SEDIMENTOLOGICAL STUDY OF D'OLIVE BAY AND ITS DRAINAGE BASIN

BALDWIN COUNTY, ALABAMA

Submitted To:

DEPARTMENT OF THE ARMY
MOBILE DISTRICT, CORPS OF ENGINEERS

FINAL REPORT

(Contract No. DAC01-80-C-0305)

By:

Wayne C. Isphording
Professor of Geology
University of South Alabama
Mobile, Alabama 36688

November, 1981

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

Page Number

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

INTRODUCTION

Statement of Problem

This study was carried out to investigate the sources of natural and man-caused erosion in the watershed area whose streams discharge into D'Olive Bay. A further goal was to determine the amount of material carried into the bay since active land development was initiated in the watershed area in the late 1960's. The investigation was prompted by public concern expressed over the constant discoloration of waters in Lake Forest reservoir and D'Olive Bay and along the eastern shore of upper Mobile Bay (see figures 1 and 2). The chief causes of this discoloration were believed to stem from large amounts of silt and clay being carried into the reservoir and bay from upland sites that were being developed for residential and commerical purposes.

To carry out the study, a detailed field sampling program was designed that involved coring of D'Olive Bay and Lake Forest reservoir and the collection of borehole samples from the surrounding upland areas in the watershed. Samples were also collected along D'Olive Creek, Tiawasee Creek, Joes Branch Creek, and in, and adjacent to, the Interstate 10 work canal north of D'Olive Bay. Further, cross-sectional profiles were developed for the work canal, Lake Forest reservoir and D'Olive Bay in order to determine the total effect of deposition in these three areas. Available reports dealing with soil studies, geology, water sampling, highway construction, environmental effects and rainfall data were also consulted in order to acquire and examine all information germane to the investigation. Topographic maps dating back to the middle of the last century were also examined for the purpose of documenting the major morphological changes that have taken place in the watershed (see Table 1).

Fig. 1.--Sediment laden waters flowing down D'Olive Creek into Interstate 10 work canal. Note overflooding into northern part of D'Olive Bay (John Carlton photo, 1970.)

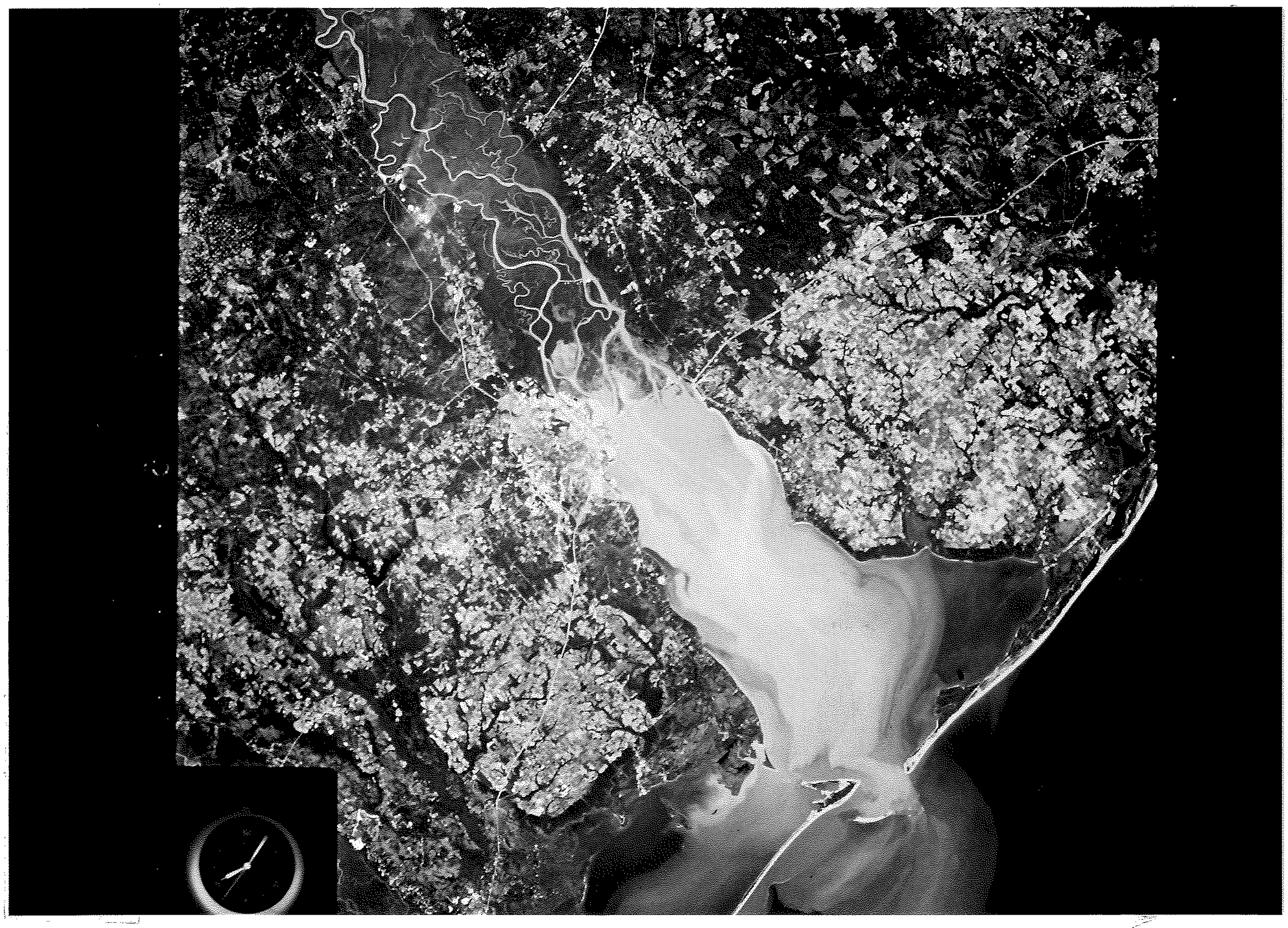


Fig. 2.--Satellite photo of Mobile Bay. Note prominent sediment plume extending southward from D'Olive Bay into Mobile Bay (SKYLAB IV photo, 21 January 1974).

Table 1.-- Chronological listing of recorded and consulted maps used in this investigation.

Description	Map Name and/or Cartographer	Date
Achusi Bay- located at terminus of Rio de Flores	"Mapa del Golfo de la Neuva Espana (anonymous)	1554
Achusi Bay (and Rio de Flores)	"La Florida" (Ortelius)	1584
Achusi Bay	"Le Nouveau Mexique et la Floride (Nicholas Sanson)	1656
Achusi Bay	"La Floride" (DuVal)	1660
Baye de la Mobile	"Carte de la Louisiane" (Guillaume Delisle)	1718
Bay of Mobile	British Admiralty Chart (anonymous)	1771
Mobile Bay	"A Map of Mobile Bay in the State of Alabama (Curtis Lewis)	1820
Mobile Bay and "D'Olive's Bay (D'Olive Creek called "Smith's Mill Creek")	Map of the Defenses of Mobile (U.S. Coast Survey)	1862
Mobile Bay, "D'Olivier's Bay" and "D'Olivier's Creek"	U. S. Army Engineers	1863(?)
D'Olive's Bay	U. S. Coast Survey	1864
D'Olive's Bay	Siege Operations at Spanish Fort	1865
D'Olive Bay and D'Olive Creek	Untitled and anonymous	1872

Aerial /Satellite Photos	
Aerial Photos, 0301-10 6-2	29 Apr 69
Aerial Photos, SAM-50-373	22 Jan 77
RB-57 Aerial Photos, SAM 3/21	19 Feb 79
Aerial Photos, SAM-21 481 45	23 Sep 79
Aerial Photos, SAM-21A 483	15 Nov 79
Satellite Photo, SAM-3-21 516	7 Oct 80

Topographic Quadrangles	
Bridgehead, Ala.	1944
Bridgehead, Ala.	1953
Bridgehead, Ala.	1953, revised, 1967
Bridgehead, Ala.	1953, revised, 1974

DESCRIPTION OF D'OLIVE BAY

General

D'Olive Bay is located in the northeasternmost corner of Mobile Bay and lies immediately south of the work canal cut for the Interstate 10 crossing (see figure 3). Marshlands cover the northern and western sides of the bay and a hilly upland area forms the eastern border. The bay is separated from the Blakeley River by a prograding peninsula of fluvial origin which is slightly over one mile in length. The bay itself is oriented nearly north-south and is just over one mile long and slightly less than one-third mile in width. Depths generally average between two to three feet, with the maximum recorded depth of 4.25 feet (3.65 feet Mean Sea Level) occurring near the south-central portion of the bay. Extensive sedimentation has taken place in the upper part of the bay and has reduced the average depth to less than two feet; depths in a northerly-trending arm adjacent to the Nautilus Restaurant are generally less than one foot. A similar shoaling of the bay was also noted in the southwestern portion adjacent to, and north of, the channel leading toward the Lake Forest Yacht Club. Access to the bay is gained by way of three natural openings. The largest lies at the southern mouth of the bay, west of Scrub Point, where the bay is nearly 1,700 feet wide and empties into Mobile Bay; some 650 feet to the north, a natural channel, which has been enlarged by dredging, breaches the prograding fluvial peninsula that forms the western side of the bay and allows small boats to access the Lake Forest Yacht Club facilities. The only other functional entrance to the bay is found in the extreme northwestern corner where a remnant distributary channel of D'Olive Creek connects the bay to the Interstate 10 work canal (Fig. 4). This opening can normally be used only in the winter and spring because of the growth of extensive marsh grass in the channel in the summer and early fall.

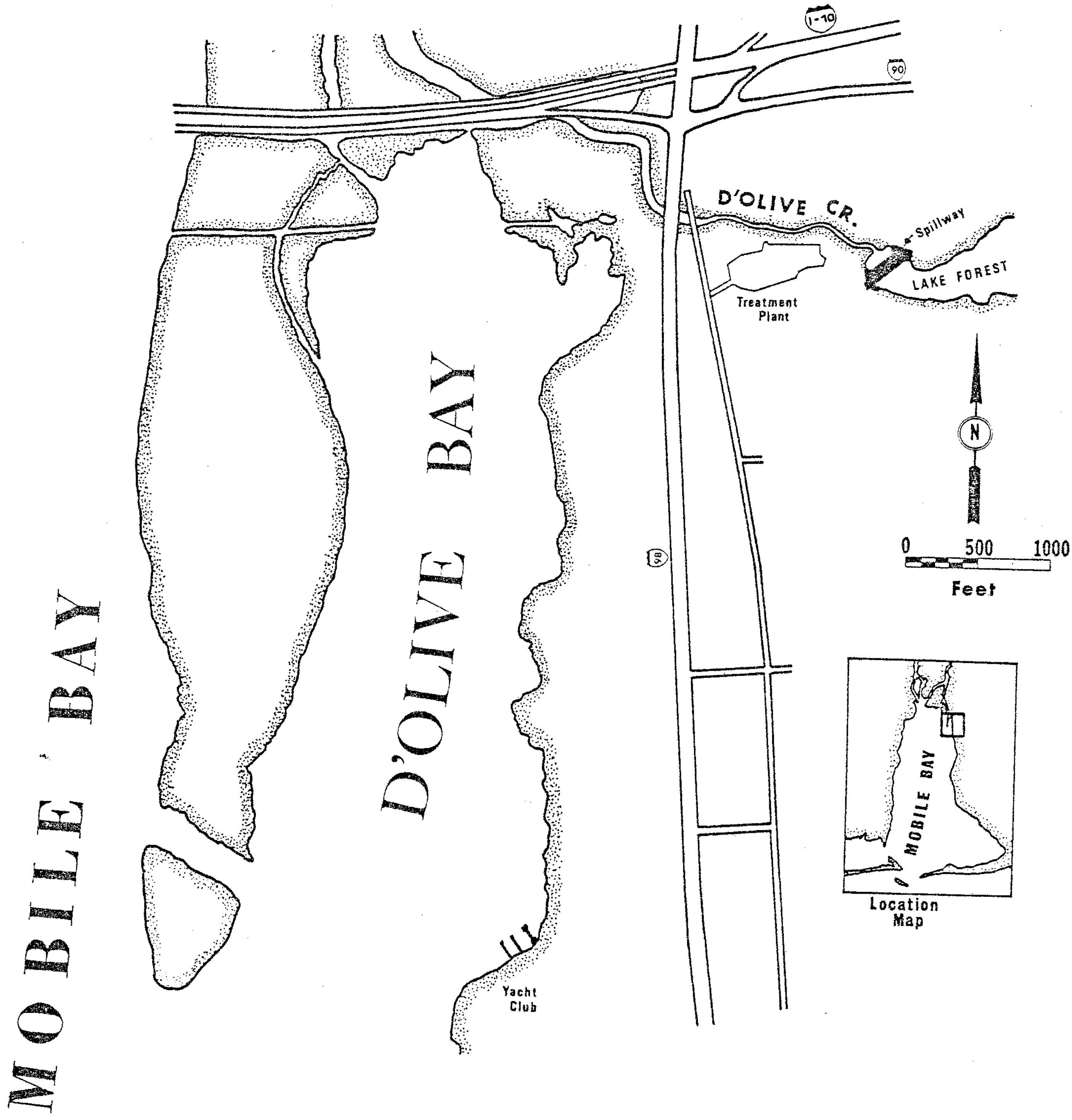


Fig. 3.--Location map for D'Olive Bay.

Flora and Fauna.--Extensive grass beds seasonally cover much of the bay and, during the summer months, make access to the bay by all but the shallowest draft boats difficult. The submerged aquatic vegetation has changed extensively in the past 30 years, with the most dramatic changes taking place in the last 10 years. Eurasian watermilfoil (*Myriophyllum spicatum*), since its introduction in the mid-1970's has become the dominant submersed aquatic plant. It has outcompeted the more beneficial fish and waterfowl species recorded by Lueth (1963), Baldwin (1957), Beshears (1972) and Vittor (1972). Borom (1979) reported that erosion from construction projects in the Spanish Fort area has caused considerable damage to the biota of both D'Olive Creek and D'Olive Bay. His conclusion was that the extensive sedimentation had not only devastated the submersed aquatic plants but may also have impacted important commercial faunal species.

Further, the increased sedimentation in D'Olive Bay has accelerated plant community succession. As available water depths decrease, submersed species are outcompeted by emergent species, such as cattail (*Typha*), cutgrass (*Zizaniopsis* and *Zizania*), duck potato (*Sagittaria*), and alligatorweed (*Alternanthera philoxeroides*). These emergents will eventually give way to higher, dryer-tolerant marsh species, such as those that presently exist on the northern and western sides of the bay. These areas are now dominated by switch grass (*Panicum virgatum*), giant cordgrass (*Spartina cynosuroides*), sawgrass (*Cladium jamaicense*), torpedo grass (*Panicum repens*), and alligatorweed, as well as a variety of minor species (Lelong, 1973, personal communication). A large portion of these grasses die off during the early fall and reappear during the summer months. Marked changes in salinity may also have a local effect, as many of the grasses do not tolerate well any significant increase in salinity. Normal salinity concentrations in the bay, further, will be decreased by any elevation of the bay bottom (such as accompanies increased deposition). The

Fig. 4.--Northwestern channel entrance to D'Olive Bay.
Interstate 10 in background (looking north).

general high productivity of these grass beds provides food for a diversity of fish life in D'Olive Bay (mullet, bass, sturgeon, anchovey, croaker, etc.) which, in turn, attract other wildlife, such as birds (pelican, herons, gulls), nutria, and alligator. One alligator was observed near the southern dredge channel during this investigation whose length was estimated at between six and seven feet.

Sediments.--Bottom sediments in D'Olive Bay are composed dominantly of sands, silty clays and sand-silt-clay mixtures. Sands are common in the northeastern portion and along the eastern margin (see figure 5), and are also found in the areas surrounding the northern bay channel and the dredged channel. The remainder of the bay consists largely of samples containing roughly equal amounts of sand, silt and clay. A more detailed account of the bay's sedimentology is present in a later section of this paper.

Tides.--The tidal cycle of D'Olive Bay is closely related to that of contiginous Mobile Bay and, in general, is diurnal. Mobile Bay itself represents the terminus for the sixth largest river system in the United States, in terms of watershed area, and includes a region of approximately 43,000 square miles. Rivers emptying into the bay rank the system as the fourth largest in the Nation, in terms of discharge, with its average 100,000 cubic feet per second influx exceeded only by the Mississippi, Columbia, and Yukon. The large delta that lies proximal to the northern terminus of Mobile contains the Mobile River and three other major distributary contributing streams: The Tensaw-Spanish River, the Apalachee River, and the Blakeley River. These rivers annually carry some five million tons of sediment into Mobile Bay and are reported to proportionally contribute the following, in terms of total discharge (Corps of Engineers data, 1979):

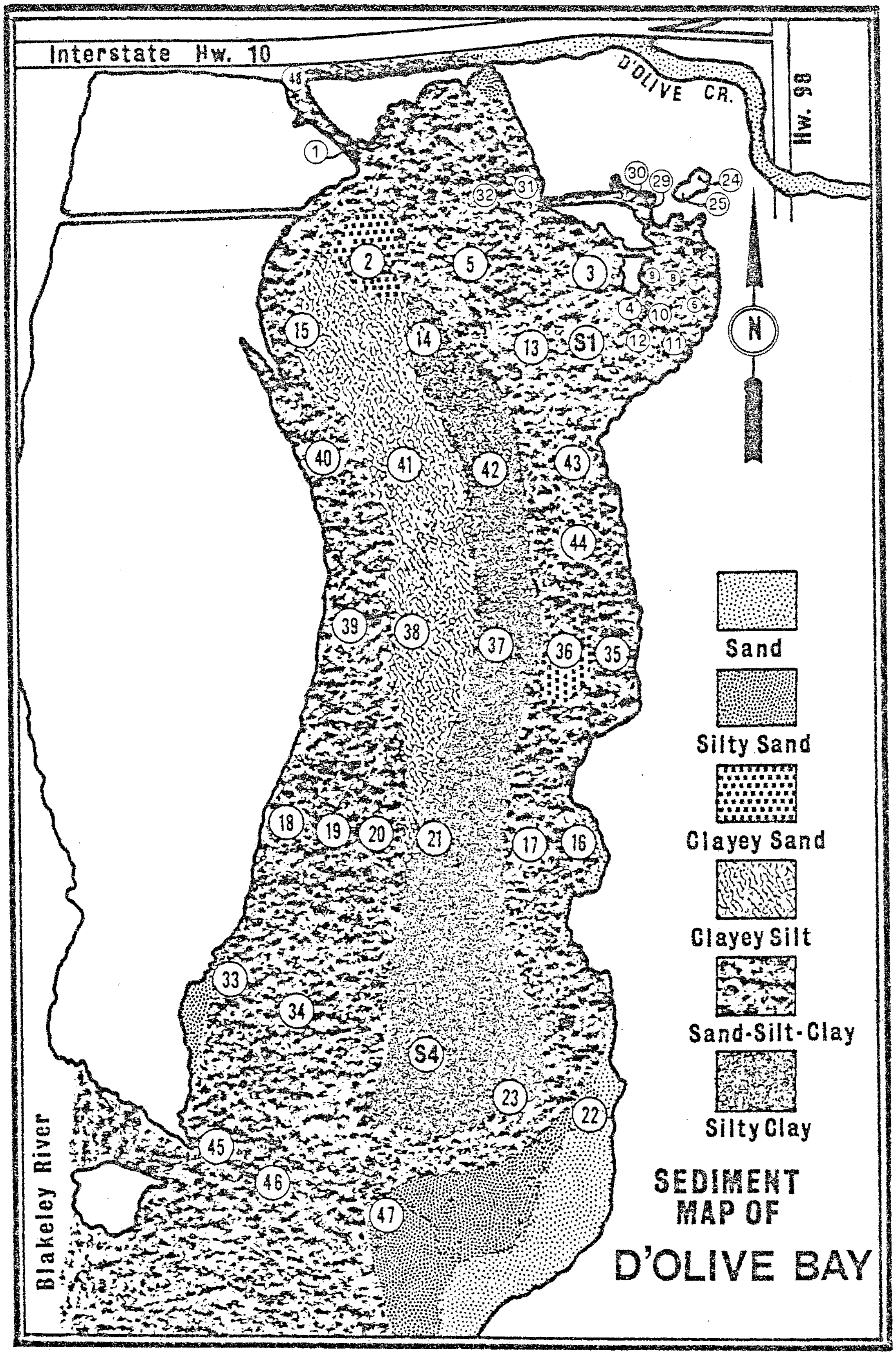


Fig. 5.--Bottom sediment map of D'Olive Bay showing core locations.

