Vertical profiles for concentrations of copper, zinc, mercury, lead and cadmium in sediments from Manatee Pocket.

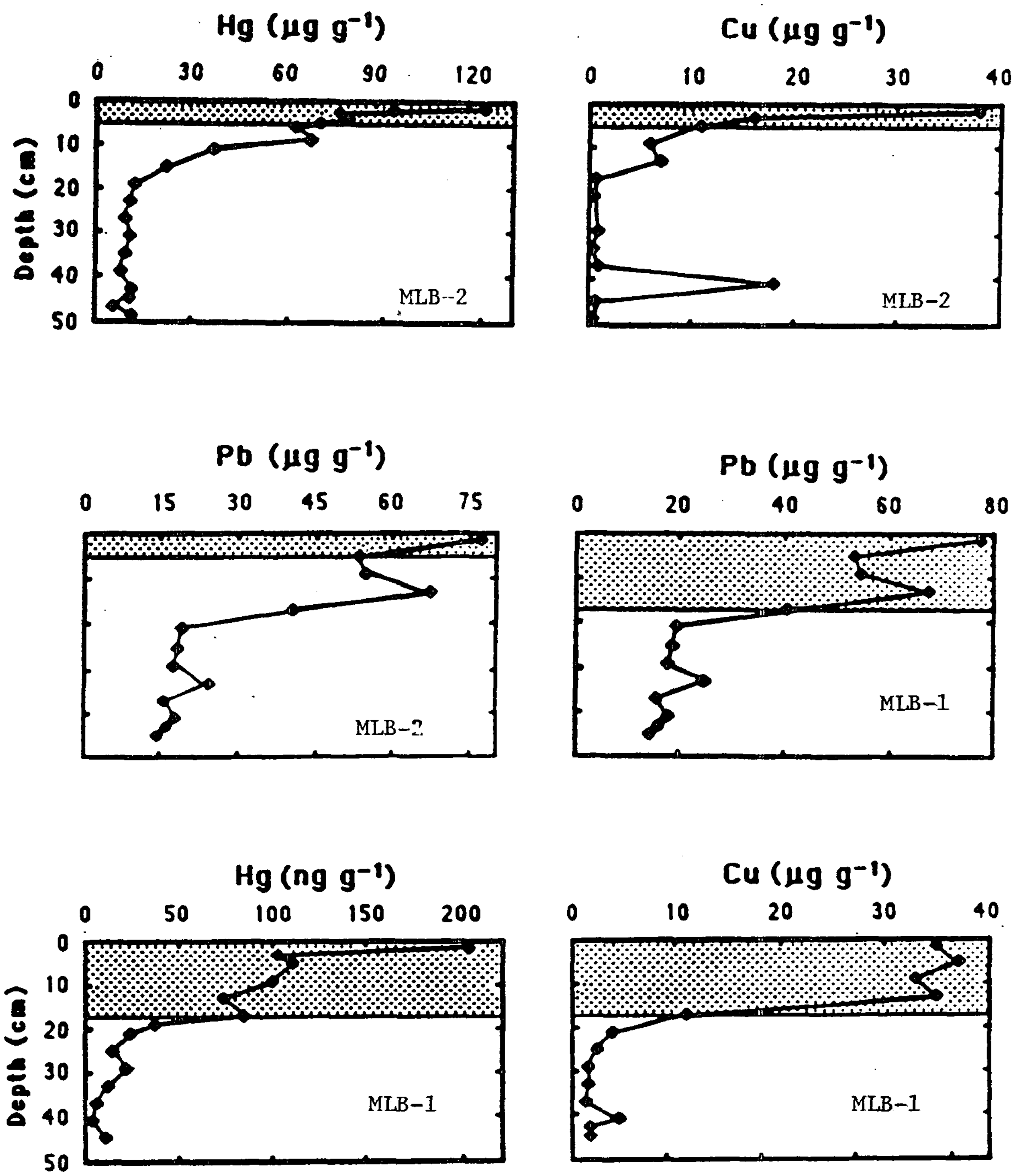


Figure 25. Vertical profiles for concentrations of mercury, copper and lead in sediments from the Melbourne area of the Indian River Lagoon. Shaded surface layer identifies muck sediment.

SUMMARY AND CONCLUSIONS

Inputs of fine-grained, organic-rich sediment to estuaries such as the Indian River Lagoon, Florida, can have an adverse effect on water quality and benthic habitats. This sediment, sometimes referred to as muck, is not the natural bottom along most of the Indian River Lagoon. Muck can be easily resuspended to increase turbidity in the water and decrease the growth of seagrasses. Muck sediments also have a high oxygen demand and can contribute to oxygen depletion in the water column. When the normal sediment of the lagoon is covered with muck, habitats for benthic organisms are often changed and inputs of contaminants can increase.

During our 1989 muck survey, more than 600 discrete sediment cores were collected and hundreds of additional observations were made along the lagoon from New Smyrna Beach to St. Lucie Inlet. Muck sediments were found throughout the Indian River Lagoon in layers as thick as 2 meters. A series of MUCKMAPS have been developed to show the distribution and thickness of muck layers and are included in the GIS data base at the St. Johns River Water Management District. Overall, less than 10% of the area of the entire lagoon is covered with muck. Muck sediments are most abundant in the central lagoon in proximity to developed areas such as Titusville, Cocoa and Melbourne. Large deposits are also found in the Vero Beach area. In the lagoon proper, muck tends to accumulate in the Intracoastal Waterway (ICW), in channels connecting the ICW to marinas or creeks, and in deeper pockets of water adjacent to developed areas.

We estimate that about 40% of the length of the ICW is coated with muck, sometimes as thick as 1 meter. In many areas, much of the muck is still retained in adjacent creeks such as Crane Creek, Turkey Creek and Manatee Pocket. An in-depth study of Manatee Pocket showed muck thicknesses of 1 to 2 meters throughout the cove. Winding tributaries along much of the lagoon have served as effective traps for incoming fine-grained, organic-rich sediment.

The typical muck sediment in the Indian River Lagoon contains 8-15% organic matter and 30-50% aluminosilicate silts and clays, with the remainder being sand and shell material. Muck deposits from the central lagoon averaged about 6% more organic matter and 10% more silt/clay than deposits from the northern and southern portions of the lagoon. This difference is most likely related to increased nutrient inputs, more soil runoff and poorer flushing along the Titusville to Melbourne stretch of the lagoon.

Muck sediment accumulation rates at locations where such measurements were possible ranged from about 0.2 to 1 cm/y. However, the age of onset of muck inputs is more variable. For example, near Melbourne, muck accumulations are 20-30 years old and are contaminated with mercury and lead. In Manatee Pocket, muck accumulation has occurred for more than 100 years. However, only sediments deposited since 1950 are contaminated with mercury, lead, copper and cadmium.

The 1989 Muck study and the MUCKMAPS produced provide a first order presentation of the distribution of fine-grained, organic-rich sediments throughout the Indian River Lagoon. Fortunately, the spatial occurrence of muck deposits is limited at present. However, available data show these deposits to be contaminated with heavy metals and suggest that they adversely affect local water quality and seagrass habitats.

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