Lower Mobile River	25 ± 2%
Tensaw-Spanish River	28 ± 3%
Apalachee River	22 ± 2%
Blakeley River	25 ± 2%

The above discharges are applicable across the entire discharge range except during low discharges of less than 1,000 cubic meters/sec (35,000 $ft.^3$/sec) when water height fluctuations in Mobile Bay may substantially override the hydraulic head of any of the distributaries, causing major changes in flow characteristics. Surface waters entering Mobile Bay tend to move down the western side from both the Mobile and Tensaw-Spanish Rivers on both tidal currents. The magnitude of the velocity of net movement is directly dependent upon the quantity of freshwater inflow and the tidal stage. Average velocities during slack tide in the ship channel are approximately one mile per hour on the surface. Currents on the bottom of the upper bay are variable and generally weaker except in the main ship channel and within other distributary outlets into the bay. Tidal currents predominate only at depths greater than the bay's natural depth, such as in the ship channel itself. A saltwater wedge does exist in the channel as far north as the mouth of Chickasaw Creek when the Mobile River discharge reaches or exceeds 50,000 cubic feet per second. Currents in the lower bay, below Great Point Clear, are variable and tidal dependent. The direction of flow during ebb tide is generally to the south. During flood tides the currents exhibit a net counter-clockwise movement because of the geometric configuration of the bay and its' outlets and the timing of the tides at the outlets. These conditions, in conjunction with the natural Coriolis effect in estuaries, accentuate the movement of water down the bay along the western shore. The effect of the Mobile Bay tides on D'Olive Bay is such that a tidal range in both bays of approximately 1.5 feet is generally experienced.

During flood tide, water moves into D'Olive Bay from the south along the eastern side and, at the northeast corner, shoals and discharge from D'Olive Creek deflect flood tide waters toward the middle of the bay; ebb tides are marked by currents entering the northern pass and southwestern dredged channel and these combine to produce a general withdrawal of bay waters toward the south. Strong winds accompaning the tides may exaggerate both the normal water depths and rates of change throughout the entire bay.

Historical Description of D'Olive and Mobile Bays

Mounds and artifacts located on beaches and bluffs not far from D'Olive Bay's shores testify that the bay was visited by pre-historic man. The first known historical visit to the upper bay, however, is still the subject of some controversy. A bronze plaque located in front of the Old Inn, at Fort Morgan, bears the inscription: "In memory of Prince Madoc, a Welsh explorer who landed on the shores of Mobile Bay in 1170 and left behind with the Indians the Welsh language". Whether fact, or fiction, the alleged visit by this un-chronicled Welshman has received serious attention by a number of scholars because of identical Welsh and Indian words used by tribes as far north as Tennessee and as far south as Mexico.

Historical knowledge of visits to Mobile Bay can be traced to 1519 when Alonzo Pineda, while on an exploration expedition, first entered the Bay of Ochus (various spellings), as it was then known by the local Indian tribes. Pineda renamed the bay Espirtu Santo and, during his 40 day stay, explored the surrounding area and mapped the bay. Panfilo de Narvaez, in 1528, is also thought to have visited the bay in search of fresh water. Somewhat later, in 1540, Francisco Maldonado is reported to have anchored in the bay with four ships in order to re-supply DeSoto's ill-fated expedition. Since that time, Mobile Bay was visited at least six different times before the Spanish began several ill-fated attempts to colonization in the area, about the year 1558.

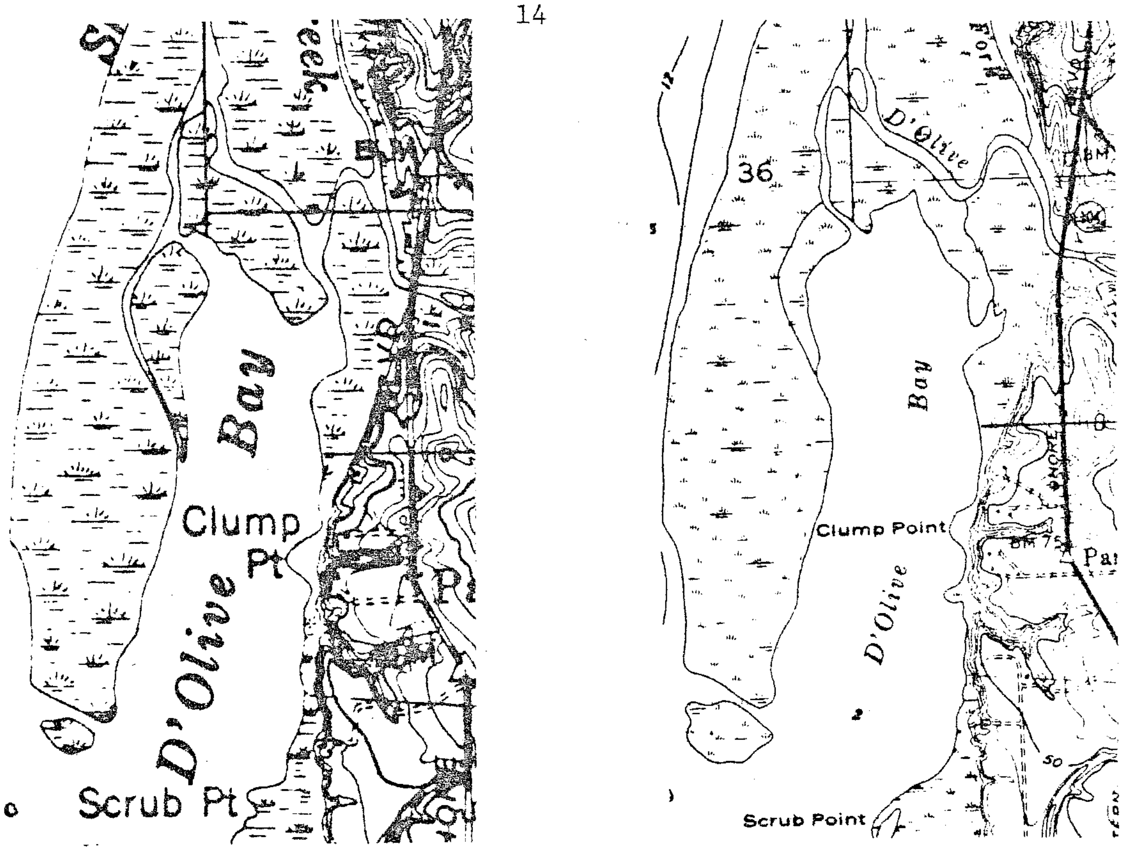
Actual settlement of the Mobile Bay area, however, was forced to await its "re-discovery" by the LeMoyne brothers, Iberville and Bienville, who entered the bay in 1699 and pronounced it an ideal site for a settlement. Iberville, in 1702, moved the Capital of French Louisiana, then at Maurepas (near present Ocean Springs, Mississippi), to the Mobile Bay area and the region has been continuously occupied since that time.

Nearly 100 years later, in 1803, a French immigrant by the name of Louis D'Olive settled on the eastern shore of Mobile Bay, just north of a small settlement known as "The Village". D'Olive was joined by his brother and both became prosperous planters. It was during the Civil War that the name "D'Olive Bay" was first assigned to the small, northeastern arm of Mobile Bay and the bay is known to have been used by both Confederate and Union troops as a docking site during the war.

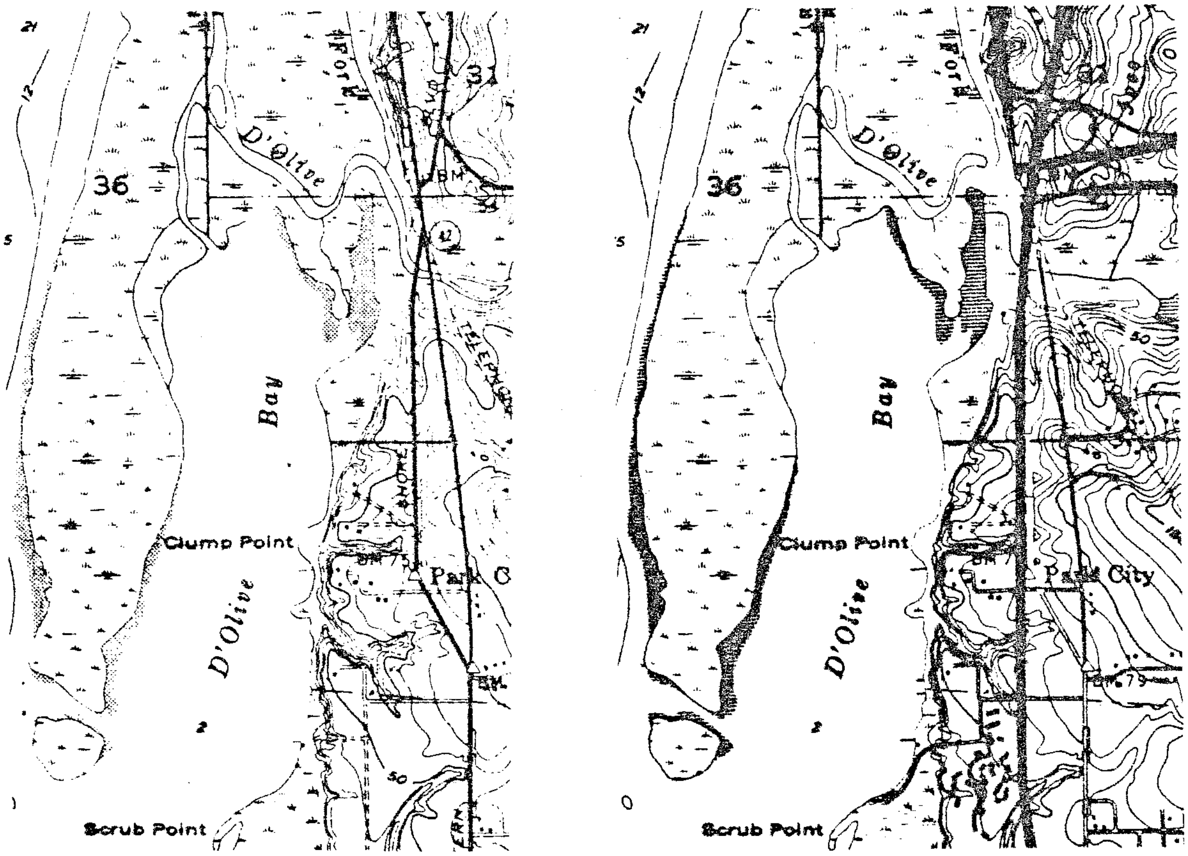
Topographic and Morphologic Evolution of D'Olive Bay

Recognition of the small northeastern section of Mobile Bay, known as D'Olive Bay, can be traced to the 1862 "Map of the Defenses of the City of Mobile," prepared by the U. S. Coastal Survey, where "D'Olive's Bay" is first shown. Maps constructed prior to this date (see Table 1) make no mention of this body of water, nor is it even shown as existing. Since the bay has formed by the process of longshore transport of sediments by the Blakeley River, it is likely that the development of the spit that separates it from the Blakeley thus occurred <u>after</u> 1820. This would coincide nicely with the development of extensive agriculture (and therefore increased erosion and sediment "loading" of rivers) in Alabama and would make the actual bay about 150 years old.

The morphological development of D'Olive Bay is shown graphically in Figure 6. The bay has as its major freshwater source, the sinuous watercourse (D'Olive Creek) which entered the bay originally from the north and through a small distributary located on its northeast corner. Sometime since 1872, a small portion of the Blakeley floodplain, approximately one half mile long, that is now located east of the Blakeley River, became isolated by a small stream that is now known as the Shellbank River. D'Olive Creek, which maps show emptied into D'Olive Bay only prior to 1872, subsequently cut a north-flowing channel to reach a terminus with the Shellbank River. The 1944 U.S.G.S. topographic map (surveyed 1939-1941) shows the northeastern distributary entrance closed off by a marshy region. As is presently the case, silt and clay-laden waters flowed into the bay during times of rapid runoff by flooding over this marsh area. D'Olive Creek continued to follow the course shown on the 1944 map until sometime in the late 1950's; the 1953 map still shows the "northeast" entrance into the bay closed off, but the 1967 revised map shows the "reappearance" of the northeastern arm which, by then, served as the main avenue of water and sediment influx into the bay. Prior to completion of Interstate 10, the 1974 map shows that deposition had essentially closed drainage of D'Olive Creek into the Shellbank River with all flowage from the creek entering D'Olive Bay by way of the enlarged northeastern arm. Subsequent photos taken in January, 1977, following completion of the Interstate highway, show that drainage of D'Olive Creek was diverted to flow into the work canal (see figure 3). During times of high runoff, however, most of the silt and clay-laden waters still flood over the low, marshy area and enter the bay from the northeast (see figure 1). These flow paths are routes by which sediment enters the bay and will, eventually, fill in the bay. This gradual filling is the fate of all such small bodies of water however, as will be shown in the following sections, man can, and does, drastically accelerate the rate of in-filling.



1944 Bridgehead Quad   1953 Bridgehead Quad



1967 Bridgehead Quad   1974 Bridgehead Quad

Fig. 6.--Morphological development of D'Olive Bay (scale 1:24,000).

Geology of D'Olive Bay Watershed Area

Baldwin County lies in the Southern Pine Hills sub-province of the Eastern Gulf Coastal Plain (Fenneman, 1938). The area generally consists of a rolling topography that is a consequence of differential erosion and dissection of older upland surfaces, capped by reddish-brown, silty, clayey sands of the Plio-Pleistocene Citronelle Formation. Underlying the Citronelle are Miocene units that Isphording (1977) subdivided into the Mobile Clay and the Ecor Rouge Sand (see figure 7). The former crops out, locally, in northern Baldwin County but all Miocene exposures in the study area are of the upper Ecor Rouge Sand unit. This formation is made up largely of a sequence of largely fluvial, cross-bedded, sands, gravelly sands and clay lenses that was named for the excellent exposure on the eastern side of the bay at Red Cliff (Ecor Rouge), north of Fairhope. Though the Miocene units are not yet formally subdivided on published geologic maps of Baldwin County, ample criteria are present to allow this two-fold differentiation. Similarly, the sands and gravelliferous units of the Citronelle Sand and Ecor Rouge Sand can also be differentiated (see Isphording and Riccio, 1972; Isphording, 1977).

No unequivocal terrace deposits of Pleistocene age were identified in the D'Olive-Tiawasee Creek watershed areas (though Blake (1978) reports terrace deposits a short distance away) and the only other potential source materials are recent alluvial deposits adjacent to the major river courses and their tributaries in the Mobile Delta area that lies to the north.

Blake (1978) reports that the Citronelle formation once formed a nearly continuous plain in this region, that sloped gently toward the south and has since undergone major dissection. The original westward-sloping Pleistocene terrace surfaces that he described along the bay shore are somewhat controversial (see Otvos, 1980), but there is little doubt as to their presence, if not their origin. A former major controversy, with respect to the study area,

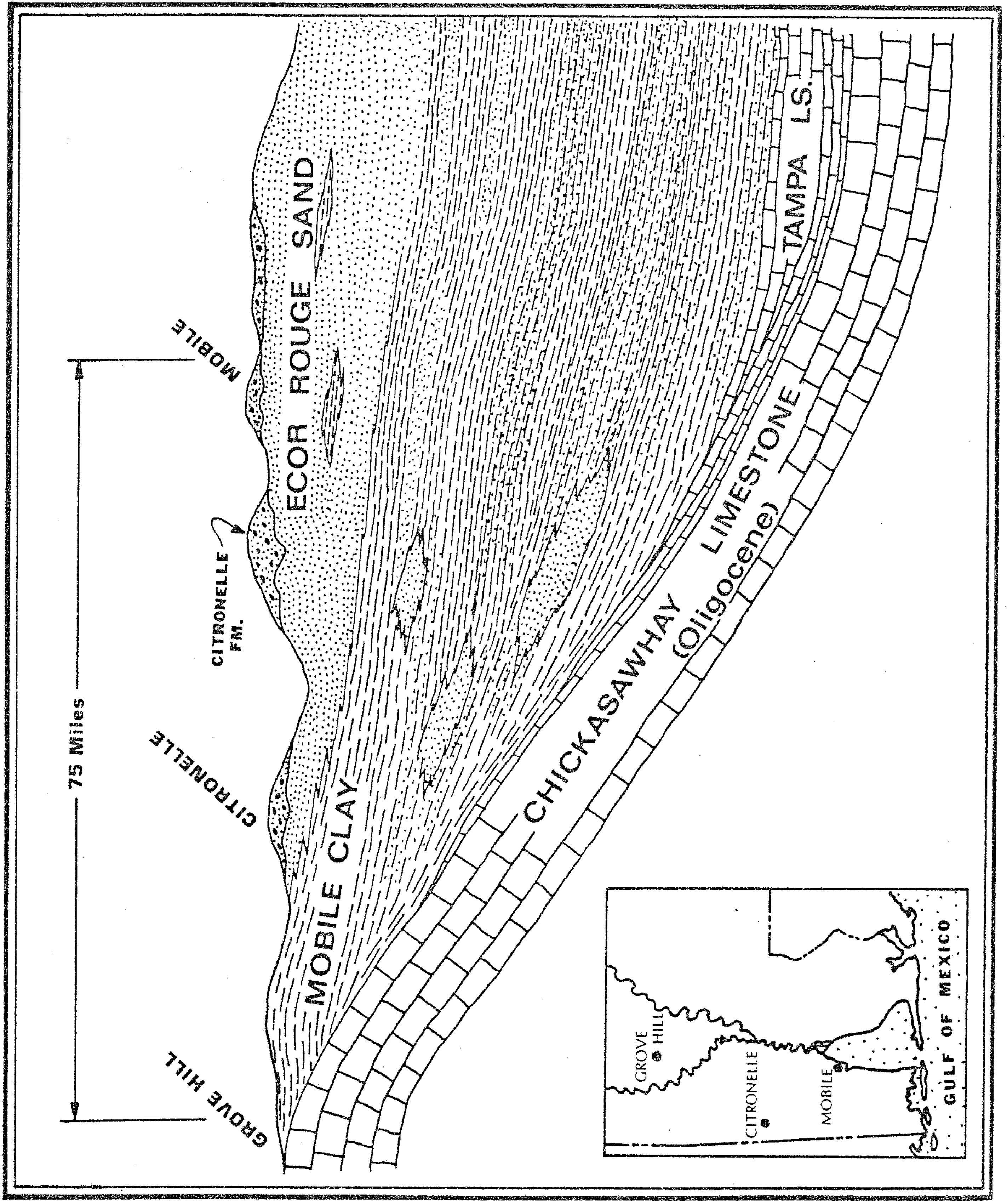


Fig. 7.--General stratigraphic relationships of Miocene and Pliocene units in southwestern Alabama.

involved the thickness of the unit that caps most of the hills in the watershed (the Citronelle Sand). Marsh (1964) reported the Citronelle as reaching 300 feet in thickness in Escambia County, Florida and as having a similar thickness near the eastern shore of Mobile Bay. Cagle and Newton (1963), in contrast, placed the maximum thickness of the Citronelle at less than 100 feet. Recent work by Isphording (1977) has shown that the apparent inconsistency resulted from Marsh's inclusion of the upper Miocene Ecor Rouge Sand in his calculation of "Citronelle" thickness and that the actual figure was closer to that suggested by Cagle and Newton. Blake (1978) has since reported values of 5 to 50 feet for the thickness of the Citronelle formation in Baldwin County. These are comparable to those noted by Isphording (1981) for the Citronelle in adjacent Mobile County.

Previous Work

Vittor (1972) carried out early studies on the D'Olive Bay area in order to assess the impact of dredging and spoil dumping in the bay during construction of the Lake Forest Marina facilities. Vittor's study furnished useful baseline information on the fauna and flora of the bay, as well as data on a number of variables measured on water column samples (dissolved oxygen, salinity, turbidity, current direction, etc.). He generally concluded that the channel dredging that took place during late summer of 1972, and the failure of a spoil area dike in August, 1972, had caused no long term effects on the bay's plant and animal life. This conclusion was not shared by Borom (1979) and the dike failure had similarly been identified as a cause for concern in an earlier environmental investigation carried out by the Mobile District, U. S. Army, Corps of Engineers (1973). Vittor (personal communication, 1981), qualified his previous conclusions to the extent that the comments made in the 1972 report were operable at that time, but not necessarily at present. That is, no significant long term variation in the turbidity was observed during the 1972 study period and, though subtle changes in the in-fauna were observed in the channel area, monitoring data indicated that the fauna was recuperating.

Palmer and Baker (1973, 1974) submitted reports on the general environmental impact of construction of the marina facilities but, with the exception of a detailed floristic study contracted to Dr. Michael Lelong, their report largely "re-hashes" older published material and provided little new information on the bay. Six sediment sampling stations were established, though, near the sewage outfall line and did furnish some useful baseline data.

Blake (1978) carried out an extensive study on the engineering geology of a portion of Baldwin County that included the D'Olive Bay watershed area. Important information was provided in this study on the structural geology of the areas as well as the engineering properties and stability of the soils that are now undergoing erosion and are being carried into D'Olive Bay. A summary of his results is presented in Table 2. Miocene sands are seen to be generally of coarser grain size and the Miocene clays are more plastic than their Citronelle or Pleistocene counterparts. Data on the Miocene sediments indicated that a decrease in grain size within the units was accompanied by decreases in dry density and increases in water content and void ratio. Loss of soil strength is known to occur in both cohesionless granular soils and cohesive fine grained soils as a consequence of their lower moisture content and higher void ratios. Further, Citronelle sediments are seen to be significantly stronger than Miocene units in terms of shear strength and compressive strength and to possess higher dry densities and greater cohesion. Lack of cohesion, especially, is known to accelerate surface wash and gullying. Of significant importance was Blake's observations on the slope stability of the various units. Problems of slope stability were most prevalent, as expected, wherever natural or

Table 2.--Physical properties of major stratigraphic units in the D'Olive Bay drainage basin (modified after Blake, 1978).

	Mean Diameter	Plastic Limit	Liquid Limit	Plasticity Index	Void Ratio	Water Content(%)	Dry Density (pcf)[1]	Permeability	Cohesion (T/ft^2)[2]	Compressive Strength (T/ft^2)[2]
MIOCENE SANDS (well graded)	.87	--	--	--				4.0×10^{-3}	--	--
					.677	10.2	113.5			
MIOCENE SANDS (poorly graded)	.42	--	--	--				1.35×10^{-1}	--	--
MIOCENE SILTS AND CLAYS	.24	21.2	50.6	29.2	.915	18.4	104.4	3.6×10^{-7}	1.55	1.57
CITRONELLE	.18	16.7	42.3	13.2	.689	16.6	121.2	1.52×10^{-6}	2.67	2.40
PLEISTOCENE	.17	20.8	23.3	2.6	.836	12.6	117.5	2.26×10^{-4}	0.51	0.55

1 pcf = pounds per cubic foot

2 T/ft^2 = tons per square foot

artificial cuts had exposed the underlying materials to erosion. Under such conditions, problems in slope stability can usually be traced to the engineering properties of the weakest soil unit exposed on the slope. Blake concluded that any commercial and residential development within the study area should occur on the relatively flat surfaces of the Citronelle formation and the Pleistocene terraces, because of their greater inherent stability; Miocene surfaces should be considered only as an alternative because the higher plasticities of the clays and the lack of cohesion in the sands produces slope stability problems. The extensive commercial and residential development in the D'Olive Bay watershed, especially in locations that were initially heavily dissected by D'Olive and Tiawasee Creeks, thus was fated to more rapid erosion rates and slope failure by virtue of the fact that Miocene sands and clays dominate the area.

Support for Blake's conclusion can also be found in a recent study carried out by Crisler (1981) for the Soil Conservation Service, U. S. Department of Agriculture. A map identifying "erosion hazard" within the D'Olive Bay watershed area was developed (see figure 8) and, as expected, the areas prone to greatest erosion were found lying within areas showing the most extensive fluvial dissection. Factors controlling sheet and rill erosion were identified and quantified by Crisler, using the Universal Soil Loss Equation (USLE), and when the weighted averages of specific parameters in the USLE were multiplied together, a value known as the "erosion hazard index" (EHI) was obtained. The elevated values of the EHI for areas 3A, 3C, and 3D shown on Table 3 (each in excess of 100) testify to the extensive "potential" for sediment contribution from these areas (see discussion in Crisler, 1981).

Carlton and Gail (1980) carried out a detailed study to determine the effects of erosion and sedimentation, within and around Lake Forest Resort and

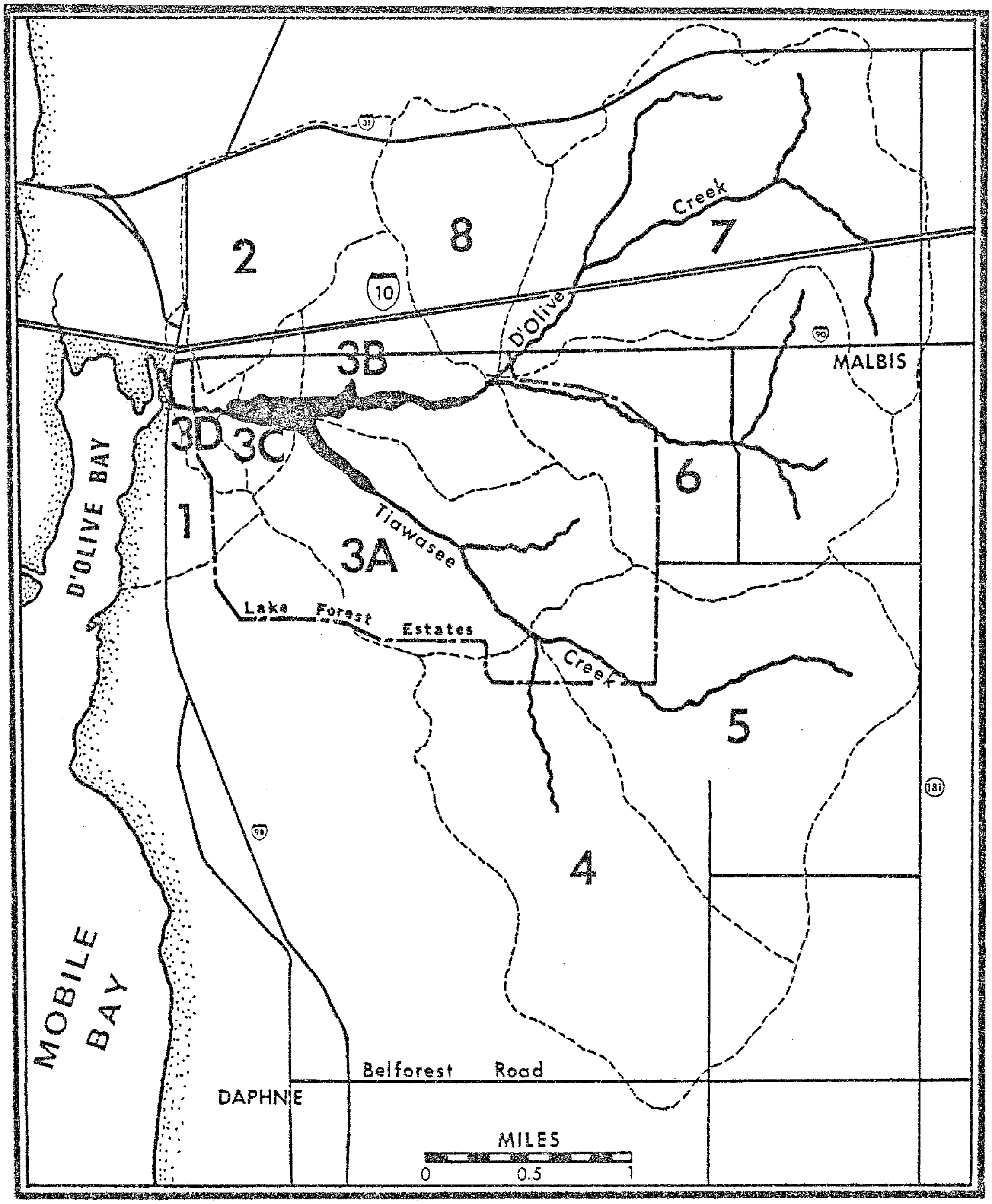


Fig. 8.--Erosion hazard index map for Table 3 (modified from Crisler, 1981).

D'OLIVE BAY WATERSHED

SUB-AREA*	ACRES	EROSION HAZARD INDEX (EHI)
1	214	42
4	1,267	51
7	1,502	54
6	1,162	58
5	1,246	66
8	468	74
2	526	98
3B	487	98
3A	767	105
3C	132	129
3D	107	138
	7,878	

*see Figure 8

EHI = K x L x R x S where:

K = value related to the inherent properties of the soil (particle size, strength, etc.)

L = slope length (measured in feet)

R = rainfall factor (dependent upon amount, pattern and intensity)

S = slope steepness (measured in percent)

Table 3.--Erosion hazard index for sub-units within the D'Olive Bay watershed area (modified from Crisler, 1981).

on the water quality of Tiawasee Creek and D'Olive Creek. Water samples were collected from a total of 38 monitoring stations and were analyzed for Total Suspended Solids and Turbidity. Analysis of the data revealed that there were three major contributors of sediment to the Tiawasee Creek and D'Olive Creek drainage basins: (1) a sand pit on Highway 90, owned by Malbis Plantation, Inc. (which is drained by D'Olive Creek), (2) a sand pit owned by J. M. Earle Contractors, located on Yancey Road, and (3) Lake Forest Resort, formerly owned by the Diamondhead Corporation but now operated by the Purcell Company, located in Pinehearst, North Carolina. Both of the latter are drained by Tiawasee Creek.

The pit located in Sec. 32 on Highway 90 (Fig. 9) can largely be excluded as a significant source of sediment pollution for two reasons: (1) the pit has been in existence only since 1978 (Ms. Mallars, Malbis Corporation, personal communication, 1981) and (2) effective action was taken immediately by the pit owners to restrict sediment discharge, following notification by the Alabama Water Improvement Commission in 1979 that abnormal turbidities had been observed downstream from the pit. Carlton and Gail's study, thus concluded, that the vast majority of material causing the excessive turbidity in Lake Forest reservoir, the lower portion of D'Olive Creek (west of the reservoir dam), and D'Olive Bay was derived from sources located along Tiawasee Creek.

The Tiawasee Creek watershed area includes some 3,280 acres and was divided by Carlton and Gail into three sub-units for purposes of assessing the contribution of each to the turbidity problem. One source of pollution was quickly identified as the large borrow pit located on Yancey Road, operated by J. M. Earle, Contractors. This quarry was first operated in July, 1976 and was also identified as a source of sediment pollution by the Alabama Water Improvement Commission (AWIC) in 1979. Subsequent construction of a holding pond in August, 1980, however, resulted in a marked decrease in the contribution of sediment to Tiawasee Creek. Monitoring data collected in 1980 by the AWIC

Fig. 9.--Sand pit in D'Olive Bay watershed located north of Interstate 10, operated by the Malbis Corporation (John Carlton photo, 1979).

Fig. 10.--Collapsed earthen dam on Tiawasee Creek (John Carlton photo, 1979).

showed that this pit was no longer contributing significant pollution to the lower watershed. The pit is now no longer used and has been inactive since early in 1980 (Ms. J. M. Earle, 1981, personal communication).

Further investigation revealed that all remaining sources of sediment contamination in Tiawasee Creek could be attributed to erosion from within Lake Forest Resort. Specific problem sites within the subdivision have been identified by Carlton and Gail including: (1) the past construction of earthern dams across Tiawasee Creek (Fig. 10), (2) the channelization of Tiawasee Creek, which has resulted in an increased velocity for the stream, causing increased erosion of the banks and preventing solids from settling out, (3) numerous unpaved roads in the subdivision (Fig. 11), (4) unstabilized bridge embankments and (5) large deposits of spoil located along the banks of Tiawasee Creek (Fig. 12). Their study also examined the contribution of materials from sources emptying into D'Olive Creek below the reservoir dam and found no significant evidence of unnatural pollution other than "...possible bedload contamination during the construction of I-10". The effects of Interstate 10 construction as a source of sediment contamination in D'Olive Creek and D'Olive Bay are discussed in a later section of this report.

Support for Carlton and Gail's conclusions was, similarly, found in Crisler's (1981) study. Crisler examined the erosion problem in the D'Olive Bay watershed and presented information on erosion estimates and land-use changes over the period from 1967 to 1980. He concluded that, while some erosion may be traced to highway construction, gullys and borrow pits in the area, that most is caused by construction practices involving grading without adequate shaping and re-vegetation (largely within the Lake Forest Resort subdivision). Further reference to Crisler's work is made in a later section of this report.

Fig. 11.--View showing a portion of the unpaved road network in Lake Forest Estates (S. Coleman photo, 1979).

Fig. 12.--View looking up southeastern arm of Lake Forest reservoir where Tiawasee Creek enters lake. Note extensive deposition along banks (S. Coleman photo, 1979).

Fig. 14.--"Split spoon" core of typical clay-rich sediments in D'Olive Bay.

PRESENT INVESTIGATION

Methodology

General.--One of the primary tasks of this investigation was to determine a means of identifying the amount of material that has been carried into D'Olive Bay since extensive development of the watershed area commenced in 1967. Previous studies have clearly established that the source for most of the turbidity observed in the bay is sediment derived largely from sources along Tiawasee Creek and, to a lesser extent, from sources along upper D'Olive Creek and Joe's Creek. The initial problem was to identify criteria that could be used to "mark" the onset of rapid sediment influx into the bay and to determine if a sediment balance for the watershed could be calculated in order to establish: (1) how much material was being trapped by Lake Forest reservoir and D'Olive Bay and (2) how much sediment passes through the bay into Mobile Bay.

Change in Mean Particle Size.--Intuitively, four possible means of identifying "impact" should be available to the investigator. The first relates to changes that might be expected in the size frequency distribution of the sediments. The disruption of natural drainage by denuding rural or wooded lands by construction activities has, historically, been shown to markedly affect the rates of sediment discharge into depositional basins. Prior to extensive development of the watershed area, the sediments carried into the bay from natural exposures along D'Olive and Tiawasee Creeks would have had a "mean" particle diameter that was a function of the overall gradients of the contributory streams. As vegetation was stripped from the watershed area during residential and commercial development, runoff velocities and quantities necessarily would increase, as would also the flow velocities in the small streams. Figure 13 suggests that a watershed, such as that contributing sediments to D'Olive Bay, could be expected to produce up to 1000 times the normal rate of

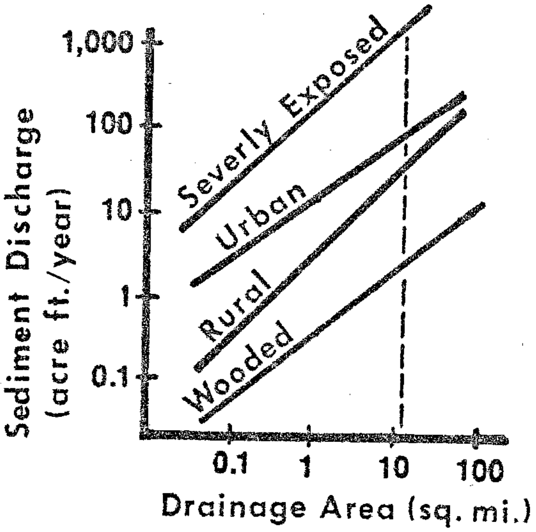


Fig. 13.--Expected sediment discharge (annual) for various size watershed areas. D'Olive Bay watershed shown with dotted line (source: U.S.G.S. Open File Report, 1972).

sediment influx, following disruption of natural runoff and infiltration by land clearing and construction activities. The sediment discharge is expected to be high in the D'Olive Bay watershed because of the extensive dissection that is present and the inherent instability of most of the exposed sediments (see discussion of Blake's work on page 18 of this report).

Sediment runoff into D'Olive Bay was not only accelerated by the extensive development that occurred in the watershed in the years since 1967, but should also reflect a change in the size frequency distribution brought about by the construction of the Lake Forest reservoir dam. Prior to construction of this feature, a complete "range" of particle sizes would be expected to have been deposited in the bay, reflecting the size distribution of the source sediments. Following construction of the dam, however, a marked change toward finer particle average diameters would be expected as a consequence of the "trapping" of the larger particles behind the dam. Hence, prior to the collection of any samples, it was concluded that cores taken within D'Olive Bay should show an abrupt "change" in mean particle size from relatively coarse (i.e., "coarser") grained sediments in the lower part of the section to finer materials toward the top of the cores that would evidence the increased amount of silt and clay size material carried as suspended load into Lake Forest reservoir and then swept through the discharge pipe into lower D'Olive Creek during times of high rainfall and rapid runoff.

Change in Mineralogy.--A second means of identifying the onset of more rapid sedimentation rates within D'Olive Bay involves changes in the mineralogy of the bay sediments. These changes would be detected in both the clay mineral fraction and the heavy mineral fraction, each for different reasons.

Changes in the clay mineral fraction would be expected within cores taken in the bay that would result from the increase in the amount of kaolinite carried in by the increased runoff from the watershed. All of the sediments exposed in the drainage basin are characterised by a clay mineral fraction composed, almost wholly, of the mineral kaolinite. Prior to any accelerated influx of sediments from this basin, the bottom sediments of D'Olive Bay would have consisted of a mixture of materials carried into the bay area by Mobile Bay tidal currents and supplementary material derived from the adjacent uplands by natural erosion. Sediments carried in from Mobile Bay would, necessarily, be largely fine grained and would contain those clay minerals that are brought into the region by the Mobile, Tensaw and Blakeley rivers. Earlier studies by Isphording and Lamb (1979) have established that the bottom sediments of Mobile Bay are dominated by montmorillonite (65%), and contain lesser amounts of kaolinite (25%) and illite (10%). Hence, allowing for sediments contributed from both natural erosion from within the D'Olive Bay watershed and fine clays carried into D'Olive Bay from Mobile Bay tidal currents, the bottom sediments of D'Olive Bay (prior to "impact") would be expected to be rich in both montmorillonite and kaolinite, with a small amount of illite also present. If a rapid increase in sediment from the D'Olive Bay watershed were to occur, an abrupt change should be noted in core samples where kaolinite suddenly becomes noticeably more abundant. Obviously, this change in abundance of kaolinite should occur at the same position in the cores as does the decrease in mean particle diameter. Both occurring at the same location in each core could hardly be considered "coincidental" and would clearly denote the onset of environment "impact".

Still another mineralogical change that should be discernible in each core penetrating the "impact" zone is one involving a change in the heavy mineral population. Heavy minerals, by definition, are those minerals present in all clastic sediments that "sink" when immersed in acetylene tetrabromide (tetrabromoethane). Acetylene tetrabromide has a specific gravity of 2.95, hence all heavy minerals have specific gravities that exceed this value. Quartz, the dominant constituent of all Gulf Coast sands, usually will comprise over 99 percent of each sample and, by virtue of its specific gravity of 2.65, can be "floated" off in acetylene tetrabromide. Numerous studies have shown that different formations may be distinguished by differences either in the heavy mineral species present in the sand fraction or by the ratios of the different heavy minerals present (see Rosen, 1969; Pirkle, Allen and Yoho, 1965; Isphording, 1976; Isphording and Flowers, 1980). The heavy minerals present in "pre-impact" D'Olive Bay sediments, as with the clay minerals, would be expected to consist of a mixture of "Mobile Bay" types (carried in by tidal currents and flood tides) and those derived by natural erosion from the D'Olive Bay drainage basin. With the onset of more rapid erosion brought about by the activities of man, an increase in the contribution of heavy minerals from the Tiawasee and D'Olive Creek sources should be apparent in the upper portions of any core penetrating the "impact" horizon, coinciding in position with changes in grain size and clay mineralogy.

Change in Organic Carbon Content.--One final means of identifying a change in the sediment regimen involves differences in the organic carbon content of "pre" versus "post" impact sediments. The amount of organic material present in D'Olive Bay bottom sediments would normally reflect a, more or less, constant, albeit seasonal, level of biological activity in the bay and debris carried into the bay be erosion. More rapid erosion taking place in the watershed would be expected to provide more organic material (i.e., woody debris) because less would be destroyed by normal oxidation and decay. Hence, at the same levels that changes are observed in grain size and mineralogy in the cores, a similar change (increase) in organic carbon content should be observed.

Sampling Program.--A total of nine sampling traverses of D'Olive Bay were carried out during the summer of 1980 (see figure 5) in order to collect sediment and bathymetric data. Forty-eight cores were taken both along traverse lines and at other locations deemed appropriate using a 1 - 3/8 inch diameter "split spoon" core barrel (see figure 14). Each core was split in the field into four inch segments and returned to the lab for analysis. Thirty auger samples and outcrop samples were similarly collected at sites throughout the watershed area and along all major streams. Eleven traverses were also carried out across Lake Forest reservoir (see figure 15) and a total of ten core samples were collected for sediment and mineral analysis. Sediment samples and bathymetric data were also collected along north-south traverses located in the Interstate 10 work canal (see Figs. 23, 24, and 25).

Laboratory Analysis.--All samples were returned to the laboratory in sealed, plastic bags. A split of approximately 10 grams was removed from each sample, placed in a plastic vial, sealed and frozen for later use in determining organic carbon content. The following paragraphs describe the procedures used to analyze each sample.

SIZE ANALYSES - Each sample was air-dried and split to approximately 50 grams. This portion was then soaked overnight in a half liter of distilled water to which 10 ml of 10% sodium hexametaphosphate was added. The sample was then disaggregated by stirring for five minutes on a soils stirrer, poured into a one liter hydrometer cylinder, diluted to volume, and a hydrometer analysis carried out using standard ASTM procedures. Following completion of the hydrometer analysis, the sample was poured through a 270 mesh (53 micron) wet sieve and the +270 mesh material was collected for sieve analysis. Sieve analyses were carried out using a one phi interval using a 230 mesh (63 micron) sieve as the sand-silt boundary. Statistical analyses of the size frequency data were performed on an IBM 4341 computer in order to determine the measures of central tendency and dispersion.

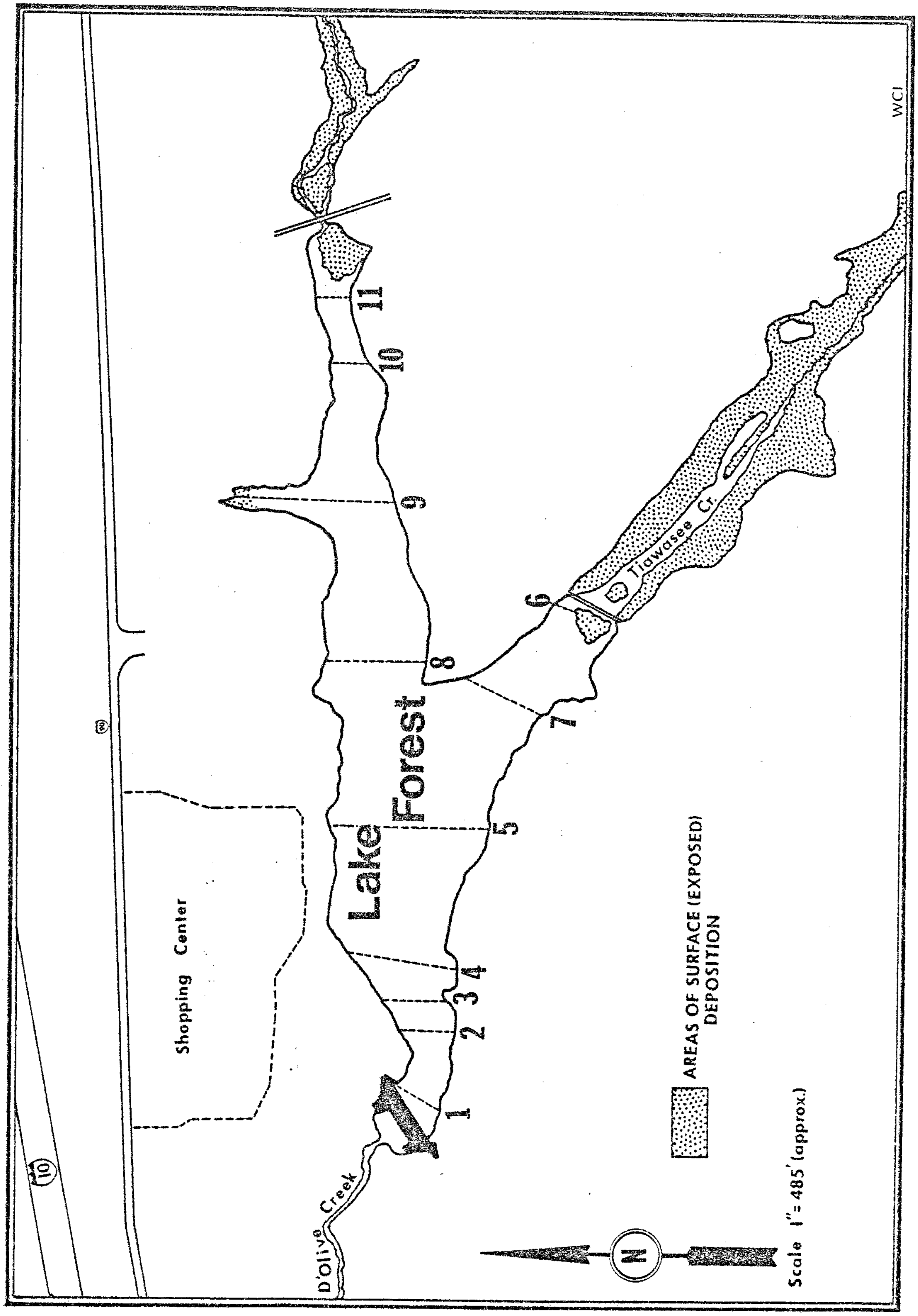


Fig. 15.--Map showing location of reservoir traverse lines and sites of extensive above water deposition.

CLAY MINERAL ANALYSES - Following completion of the 20 hour hydrometer reading, the suspended sediment remaining in the upper 15 cm was poured off and flocculated by adding 10 ml of 10% $MgCl_2$. The flocculated material was then centrifuged and a small quantity removed and placed evenly on three 45 x 26 mm glass slides so as to obtain a thickness of between 0.07 and 0.12 mm. This thickness has been shown to produce the minimum background by X-ray scattering and to yield an optimum diffraction pattern. After each slide had dried, it was transferred to a dessicator where it remained until X-ray analysis was carried out or until it was subjected to glycol treatment or thermal analysis. All X-ray analyses were performed using a Philips X-ray diffraction system, equipped with single crystal graphite monochrometer and copper radiation. Scans of all untreated slides were run from two degrees to approximately twenty degrees two-theta in order to identify all clay mineral phases present. Glycol or thermally treated slides were scanned from two degrees to fifteen degrees two theta. A total of 232 X-ray analyses were carried out.

HEAVY MINERAL ANALYSES - Samples of the -60 mesh (0.25 mm), +120 mesh (0.125 mm) sand fraction of each sample were selected for heavy mineral analysis. Each sample was poured into a stoppered funnel to which acetylene tetrabromide had been added. Following stirring, the sample was allowed to settle for 30 minutes and the settled minerals tapped off. More tetrabromoethane was then added to the sample and the procedure repeated one additional time. The heavy mineral portion was then washed in acetone and mounted on standard 45 x 26 mm glass slides using AROCHLOR 4465 (refractive index, 1.66) as a mounting medium. Heavy mineral counts were made for each slide using a Leitz-Wetzlar petrographic microscope equipped with mechanical stage and grid ocular. Identification of specific opaque and non-opaque minerals was carried out using standard optical mineralogy reference texts.

ORGANIC CARBON ANALYSES - No attempt was made to determine the actual carbon content in samples selected for analysis. Rather the amount of organic carbon was indirectly estimated by determining the Loss on Ignition (weight percent) by heating the sample in a muffle furnace at 110°C for 30 minutes.

DENSITY DETERMINATIONS - Eighteen samples were selected for Bulk Density analysis in order to supply information necessary for calculating sediment volumes. Four inch segments were removed from the split-spoon core barrel and were immediately sealed in air-tight plastic bags. On return to the lab, the sample was weighed and then placed in a 50°C and dried overnight. The sample was then removed, placed in a dessicator and allowed to cool to room temperature. The sample was then re-weighed in order to determine both the Percent Moisture and the Bulk Density, using appropriate equations (see Appendix).

RESULTS OF ANALYSIS

Rainfall

As shown earlier, soil within the D'Olive Bay watershed has unstable properties and when its natural condition is modified by the works of man, severe erosion can result. The major cause of erosion is rainfall and the main transport mechanism of the eroded sediments is rainfall runoff. The amount of sediment discharge generally increases with increases in water quantity. However, the selection of a "...rainfall factor used to estimate average annual soil loss must include the cumulative effects of the many moderate-sized storms, as well as the effects of the occasional severe ones..." (Wischmeir, et al, 1978). Complete rainfall records for the Fairhope station were examined back through the year 1967 and a summary of the data is shown in Table 4. Also shown in Table 4 is the frequency of occurrence of the 24-hour rainfalls (Hershfield, 1961). The rainfall data show that in only one year, 1978, did a 24-hour rainfall occur with a frequency greater than the 14-year period of study. This rainfall occurs on the average of once each 44 years. For the other years, all the maximum 24-hour rainfalls have frequencies of less than 2.7 years and for seven of the years the frequency of occurrence is more than once per year. Examination of the rainfall data yields a more complete understanding of the relationship between soil instability-construction practices and consequential erosion.

YEAR	ANNUAL RAINFALL	AVERAGE RAINFALL FOR DAYS RAINFALL REPORTED	TOTAL DAYS RAINFALL REPORTED	MAXIMUM 24 HOUR REPORTED	FREQUENCY OF 24-HOUR RAINFALL (YEARS)
1967	51.88	0.541 inches	96	4.25	1.0
1968	41.17	0.401	103	2.81	1.0
1969	75.91	0.656	116	6.15	2.7
1970	64.62	0.479	135	4.58	1.0
1971	55.98	0.413	136	2.47	1.0
1972	57.10	0.545	105	4.12	1.0
1973	71.12	0.545	132	2.92	1.0
1974	55.34	0.459	121	5.12	1.5
1975	88.12	0.527	168	5.55	2.0
1976	64.90	0.533	122	4.90	1.3
1977	57.90	0.409	136	2.96	1.0
1978	94.06	0.719	131	11.25	44.0
1979	70.16	0.546	129	4.91	1.3
1980	67.75	0.503	131	5.47	1.8
"normal"=65.60		0.520 (average/reporting "incident")	1,761		

Table 4.--Summary of rainfall data, Fairhope Station, 1967-80.

Sedimentary Environmental Impact, 1967-1980, Lake Forest Estates

The region included in the D'Olive Bay watershed covers an area of nearly 8,000 acres (see Table 5). Fifteen years ago, most of the land was in the form of forests or in agriculture use and, referring to figure 13, it can be seen that a minimal amount of rainfall runoff and sediment discharge into D'Olive Bay would be expected. Commercially and residentially developed lands have more than tripled since 1967, largely in the area known as Lake Forest Estates (Resort), and have brought about marked changes in both rainfall runoff/infiltration and soil erosion/deposition budgets for the watershed.

Land Use	1967	1980	Change
Forest	6,034 (77%)	3,938 (50%)	-2,096 (-27%
Agricultural	1,125 (14%)	1,313 (17%)	+188 (+3%)
Urban	640 (8%)	2,146 (27%)	+1,506 (+19%)
Miscellaneous	79 (1%)	191 (2%)	+122 (+1%)
Multilane Highways	0 (0%)	290 (4%)	+290 (+4%)
	7,878	7,878	

Table 5.--Land use in D'Olive Bay Watershed area (in acres) 1967 versus 1980 (modifed after Crisler, 1981).

As seen in Table 5, the only land use category to lose acreage was forested land (approximately 2,100 acres). Urbanization, in contrast, accounted for about 1,500 acres of lost forest land with the other categories making up the balance. The conversion from forest to urban land, it should be noted, occurred almost entirely within the Lake Forest Resort area. The effect of this change in land use has been to increase erosion rates to an estimated level six times as great as those occurring within the watershed in 1967 (Crisler, 1981). Unfortunately, much of this eroded material has been deposited with detrimental effect in Lake Forest reservoir and in D'Olive Bay. The land use conversions shown on Table 5 would not, under normal circumstances, be accompanied by erosion rates six times the former levels except that a significant amount of residential development was apparently carried out in a manner that could only produce dire consequences. Not only was extensive land clearing being effected on soils that were strongly prone to slope failure without adequate protection but other factors, such as climate, a vast network of unpaved roads, and the apparent inadequate design of drainage channels, in combination, produced large scale gullying and erosion throughout the residential area. Though attempts have been made to reduce the number of dirt streets, it is estimated that unpaved roads presently existing in the Lake Forest community (approximately 6.6 miles) annually produce some 1,250 tons of sediment per mile (see Table 6). This source alone has been estimated to have contributed about 44,000 tons of eroded sediment per year to the drainage basin during the interval 1971-1974. The completion of the paving of the remaining 6.6 miles is one obvious necessary step to alleviate the existing sediment runoff problem.

Year	Miles of Unpaved Roads	Miles of Paved Roads
1971	35	3
1974	27	11
1975	17	21
1976	10	28
1980	6.6	31.4

Table 6.--Number of miles of paved versus unpaved roads in Lake Forest community (modified after Crisler, 1981).

Other steps will be required, however, before the Lake Forest community area can reduce runoff levels to near normal values. Numerous sites are present (see figures 16-19) where storm water drains have ruptured and where gullying is

Fig. 16.--Collapsed street in Lake Forest Estates caused by culvert failure and headward erosion of gully (Lake Forest Estates, 1980).

Fig. 17.--View showing broken culvert and undercutting of street (Lake Forest Estates, 1980).

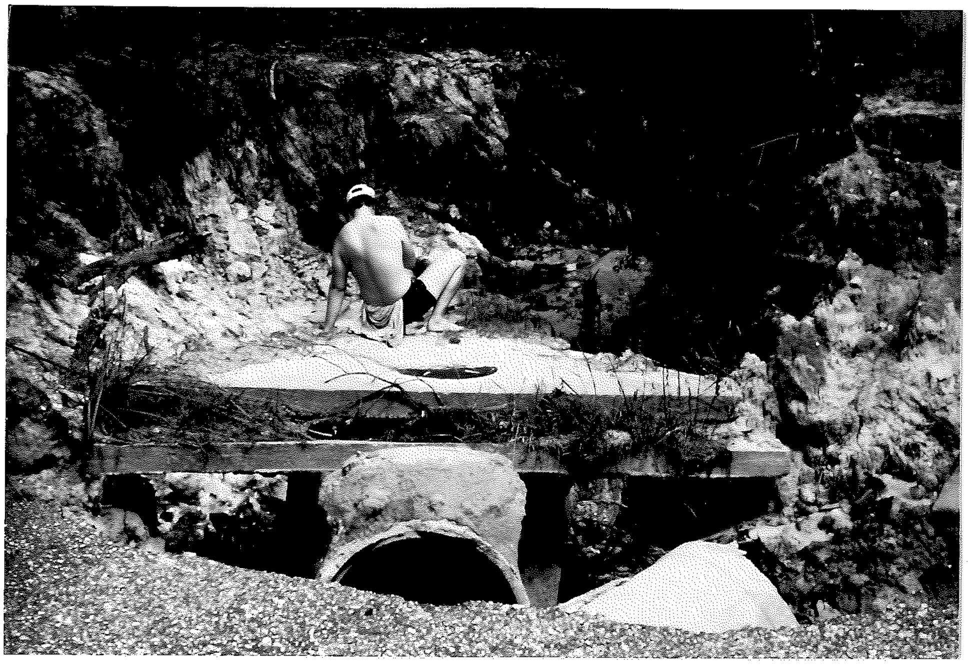


Fig. 18.--Exposure and distruction of culvert pipes by gully erosion (Lake Forest Estates, 1980).

Fig. 19.--Slope failure and exposure of 3 foot diameter, corrugated culvert pipe (Lake Forest Estates, 1980).

actively widening older stream channels. Sheet wash in unprotected areas, especially on slopes, rapidly removes soil cover, exacerbating the problem. As slope steepness increases, there is a corresponding rise in the velocity of the surface runoff and, therefore, erosion. A doubling of the velocity of water produced by increasing the degree and length of the slope enables water to move sediment particles 64 times larger and allows it to carry 32 times more soil material, making the total erosive power a total of 4 times greater (EPA, 1976). Once soil and vegetation is removed, water will flow over the land in the path of least resistance with the result that numerous rills are developed on the unprotected surface. Continued enlargement of the rills by subsequent rains form gullys which carry eroded debris downslope until it is deposited into "feeder" streams. Numerous locations are present throughout the Lake Forest area where large gullys have developed in close proximity to major feeder streams assuring a "maximum" removal of material. Once eroded debris reaches any of the small streams, its eventual removal downstream is assured by the high stream gradients. Further, when such sediments eventually reach the major streams in the watershed (D'Olive Creek and Tiawasee Creek), similar high gradients (see figure 20) carry the eroded material into Lake Forest reservoir where the coarser particles settle out forming large deltas at the creek mouths. An example of one such delta is shown in figures 21 and 22 which has formed at the head of Lake Forest reservoir where D'Olive Creek empties into the lake. Deposition of this type has persisted at a high rate for the past 14 years with the result that the trap efficiency and volume of the reservoir has been severely reduced. The total amount of sediment carried into the reservoir over the 14 year period was estimated by first determining the original reservoir volume by planimeter from the 1967 and 1974 U.S.G.S. Bridgehead topographic quadrangles. The reduction in this volume was then determined by running a series of cross-sectional bathymetric profiles across

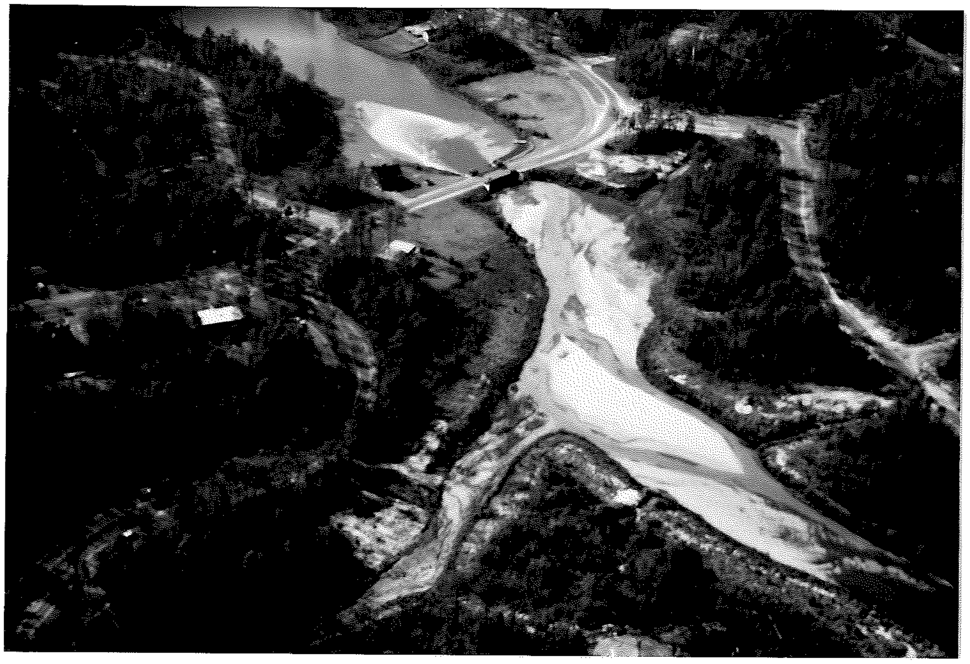
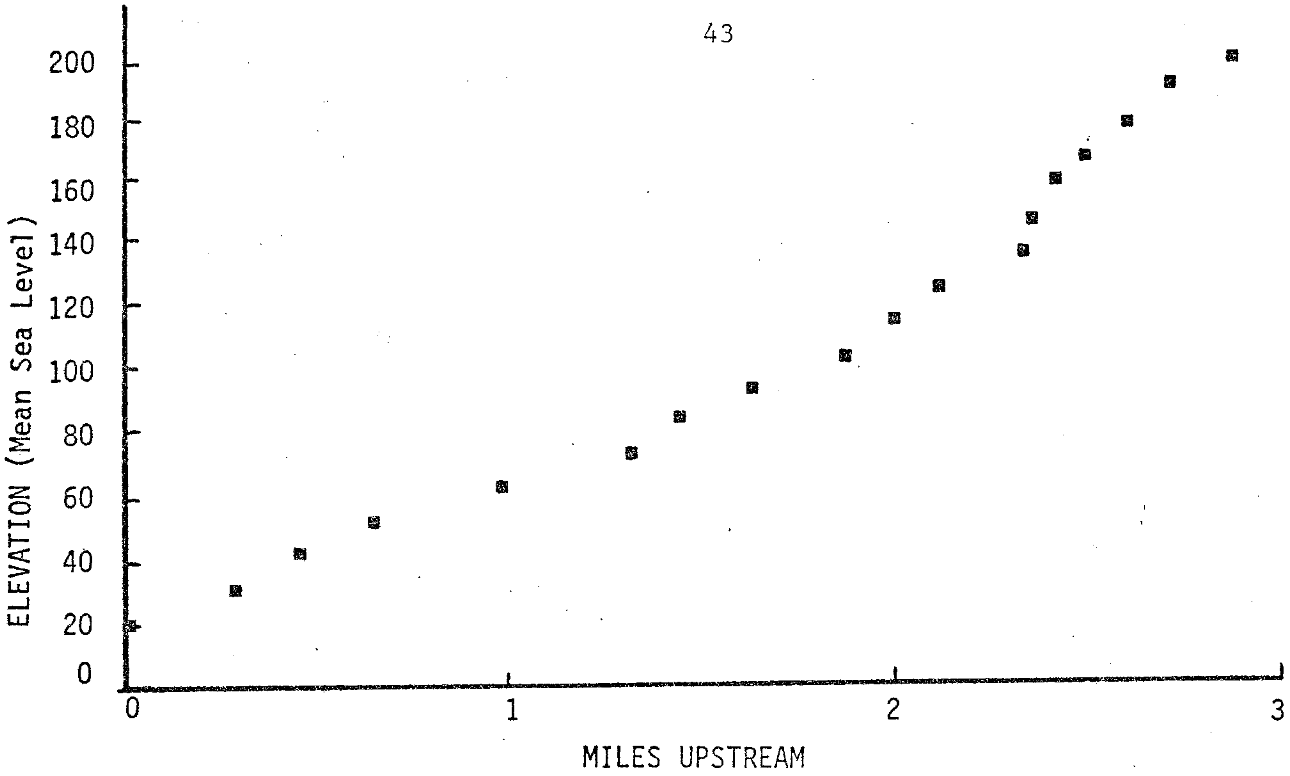
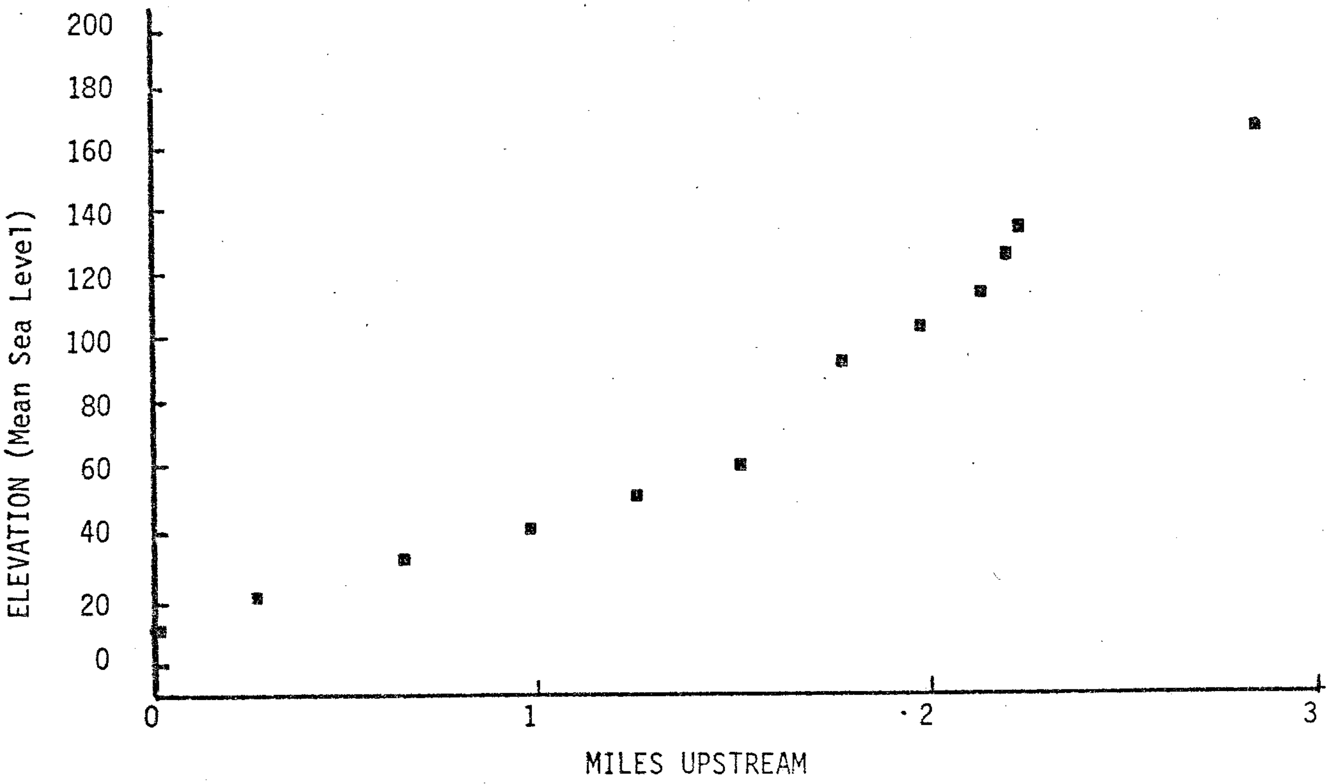


Fig. 21.--Aerial view showing extensive deposition along D'Olive Creek, east of Lake Forest reservoir, and delta forming where creek enters lake (1980).

Fig. 22.--Ground view of delta at eastern end of Lake Forest reservoir (1980).



Gradient of D'Olive Creek beginning at original lake head (mile 0)



Gradient of Tiawasee Creek beginning at original lake head (mile 0)

Fig. 20.--Gradients of D'Olive and Tiawasee creeks based on "zero" point location near head of original lake.

the reservoir (cross sections are included in the Appendix). The actual calculations are summarized below.

1967 Reservoir Volume	620.20 Acre Feet
1980 Reservoir Volume	265.75 Acre Feet
Deposition =	345.45 Acre Feet

345.45 Ac. Ft. x 43,560 ft.^{3}/Ac. Ft. = 15,349,842 ft.^{3} of deposited material.

15,439,842 ft.^{3} x 93 lbs./ft.^{3} (density of sand) = 1,435,905,305 pounds of sediment deposited.

1,435,905,305 lbs./2000 lbs./ton = 717,953 Tons of Sediment Deposited in 14 Years.

Unfortunately, Lake Forest reservoir has acted to trap only the coarse grained sediments and, during times of high rainfall and runoff, the finer silts and clays remain in suspension and are washed through the dam's discharge pipe, ending up in D'Olive Bay. This can be especially well seen in Figure 1 which shows the sediment-laden waters emptying out into the work canal of Interstate 10 and flooding into D'Olive Bay. Figure 2, taken by Skylab IV satellite, shows a sediment plume extending southward into Mobile Bay following rainfall in the previous 24 hours that amounted to some 1.46 inches (measured at the Fairhope station). Prominent plumes of waters discolored by high sediment content are common following rains in this area and testify to the fact that a portion of the debris eroded from the watershed is carried all the way into Mobile Bay.

Sedimentary Environmental Impact, 1967-1980, D'Olive Bay

Interstate 10 Work Canal.--That D'Olive Creek serves as the principal entry point of most materials deposited in D'Olive Bay in the past 14 years is obvious from several lines of evidence. Not only is the clay mineral content of surface sediments found in D'Olive Bay distinctly different from the sediments in the Blakeley River (and Mobile Bay) but, as will be discussed later, the texture of the sediments also are markedly different. Further, reference to figures 3 and 23 show that, other than D'Olive Creek, the only additional conceivable source for sediment in the bay would be from the Blakeley River. While a small amount of sediment may, during times of flooding, overtop the boundary marsh or move eastwardly along the work canal, and then south through the northwest channel entrance into the bay, any large scale transport of such material is unlikely. Bathymetric traverses taken across the work canal (see figure 23) clearly show that negligible "in filling" of the work canal has taken place from the northern side while a substantial reduction in cross sectional volume has occurred at the mouth of D'Olive Creek and westward along the southern margin of the canal. This can be seen in figure 24 which shows the bottom configuration along the four profiles and the reduction of the original 10 foot canal depth by extensive deposition from D'Olive Creek. Material is obviously building outward from D'Olive Creek and has been carried westward along the canal and, for all practical purposes, has sealed off an older "north" entrance to the bay. This "pass" can no longer be used, even by small skiffs, and the bay now can be entered only by the northwestern channel entrance (Figure 4) or at its southern terminus with Mobile Bay. Continued deposition by D'Olive Creek will, ultimately, seal off the northwest entrance and may well create future access problems for work crews carrying out repair or maintenance work on the Interstate 10 piers in the work canal.

Description of Sediments.--To document the effect that accelerated deposition from D'Olive Creek has had on D'Olive Bay over the past 14 years, a series of eight coring traverses were carried out in order to identify: (1) the distribution of different sediment types within the bay and (2) to determine if it was possible to establish a depth in the cores that would testify to the

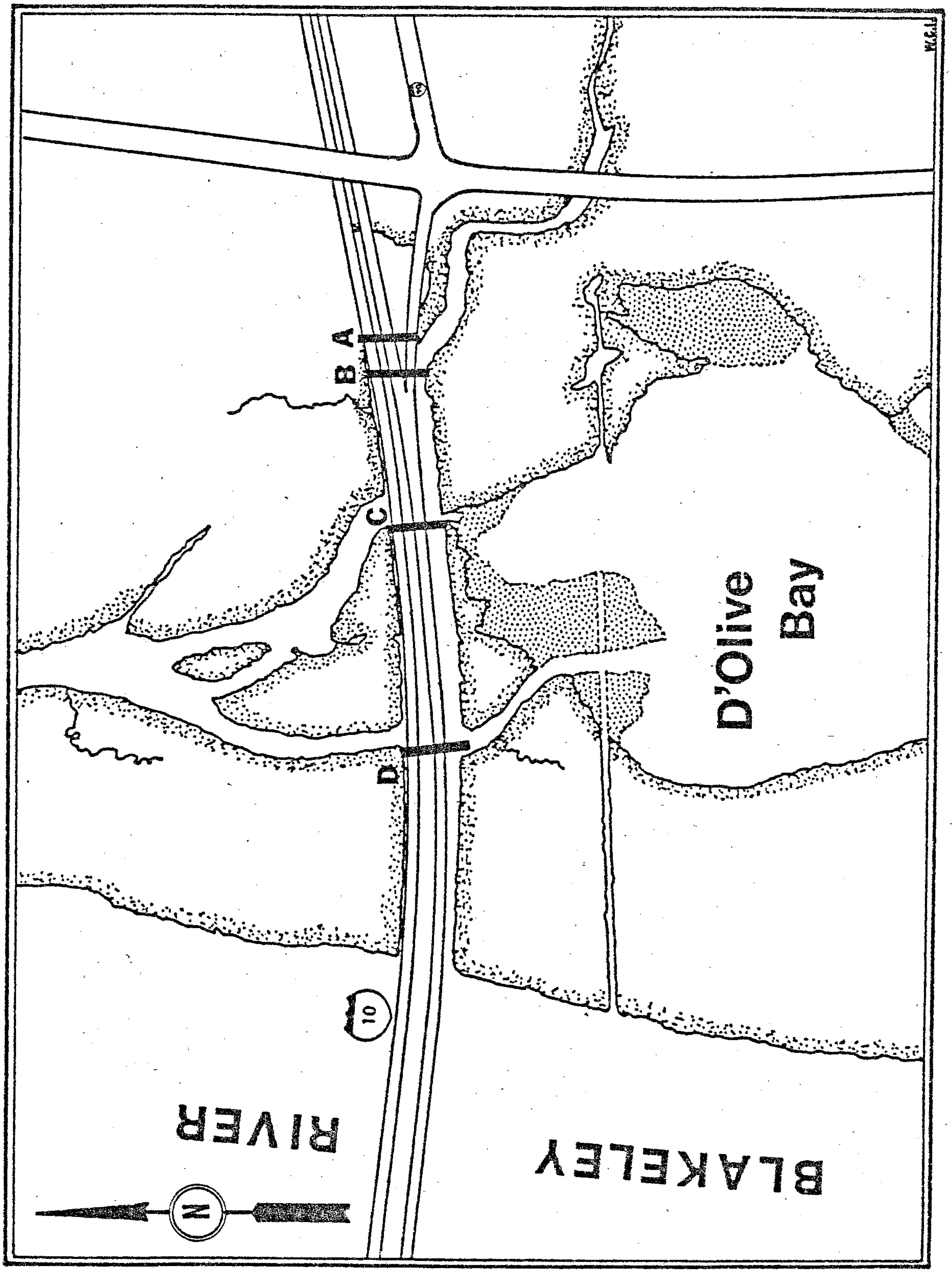


Fig. 23.--Map showing location of Interstate 10 work canal traverse lines (scale: 1" = 485').

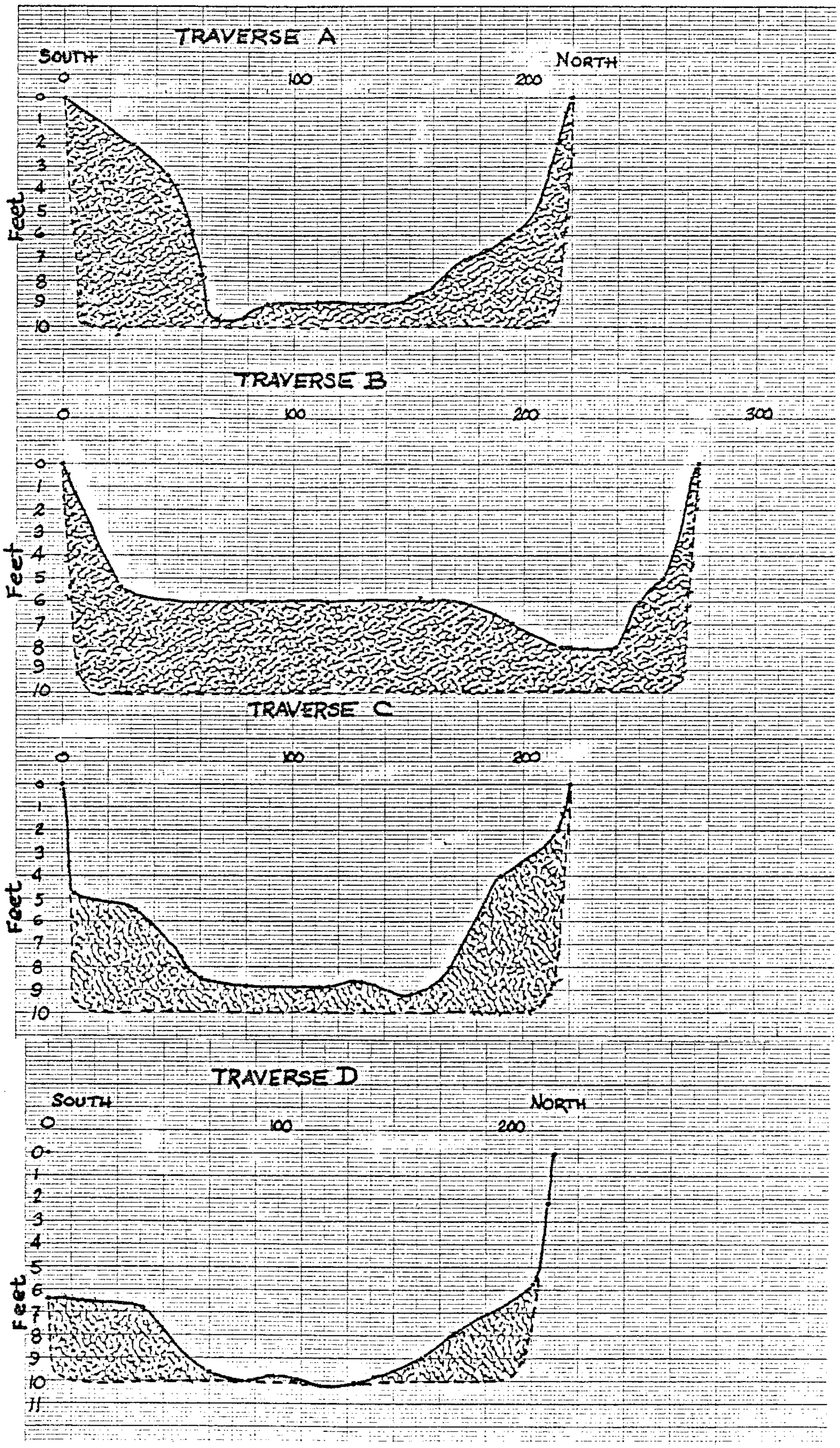


Fig. 24.--Bottom sediment profiles across Interstate 10 work canal showing reduction of original ten foot depth.

initiation of a marked change in the bay's sediment regimen. The rationale for this has been discussed in an earlier section of this report.

Surface sediments vary widely within D'Olive Bay from pure sands in the northeast corner, where most coarse detritus from D'Olive Creek is deposited, to dominantly sand-silt-clay mixtures throughout much of the remainder of the bay. Sands are also common along the eastern side of the bay, near Scrub Point, where they are derived from erosion of the adjacent land area, and north of the western entrance of the dredged channel at the southern terminus of the bay. The overall distribution of sediment types differs markedly from those found in Mobile Bay, testifying to a difference in source for the D'Olive Bay sediments (see figure 25). Pure clays (i.e., greater than 90% clay-size material) are common in Mobile Bay as are also silty clays. D'Olive Bay sediments in contrast, are considerably richer in silt and sand components, reflecting the major contribution of both D'Olive and Tiawasee creeks.

Grain Size Variation.--Identification of the position in core samples that reflected the beginning of "impact" was clearly seen by analysis of variations in mean particle diameter. Figure 26 shows that an abrupt change in diameter from generally coarse grained sediments (mean diameter greater than 50 microns) to fine grained sediments (mean less than 20 microns) is clearly visible in the cores of Transects 2A, 3 and 4 at an average depth of approximately 18 inches. This change simply is an indication that the sediment regimen of the bay underwent a relatively rapid change, beginning about 14 years ago, involving an influx of finer grained material. Coarse sediments (sands) are much less common as a dominant constituent, having largely settled out in Lake Forest reservoir or near the head of the bay. The cross sections also show that at one time sandy sediments were common toward the mouth of the bay, prior to the construction of the dam, when heavy rains occurring in the watershed would transport

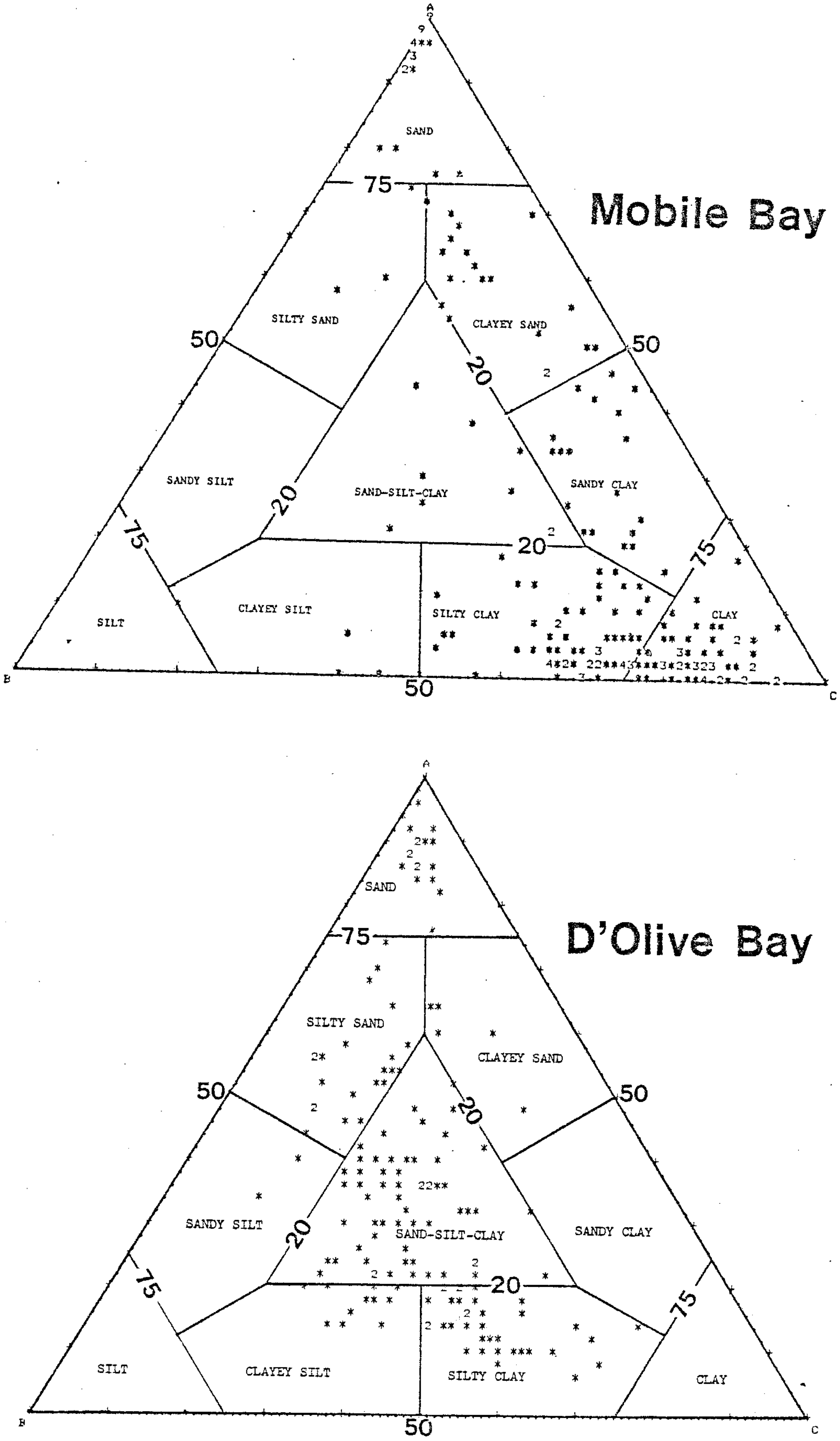


Fig. 25.--Ternary diagrams comparing sand-silt-clay ratios for Mobile Bay and D'Olive Bay (sediment classification after Shepard, 1954).

materials of all sizes down D'Olive and Tiawasee creeks, to be discharged into D'Olive Bay.

Clay Mineralogy.--A similar striking change is also observed in the clay mineralogy of the bottom sediments (Fig. 26). Again, an abrupt change is observed upward in the cores, with respect to the kaolinite (and montmorillonite) contents. Kaolinite is characteristically low in the "pre-impact" sediments, averaging less than 20 percent, and evidences the original presence of substantial amounts of montmorillonite on the bottom with later additions carried into the bay from Mobile Bay by tidal currents. Once this contribution of Mobile Bay material no longer dominated the bottom sediments, because of the increased amount of material deposited from the D'Olive Bay watershed, montmorillonite would be expected to decrease abruptly. Analysis of the bottom material conclusively shows that it does and that the clay mineral fraction becomes dominated by a kaolinite-rich source (the Citronelle and Ecor Rouge formation in the adjacent highlands). Upper sections of cores, therefore, show kaolinite contents that average nearly 30 percent and, in some cases, the mineral makes up over 40 percent of the sample!

Heavy Minerals.--Heavy mineral analyses also clearly confirmed the position of the impact boundary in D'Olive Bay and showed that distinct statistical differences exist between sediments above and below the boundary.

These differences were quantitatively identified by using a multivariate statistical procedure known as discriminant analysis. The mathematical objective of a discriminant analysis is to "weigh", and compare, variables from two (or more) groups and to then linearly combine the weighting in a manner such that the groups are forced to be as statistically distinct as possible (see Isphording and Flowers, 1980). This operation thus acts to transform the measured values obtained for all variables in a given sample into a single

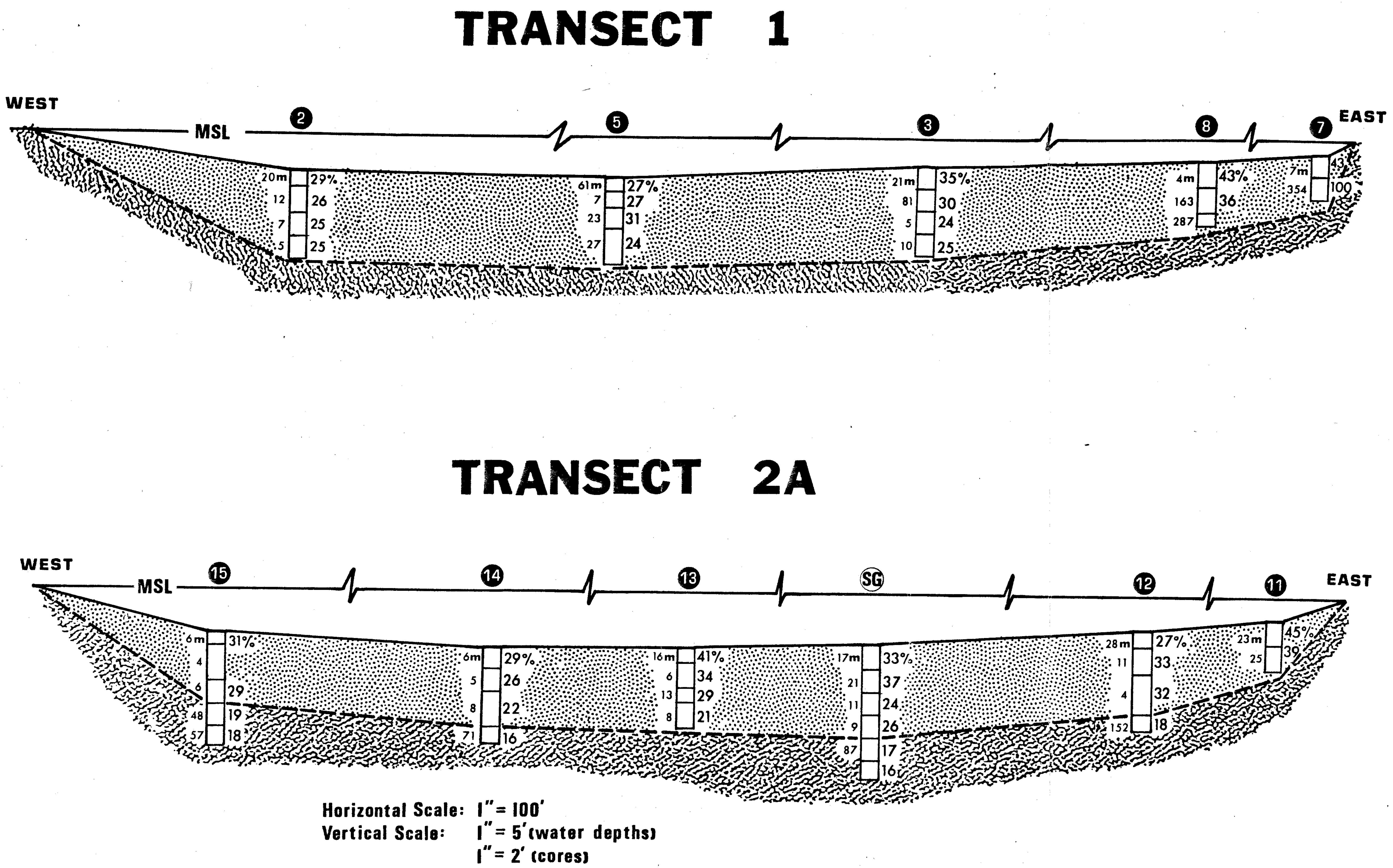
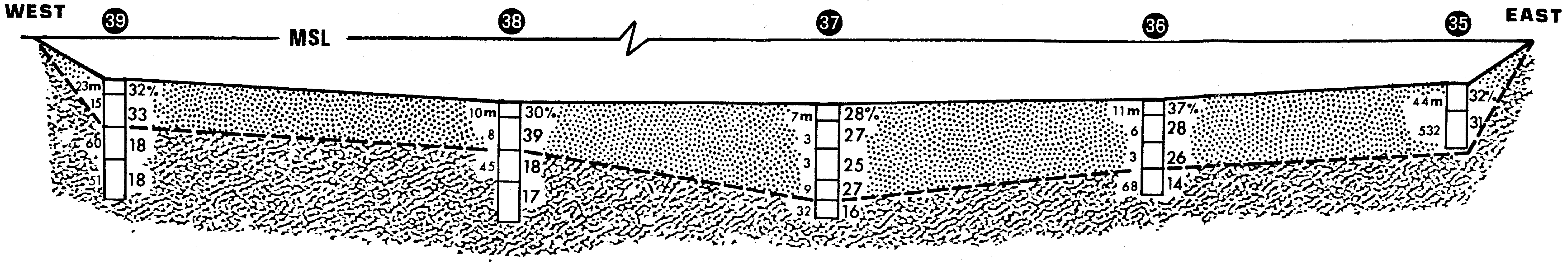


Fig. 26.--Cross-sectional profiles of D'Olive Bay showing variation in median diameter (measured in microns on left side of cores) and in kaolinite content (measured in percent on right side of cores). Scales are applicable to original, unreduced diagrams only.

TRANSECT 3



TRANSECT 4

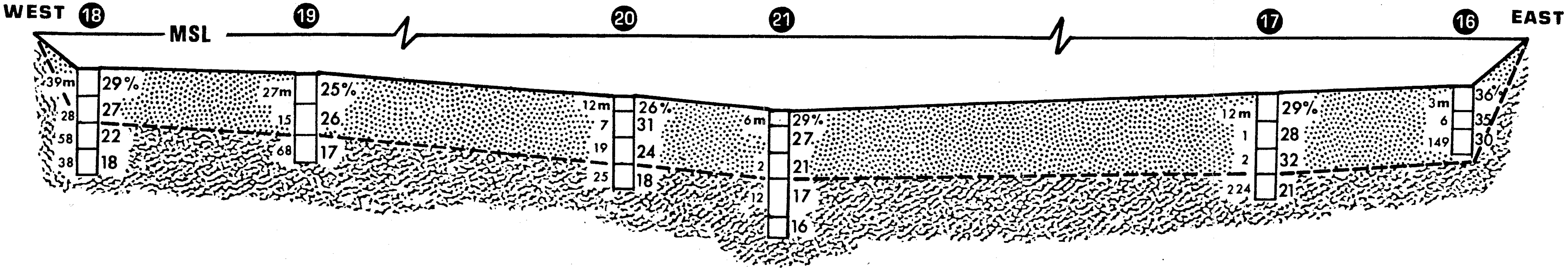


Fig. 26.--(continued)

discriminant score that can be plotted on the resulting discriminant line. The transformation can therefore be visualized as a search for an orientation in multivariate space where the two (or more) groups show the greatest separation and the least dispersion.

For the D'Olive Bay problem, each discriminant score plotted on the discriminant function (line) represents a weighting of the percentages of the different mineral species present in sediment samples from above and below the "impact boundary". The excellent separation of "pre-impact" from "post-impact" sample scores on the discriminant line leaves little doubt as to the validity of this contact (see figure 27).

Table 7 presents the results of the discriminant analysis and shows that the discriminating variables that were most effective in differentiating the two groups (i.e., "pre" vs. "post" impact sediments) were tourmaline, rutile, kyanite and leucoxene. Samples from above the impact boundary were characteristically lower in all four minerals by small, but statistically consistent, amounts. The average percentage of grains present in each sample from above and below the boundary is summarized below.

	Rutile	Kyanite	Tourmaline	Leucoxene
Above boundary samples	2	14	7	7
Below boundary samples	4	16	8	9

Samples were chosen from each group by using a random number generator in order not to introduce bias into the analysis. A total of 32 samples were used from above the boundary position and 23 from below. In all cases, only those mineral counts for which at least 300 grains had been counted were used in the analysis.

Organic Carbon.--Total organic carbon, as estimated from "loss on ignition" at 110° Celsius, was found to be the least effective of the four methods for

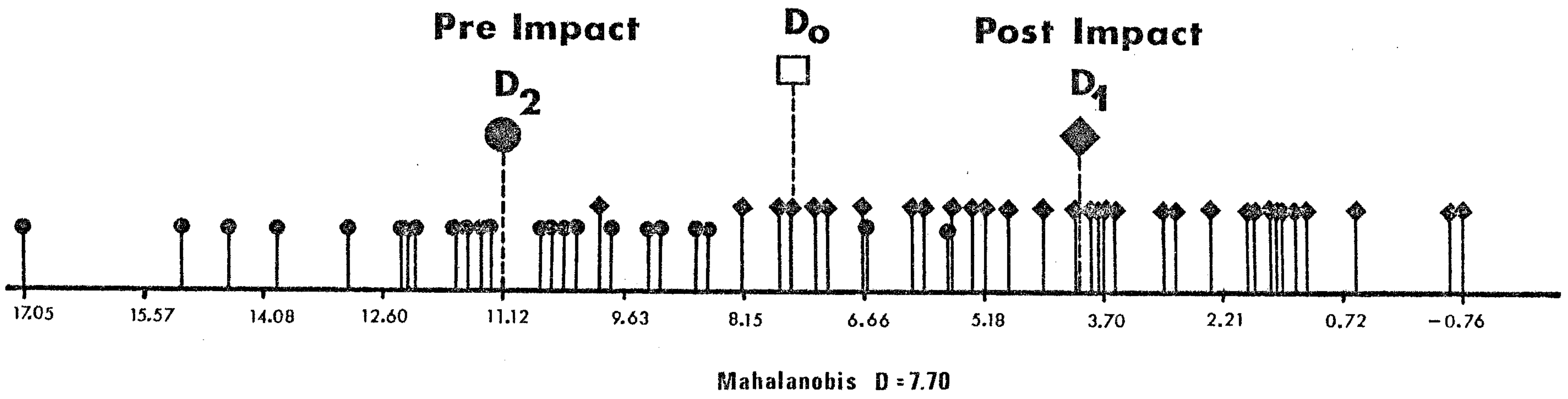


Fig. 27.--Discriminant score plots of "pre-impact" versus "post-impact" samples.

Table 7.--Results of discriminant function analysis for "pre-impact" versus "post-impact" samples.

Variable	Mineral	Constant*	Percent**
1	Epidote	-3.292	-28.67
2	Garnet	-4.532	-1.38
3	Hornblende	-5.202	-59.37
4	Kyanite	-5.416	+227.37
5	Pyrite	-5.291	+42.44
6	Rutile	-5.581	+220.76
7	Sillimanite	-5.013	+13.35
8	Staurolite	-5.188	+5.89
9	Tourmaline	-5.760	+144.87
10	Zircon	-5.471	+89.15
11	Ilmenite	-5.170	-556.46
12	Leucoxene	-5.431	+226.00
13	Tan Opaques	-4.743	-263.95

$F_{(13,42,.05)} = 2.00$ (from tables)

$F_{(\text{calculated})} = 2.64$

Reject Null Hypothesis H_0: $D_1 = D_2$
(and conclude the two groups are statistically different)

*Predictive coefficients used in the discriminant equation.

**Variables preceded by negative signs are "associating" variables. They act to draw the two data sets together because of similar values in both data sets, thus confounding the discrimination process. Those preceded by a positive sign are the "discriminating" variables that serve to separate (distinguish) the two groups.

placing the impact boundary. While a general tendency was found for sediments above the boundary to possess the expected higher organic carbon content, the differences were often not of significant magnitude to allow the unequivocal placement of the boundary position on the basis of this variable alone. The reason for the lack of effectiveness of this variable is unclear but probably can be traced to a combination of three causes: (1) the fact that "loss on ignition" does not truly measure "total organic carbon" but, rather, measures the weight loss in the sediment of materials that will volatilize at 110° C. This would also include small amounts of adsorbed (non-structural) water and possibly other inorganic forms of carbon of low volatility. Better (i.e., more consistent) results might, therefore, have been obtained if an Induction Furnace method or Carbon Analyzer had been used. (2) A further cause of imperfect results might be traced to the fact that carbon is oxidized at different rates when exposed on the surface, thus producing more "random" results, or is, in some way, removed spuriously in bottom sediments by organisms in some metabolic manner. (3) A final reason might be that some of the light weight "woody" material may have simply been transported out of D'Olive Bay into Mobile Bay by storm-water runoff and tidal currents. The excellent agreement of results obtained with the first three methods, however, allowed the boundary to be clearly established and permitted the total sediment volume to be calculated.

Calculation of Depositional Totals

Following normalization of each traverse line, using the cosine rule, the cross-sectional areas were calculated for seven of the traverses and the total volume of sediment computed. The total figure for the bay, and its calculation, is shown on the following page.

Total volume of sediment in bay above impact boundary = 9,965,674.6 ft.^3

Average dry density of sediments from above impact boundary:

$$0.73 \times 62.4 \text{ lbs./ft.}^3 = 45.55 \text{ lbs./ft.}^3$$

$$\frac{9{,}965{,}674.6 \text{ ft.}^3 \times 45.55 \text{ lbs./ft.}^3}{2{,}000 \text{ lbs./ton}} = 226{,}978 \text{ tons of sediment}$$

$$\frac{226{,}978 \text{ tons}}{14 \text{ years}} = 16{,}213 \text{ tons/year}$$

When this figure is added to the 14 year depositional total for material trapped in Lake Forest reservoir (717,953 tons), a figure of 944,000 tons of sediment produced is the result. Because D'Olive Bay acts as only a partial trap for fine clastics, this figure must be augmented by an amount equivalent to that of material that is carried <u>through</u> the bay, southward into Mobile Bay. Based on a calculated trap efficiency of 77 percent for D'Olive Bay a total of:

$$\frac{226{,}978}{.77} = 294{,}776.6 \text{ tons of sediment entered D'Olive Bay (14 years)}$$

Subtracting the total input from the total remaining yields:

$$294{,}777 - 226{,}978 = 67{,}999 \text{ tons of sediment entering Mobile Bay (14 years)}$$

These figures are summarized in Table 8.

Location	1967-1980 14 Year Sediment Volume (tons)	Average Annual Sediment Volume (tons)
Lake Forest Reservoir	717,953	51,282
D'Olive Bay	226,978	16,213
Mobile Bay	67,799	4,843
	1,012,730 (14 year total)	72,338 (average per year)

Table 8.--Total sediment volumes deposited in Lake Forest reservoir, D'Olive and Mobile bays, annually and over 14 year period since extensive commercial development of watershed began.

If the 1967 figure of 11,279 tons/year (Crisler 1981) is used as the average "natural" erosion loss, before impact, and multiplied by the 14 year period, a figure of 157,906 tons is computed for the expected natural erosion loss in the watershed. If this amount is subtracted from the "totals" in column 1 of table 8, a total of 854,824 tons of sediment may be attributed to man-caused processes and thus justifies, fully, the use of the term "environmental impact". To further put the amount of sediment deposited in D'Olive Bay in perspective, consider the fact that the calculations of Hardin, et al (1976) showed that upper Mobile Bay has filled some 0.53 feet during the past 50 years (or about 0.011 feet/year). D'Olive Bay, in contrast, has filled approximately 1.50 feet in just 14 years (for an average of 0.107 feet/year). If Crisler's (1981) figure of 11,279 tons/year is multiplied by 22 percent (the percent of the total eroded material deposited in D'Olive Bay), and this figure is multiplied by 14 years, the deposition in D'Olive Bay would be 34,739 tons for the period. The conversion of the 34,739 tons to a volume results in a value of 0.23 feet of depositional thickness which becomes the calculated "expected amount of fill" for the bay for the 14 year period (an average of 0.016 feet/year). When the actual amount of deposition (0.107 feet/year) is compared to the expected amount (0.016 feet/year), it is found that the actual value is 6.7 times the expected figure. Investigation has shown, however, that the great bulk of sediment influx into D'Olive Bay probably coincided with the massive road construction program in Lake Forest Estates which began in 1971. For this time interval, then, the measured deposition in the bay would actually be 10.4 times the amount that should have been expected from the drainage basin.

Sources of Depositional Materials in Reservoir and Bays

Potential significant sources for sediment in D'Olive Bay include quarrying operations north of Interstate Highway 10 and southwest of Lake Forest Estates, recent commercial construction on Highway 98, and material that might have entered D'Olive Bay during construction of the Interstate highway and its associated work canal.

The quarries can largely be ruled out as major sources of materials because of their relatively short time of existence and the preventative measures (sediment holding ponds) that were taken to control any erosion problems. Carlton and Gail (1980) reported only neglible amounts of suspended solids present in samples collected downstream from quarry sites in 1980. Further, the general shape of the pits (steep sides and level floors) would be expected to contribute less sediment than a "gullyed" morphology and all of the pits in the watershed are characterized by a relatively small drainage area "upslope". The total area occupied by quarries in the watershed, in fact, is presently only 61 acres representing less than 1 percent of the land use in the entire 7,878 acre watershed (see Crisler, 1981).

The Interstate highway, similarly, appears to have escaped culpability because of strict adherence to Alabama Water Improvement Commission regulations during the construction phase. These regulations (adopted May 5, 1967) classify D'Olive Creek, and its tributaries, under the catagory "Fish and Wildlife" (see p. 16, AWIC Regulations, Title II, Water Quality Criteria and Use Classifications). Such classification places certain restrictions on the use of such waters and, further, defines allowable tolerances of a number of variables (turbidity, bacteria, taste, odor, pH, temperature, etc.). All dredged material during highway construction of the work canal was pumped several miles away to a large spoil area on the north side of the causeway and, similarly, settling ponds were constructed to prevent sediment escape during construction of the highway, eastward, toward Malbis (Ivie Well and Royden Jaye, Alabama State Highway Department, personal communication, 1981). Thus, the statement made by Vittor (1972, p. 29) that "Highway construction along D'Olive Creek caused heavy siltation in the upper bay area..." is not supported because no attempt was made to actually determine the source of these sediments or to determine if the highway contractors were controlling loss of sediment during construction.

Construction occurring along Highway 98 has had some local effect on sedimentation within the watershed but, for the most part, this construction has taken place in a relatively small area and most has been within the past few years. Any significant amount of potential sedimentation from this source has largely been trapped by the construction of retaining walls and natural vegetation on the slopes.

CONCLUSIONS

D'Olive Bay, from its formation in the early 1800's until recent time was relatively unimpacted by the activities of man. During this interval, little would distinguish it from other such bays in the area. In the late 1960's the bay had an average depth of approximately four feet and a diverse fauna and flora. The daily tides and periodic rains carried in minor amounts of suspended sediment, some of which was deposited in the bay. Beginning some fourteen years ago, however, the bay became impacted by rapid deposition resulting from construction activity that was taking place within its watershed. The accelerated sedimentation has markedly affected the growth of flora within the bay and caused changes in species abundance and diversity as the bottom of the bay became elevated. As the depth of the water continues to shallow, a point will be reached where vegetation such as alligatorweed, cattail, cutgrass, torpedo grass, duck potato, and sawgrass will gradually encroach on the bay from its perimeter and will, eventually, cover most, if not all, of its present surface (Corps of Engineers, 1981, personal communication). At the present fill rate of 0.107-0.166 feet per year, vegetation would completely cover the bay within 15 to 20 years. At this point, human utilization of the bay would virtually cease.

The principal source for the sediments in D'Olive Bay was, and continues to be, detrital materials originating within the confines of Lake Forest Estates. Evidence of widespread erosion, gullying and sheetwash is apparent throughout this portion of the watershed and the lack of an adequate rainfall drainage system is a major, continuing problem within the area. Only when effective measures are made to restrict runoff and retard sediment transport by the developers will any relief be in sight for D'Olive Bay and Lake Forest reservoir. Until that time, D'Olive Bay will continue to receive large amounts of clastic sediments, following each rain, and Lake Forest reservoir will continue to have its trap efficiency further reduced as the coarse clastics settle out behind the dam. When the reservoir is completely filled with sediment, the entire sediment load will then pass into D'Olive Bay, and the rate of filling will be markedly increased. Destruction of the bay will then be accomplished many tens, or possibly hundreds, of years before natural processes would have effected the same result.

BIBLIOGRAPHY

Baldwin, W. (1957), An Inspection of Waterfowl Habitats in the Mobile Bay Area. Alabama Department of Conservation, Game and Fish Division, Spec. Report No. 2, 41 p.

Behears, W. (1972), Mobile Delta Vegetative Study. Alabama Department of Conservation and Natural Resources, Montgomery, Alabama.

Blake, A. (1978), Engineering Geology of a Selected Area in Baldwin County, Alabama. M.S. Thesis, Department of Geology and Geography, University of Alabama, University, Alabama, 111 p.

Borom, J. (1979), Submerged grassbed communities in Mobile Bay. In: Symposium on the Natural Resources of the Mobile Estuary, Alabama, Loyacano and Smith, Editors, Joint Publication by U.S. Fish and Wildlife Service, Mississippi-Alabama SEA GRANT Consortium, and Alabama Coastal Area Board, p. 123-132.

Cagle, J. and Newton, J. (1963), Geology and groundwater resources of Escambia County, Alabama. Alabama Geol. Survey Bull. 74, 205 p.

Carlton, J. and Gail, T. (1980), Special Study: D'Olive Creek, Tiawasee Creek and D'Olive Bay in Baldwin County, Alabama. Prepared by the Alabama Water Improvement Commission, Mobile Field Office, 94 p.

Crisler, R. (1981), Report on Erosion in the Area Draining to D'Olive Bay in Baldwin County, Alabama for the Years 1967 and 1980. Prepared for Mobile District, Corps of Engineers by U. S. Department of Agriculture, Soil Conservation Service, 14 p.

Corps of Engineers (1973), Environmental Investigations of Dredging Activities in Mobile Bay, Alabama, Final Report, 53 p.

Corps of Engineers (1979), In: Dispersion and Impact of Mobile River System Waters in Mobile Bay, Alabama. WPRI Report, Project A-058-ALA, Bulletin 37.

Environmental Protection Agency (1976), Technology Transfer: Erosion and Sediment Control, Surface Mining in the Eastern U.S., Section IV, Erosion Control. EPA-625/3-76-006.

Fenneman, N. (1938), The Physiography of Eastern United States. McGraw-Hill Book Co., New York, 714 p.

Hardin, J., Sapp, C., Emplaincourt, J. and Richter, K. (1976), Shoreline and Bathymetric Changes in the Coastal Area of Alabama, A Remote Sensing Approach. Ala. Geol. Survey Information Series 50, 125 p.

Hershfield, D. (1961), Rainfall Frequency Atlas of the United States, Tech. Paper No. 40, Soil Conservation Service.

Isphording, W. (1976), Multivariate mineral analysis of Miocene-Pliocene Coastal Plain sediments. Trans., Gulf Coast Assoc. Geol. Soc., v. 26, p. 326-331.

Isphording, W. (1977), Petrology and Stratigraphy of the Alabama Miocene. Trans., Gulf Coast Assn. Geol. Soc., v. 27, p. 304-313.

Isphording, W. (1981), Neogene Geology of Southeastern Mississippi and Southwestern Alabama. In: Fieldtrip Guidebook for Southern Mississippi, Southern Geological Soc. Publ. No. 2 (SEGSA), p. 1-25.

Isphording, W. and Flowers, G. (1980), Use of classification procedures and discriminant analysis in differentiating Tertiary coarse clastics in the Alabama Coastal Plain. Jour. Sed. Petrol., v. 50, p. 31-41.

Isphording, W. and Lamb, G. (1979), The Sediments of Mobile Bay. Alabama Coastal Area Board Report, published by Dauphin Island Sea Lab as Report No. 80-002, 31 p.

Isphording, W. and Riccio, J. (1972), Petrology and identification of the Citronelle Formation in Alabama. Abs., Southeastern Section meeting, Geol. Soc. Amer., Tuscaloosa, Ala., p. 82-83.

Lueth, F. (1963), Mobile Delta Waterfowl and Muskrat Research. Alabama Department of Conservation, Pittman-Robinson Project 7R, Final Report, 86 p.

Marsh, O. (1964), Geology of Escambia and Santa Rosa Counties, western Florida panhandle. Fla. Geol. Survey Bull., v. 46, 140 p.

Otvos, E. (1981), Post-Miocene Units, Mississippi-Alabama Coast - A Brief Outline. In: Fieldtrip Guidebook for Southern Mississippi, Southern Geological Soc. Publ. No. 2 (SEGSA), p. 1b-1 - 1b-20.

Palmer and Baker, Engineers, Inc. (1973), Environmental Impact Study of Proposed Marina Facilities on D'Olive Bay, Baldwin County, Alabama. Report prepared for Lake Forest, Inc., 55 p.

Palmer and Baker, Engineers, Inc. (1974), Supplement to the Environmental Impact Study of Proposed Marina Facilities on D'Olive Bay, Baldwin County, Alabama. Report prepared for Lake Forest, Inc., 15 p.

Palmer and Baker, Engineers, Inc. (1974), Reconnaissance Study of Erosion Within and in the Vicinity of Lake Forest, Inc., Baldwin County, Alabama. Report prepared for Lake Forest, Inc., 18 p.

Pirkle, E., Yoho, W. and Allen, A. (1965), Hawthorn, Bone Valley and Citronelle sediments of Florida. Florida Acad. Sic. Quart. Jour., v. 28, p. 7-58.

Rosen, N. (1969), Heavy minerals and size analysis of the Citronelle Formation of the Gulf Coastal Plain. Jour. Sed. Petrol., v. 39, p. 1552-1565.

Vittor, B. (1972), The Ecological Consequences of Channel Dredging in D'Olive Bay, Alabama. Final Report, U. S. Army Engineering District, Mobile, Alabama, Contract No. DACW01-72-C-0085, 35 p.

Wischmeir, W. and Smith, D. (1978), Predicting Rainfall Erosion Losses--A Guide to Conservation Planning. U.S. Department of Agriculture Handbook No. 537.

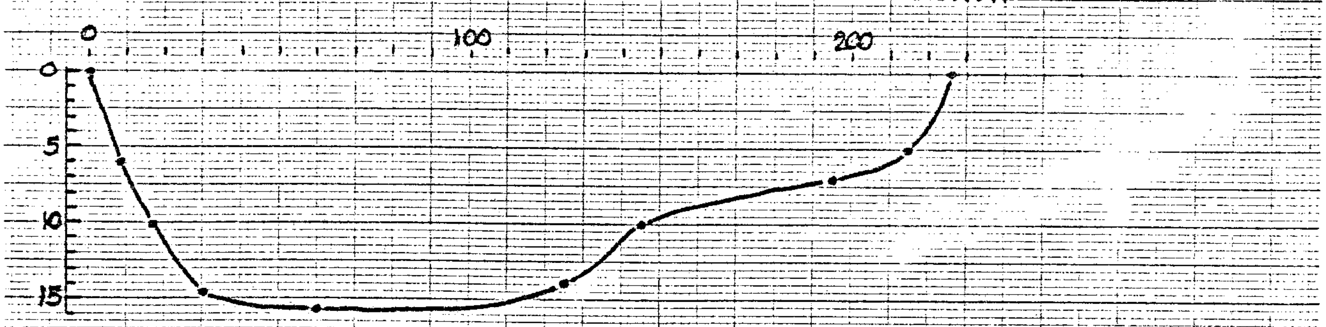
ACKNOWLEDGEMENTS

The report author would like to take this opportunity to thank John Carlton for supplying a number of the photographs used in the report. Dr. Glenn Sebastian carried out the sediment analysis phase and Gregory and Gary Isphording assisted in the field sampling and coring operations. Mrs. Diane Hartley collated and typed the final manuscript.

APPENDIX I

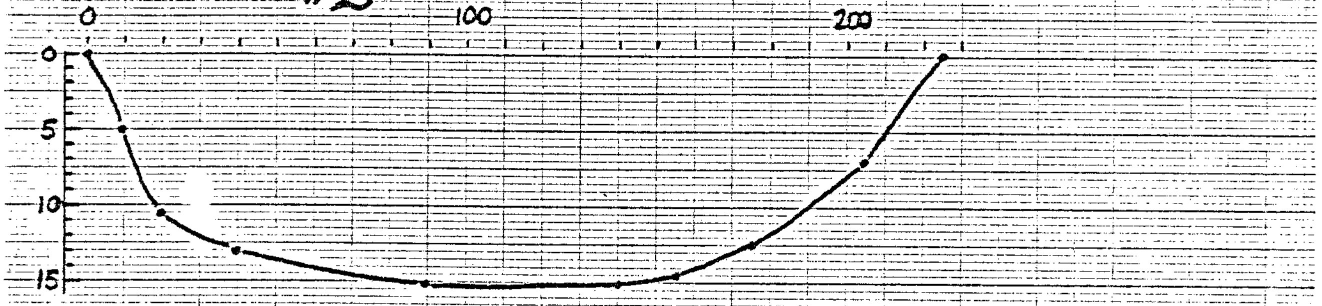
Cross-sectional profiles of Lake Forest Reservoir (distances and depths in feet).

#1



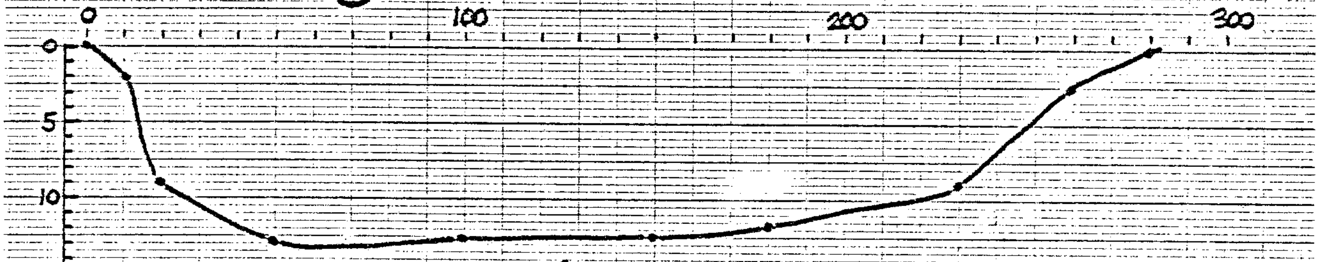
N 30°E

#2



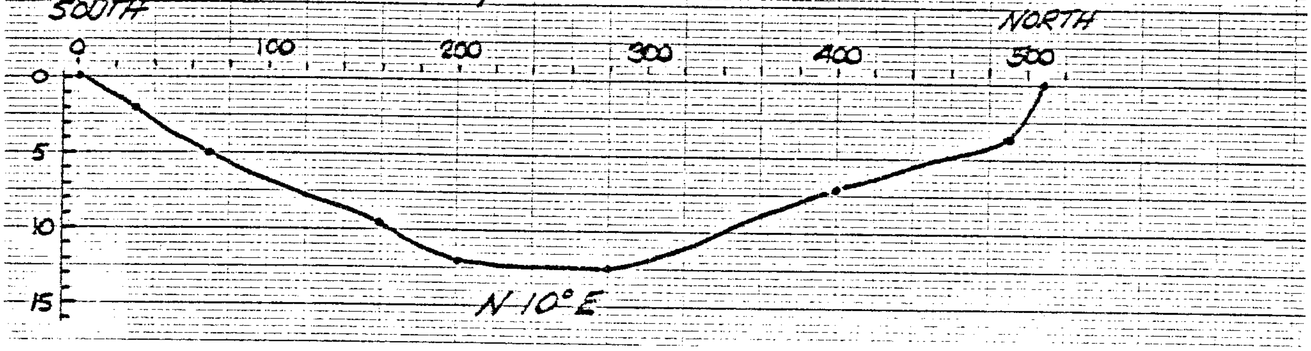
N 0°E

#3



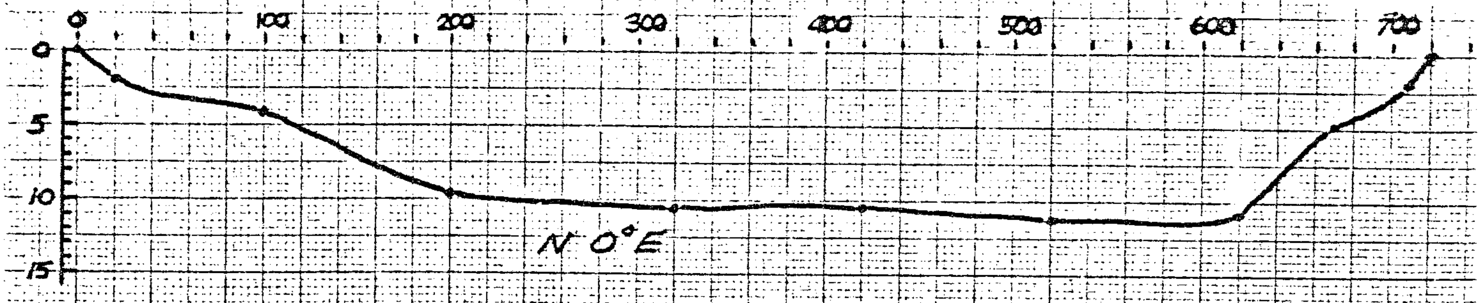
N 0°E

#4

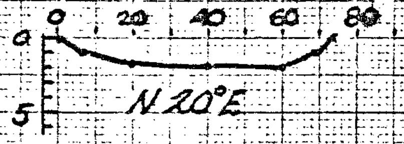


N 10°E

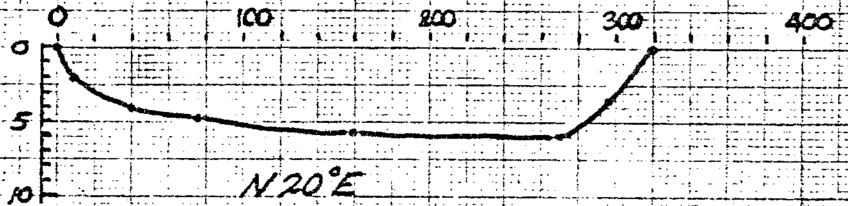
#5


0
100
200
300
400
500
600
700
0
5
10
15
N 0°E

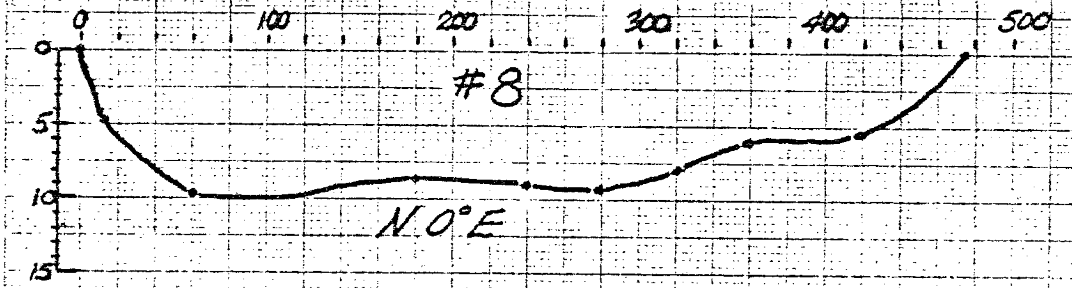
#6


0
20
40
60
80
0
5
N 20°E

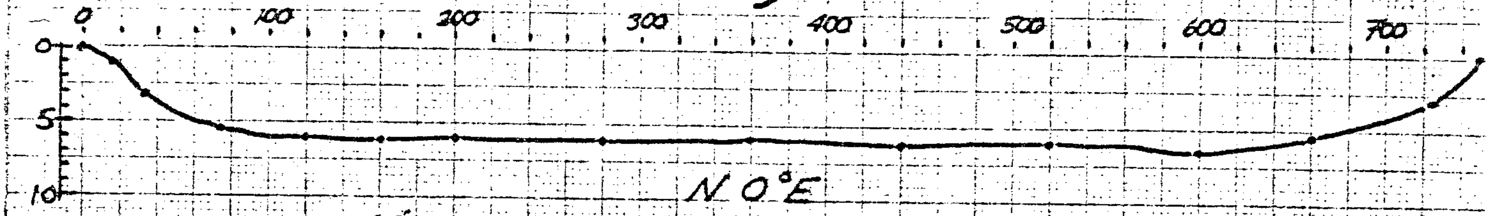
#7


0
100
200
300
400
0
5
10
N 20°E

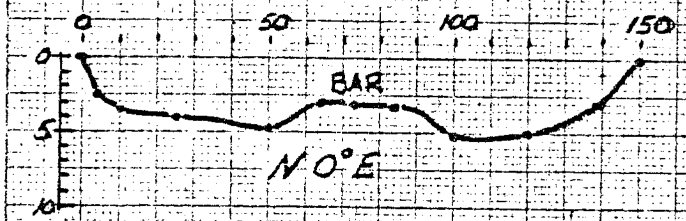
#8


0
100
200
300
400
500
0
5
10
15
N 0°E

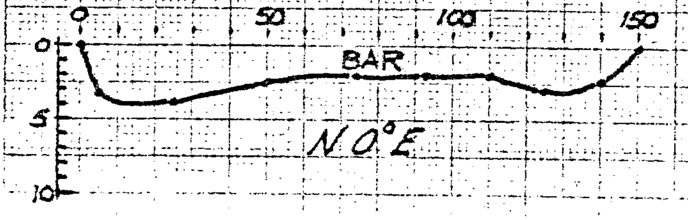
#9


0
100
200
300
400
500
600
700
0
5
10
N 0°E

#10


0
50
100
150
0
5
10
BAR
N 0°E

#11


0
50
100
150
0
5
10
BAR
N 0°E

APPENDIX II

Sediment texture and clay mineralogy data for D'Olive Bay and D'Olive Bay watershed samples.

D'OLIVE BAY SAMPLES

SAMPLE NUMBER	PCT. GRAVEL	PCT. SAND	PCT. SILT	PCT. CLAY	MEDIAN DIA.	MEAN DIA.	SORTING COEF.	PCT. SMECTITE	PCT. KAOLINITE
1-1	TR	36	37	27	34.68	17.11	3.04	61	28
1-2A	TR	39	33	28	35.08	16.19	3.24	63	29
1-2B	TR	9	38	53	4.15	---	---	66	26
1-3	TR	7	37	57	3.49	---	---	66	25
2-1	---	60	11	28	53.62	31.29	2.08	61	29
2-2	---	24	40	37	12.00	---	---	64	26
2-3	---	19	36	44	7.04	---	---	63	25
2-4	---	10	39	51	4.75	---	---	68	25
3-1	3	32	31	34	21.39	---	---	56	35
3-2	---	59	19	23	80.92	29.46	3.50	60	30
3-3	---	---	---	---	---	---	---	68	24
3-4	1	30	30	40	9.56	---	---	67	25
4-1	---	19	47	34	11.30	10.02	2.53	54	39
4-2	1	18	36	45	6.74	---	---	61	29
4-3	TR	36	29	36	18.46	---	---	68	25
4-4	1	36	32	32	22.33	15.35	3.55	63	31
4-5	TR	85	9	6	175.07	175.17	1.71	63	27
5-1	1	54	27	18	60.97	32.78	2.74	57	27
5-2	TR	22	32	46	6.51	---	---	58	27
5-3	TR	39	29	32	23.16	---	---	61	31
5-4	TR	36	42	21	27.37	5.07	2.80	65	24
6-1	4	20	31	45	6.70	---	---	---	---
6-2	TR	86	8	6	261.88	207.99	1.66	61	22
6-2A	2	87	7	4	468.90	481.52	1.00	46	38
7-1	1	46	23	31	42.78	---	---	45	43
7-2	3	84	9	4	354.33	247.74	1.90	0	100
8-1	TR	12	34	54	4.23	---	---	45	43
8-2	TR	63	17	20	162.74	62.99	3.65	58	36
8-3	---	82	7	11	286.68	208.36	1.81	54	36
9-1	1	21	36	41	7.77	8.74	2.72	50	46
9-2	2	12	55	32	10.80	---	---	55	33
9-3	2	34	32	31	14.75	20.71	3.88	54	34
9-4	TR	75	12	12	294.43	119.07	3.07	55	35
10-1	1	62	18	19	277.19	80.65	4.24	65	25
10-2	2	16	28	54	3.97	---	---	59	33
10-3	1	23	31	45	6.59	---	---	57	38
11-1	---	41	22	37	23.44	---	---	48	35
11-2	---	---	---	---	---	---	---	43	39
12-1	TR	38	36	27	27.99	27.69	3.78	65	27
12-2	TR	32	28	40	11.06	---	---	59	33
12-3	TR	15	30	56	3.56	---	---	58	32
12-4	TR	63	23	14	152.20	76.02	3.16	67	18

SAMPLE NUMBER	PCT. GRAVEL	PCT. SAND	PCT. SILT	PCT. CLAY	MEDIAN DIA.	MEAN DIA.	SORTING COEF.	PCT. SMECTITE	PCT. KAOLINITE
13-1	---	35	32	34	15.61	---	---	50	41
13-1	TR	16	51	32	13.46	---	---	---	---
13-2	1	16	37	46	6.18	---	---	54	34
13-3	---	---	---	---	---	---	---	58	29
13-4	1	46	14	39	8.07	---	---	64	21
14-1	1	14	37	48	5.50	---	---	60	29
14-2	TR	13	38	48	5.40	---	---	64	26
14-3	10	21	28	41	8.27	---	---	73	22
14-4	TR	51	30	19	70.87	39.21	3.86	63	16
15-1	TR	19	34	47	5.97	---	---	57	31
15-3	---	15	37	48	5.56	---	---	61	29
15-4	TR	49	35	16	47.70	35.50	2.60	72	19
15-5	---	52	34	14	56.89	48.72	2.60	72	19
16-1	TR	22	23	56	3.20	---	---	56	36
16-2	---	32	20	48	6.10	---	---	58	35
16-3	TR	84	7	9	149.37	136.84	1.11	60	30
17-1	1	20	46	33	11.54	---	---	60	29
17-1	TR	13	49	38	7.82	---	---	---	---
17-2	---	8	23	69	1.13	---	---	57	28
17-3	---	10	28	62	2.39	---	---	61	23
17-4	1	83	9	7	223.59	180.44	1.43	68	20
18-1	---	41	38	20	38.62	23.08	2.65	64	29
18-2	---	24	50	26	27.82	14.12	3.03	62	27
18-3	---	48	40	12	58.11	37.45	1.99	71	23
18-4	---	39	47	14	38.67	27.60	1.94	74	18
19-1	---	20	55	25	27.50	13.96	2.91	64	25
19-2	TR	14	53	33	14.81	---	---	68	26
19-3	---	55	37	8	67.73	49.77	1.45	70	17
20-1	1	20	44	35	12.45	---	---	64	26
20-2	TR	14	42	44	6.82	---	---	56	31
20-3	---	19	53	28	19.65	---	---	72	24
20-4	---	33	55	12	24.52	26.11	1.91	67	18
21-1	---	---	---	---	---	---	---	62	29
21-2	TR	14	39	47	5.86	---	---	66	27
21-3	---	14	23	63	1.85	---	---	64	21
21-4	---	25	40	35	11.50	---	---	68	17
22-1	---	---	---	---	---	---	---	63	28
22-2	1	90	4	6	174.10	178.69	1.23	58	27
23-1	---	12	36	52	4.42	---	---	61	29
23-2	---	6	27	68	2.11	---	---	56	33
23-3	TR	16	34	50	3.87	---	---	63	28
23-4	TR	86	10	4	201.20	169.35	1.45	70	19
24-1	1	45	27	27	42.34	27.19	4.25	53	35
24-2	1	56	24	20	66.54	47.61	3.68	49	38
24-3	7	83	6	4	582.70	487.70	1.72	---	---
25-1	1	90	7	2	319.57	252.65	1.77	63	24
25-3	2	85	9	4	397.21	305.21	1.78	---	---
26-1	---	96	3	1	388.06	410.84	0.70	0	40
26-2	---	52	20	28	53.71	---	---	62	30
26-3	1	18	34	46	6.05	---	---	51	37

SAMPLE NUMBER	PCT. GRAVEL	PCT. SAND	PCT. SILT	PCT. CLAY	MEDIAN DIA.	MEAN DIA.	SORTING COEF.	PCT. SMECTITE	PCT. KAOLINITE
27-1	TR	94	6	2	384.33	405.96	0.70	36	57
28-1	TR	98	2	0	353.18	352.17	0.46	9	30
28-2	---	29	37	35	16.09	---	---	47	44
29-1	---	---	---	---	---	---	---	48	42
30-1	TR	30	41	29	34.91	---	---	---	---
31-1	---	36	31	33	17.97	---	---	60	30
31-2	TR	35	36	29	35.70	---	---	66	27
31-3	TR	30	34	37	13.85	---	---	---	---
31-4	TR	20	37	43	7.83	---	---	64	29
32-1	2	36	41	21	35.29	30.48	3.13	---	---
32-2	2	17	38	43	8.20	---	---	---	---
32-3	TR	9	36	55	3.89	---	---	63	28
32-4	TR	20	37	43	7.73	---	---	69	25
33-1	TR	54	27	19	55.76	26.94	2.60	---	---
33-2	---	67	24	9	68.09	56.32	1.10	74	18
33-3	TR	69	22	9	73.99	53.98	1.45	68	20
33-4	TR	73	19	8	77.27	65.11	1.04	68	21
34-1	TR	24	45	31	12.95	---	---	66	25
34-2	---	56	35	10	56.64	40.82	1.64	73	19
34-3	TR	48	40	12	48.02	35.61	1.67	72	18
35-1	3	44	28	25	44.15	33.03	3.87	57	32
35-2	26	64	4	6	532.45	531.32	2.56	61	31
36-1	6	12	48	34	11.07	---	---	53	37
36-2	TR	13	41	46	6.05	---	---	63	28
36-3	TR	9	34	57	3.36	---	---	67	26
36-4	TR	54	28	18	67.96	43.17	3.17	78	14
37-1	1	13	42	45	6.73	---	---	57	28
37-2	1	10	23	65	2.69	---	---	68	27
37-3	TR	10	32	58	3.30	---	---	68	25
37-4	---	39	37	23	32.29	21.69	3.36	80	16
38-1	1	19	43	38	9.69	---	---	62	29
38-2	TR	17	41	41	8.40	---	---	56	39
38-3	TR	46	37	17	45.14	30.98	2.54	75	18
38-4	TR	23	50	26	16.94	---	---	74	17
39-1	TR	26	45	28	22.74	---	---	63	29
39-2	TR	22	45	33	14.90	---	---	61	33
39-3	---	57	32	11	60.08	42.81	1.72	71	18
39-4	---	51	38	10	51.34	40.68	1.51	76	18
40-1	TR	29	46	25	23.55	15.74	2.76	67	28
40-2	1	29	38	33	18.92	---	---	60	32
40-3	TR	17	46	37	11.00	---	---	70	22
40-4	TR	56	36	7	56.65	48.78	1.29	71	20
41-2	TR	18	47	34	10.79	9.16	2.69	65	31
41-3	TR	12	35	53	4.25	---	---	65	29
41-4	TR	36	40	24	32.41	21.40	3.25	75	18
42-1	TR	13	36	50	4.97	---	---	60	30
42-2	TR	10	31	59	2.99	---	---	58	35
42-3	TR	13	16	71	2.08	---	---	---	---
42-4	TR	46	35	19	41.93	35.26	3.37	77	15

SAMPLE NUMBER	PCT. GRAVEL	PCT. SAND	PCT. SILT	PCT. CLAY	MEDIAN DIA.	MEAN DIA.	SORTING COEF.	PCT. SMECTITE	PCT. KAOLINITE
43-1	TR	43	26	30	34.86	26.31	4.28	60	35
43-2	TR	89	6	5	320.80	279.22	1.40	62	31
44-1	TR	24	39	37	10.49	---	---	60	32
44-2	TR	85	7	8	262.01	221.13	1.86	34	57
45-1	4	23	43	30	18.52	12.45	3.05	71	22
45-2	TR	39	35	26	37.19	17.76	2.95	77	18
45-3	1	36	35	28	35.22	16.26	3.10	76	21
45-4	---	52	30	19	52.13	24.20	2.70	71	17
46-1	TR	22	52	26	19.24	11.77	2.71	72	21
46-2	2	27	41	29	22.18	13.88	3.00	74	20
46-3	TR	22	40	38	12.18	---	---	77	17
46-4	TR	34	40	25	35.30	16.53	2.92	77	19
47-1	---	53	27	20	55.80	29.37	2.83	66	21
47-2	1	43	33	23	41.38	21.59	2.86	68	22
47-3	TR	37	40	23	33.72	18.64	2.89	68	23
47-4	---	31	37	32	22.08	---	---	---	---
47-5	TR	22	38	39	10.97	---	---	59	33
48-1	TR	40	38	22	41.52	22.49	2.74	54	40
48-2	4	35	32	29	37.59	19.52	3.46	53	39
48-3	7	26	37	29	33.34	22.44	3.55	57	34
48-4	---	43	44	13	43.26	31.06	1.85	74	18

BOREHOLE AND OUTCROP SAMPLES FROM D'OLIVE WATERSHED

SAMPLE NUMBER	PCT. GRAVEL	PCT. SAND	PCT. SILT	PCT. CLAY	MEDIAN DIA.	MEAN DIA.	SORTING COEF.	PCT. 14 ANGS.	PCT. KAOLINITE
61-1	---	---	---	---	---	---	---	51	44
61-2	TR	99	1	---	335.88	329.54	0.85	55	22
62-1	---	---	---	---	---	---	---	17	64
63-1	2	89	---	---	412.55	434.93	0.93	34	38
63-2	3	97	---	---	397.62	412.43	1.02	51	38
70-1	10	85	5	---	206.45	225.07	1.03	11	45
71	TR	87	8	4	273.01	214.32	1.25	55	45
72	1	93	6	---	190.12	197.07	0.84	35	51
73	---	59	41		75.44	---	---	36	57
74	1	98	1	---	283.23	275.41	0.80	25	43
75	4	96	---	---	399.38	422.76	1.02	40	43
76	3	95	2	---	285.98	289.05	0.99	57	35
80-1	TR	98	2	---	347.60	344.53	0	40	
80-2	TR	99	1	---	414.38	438.28	0.76	14	40
80-3	1	85	8	5	309.04	255.24	1.43	35	59
80-4	2	97	1	---	397.90	421.08	0.94	27	34
80-5	7	76	10	7	277.52	---	---	37	51
80-5A	1	79	12	8	351.12	---	---	20	74
80-6	TR	100	---	---	359.06	369.78	0.60	33	39
80-7	1	97	2	---	264.50	261.84	0.83	29	34
80-8	1	98	1	---	456.78	479.89	0.82	12	37
80-9	---	---	---	---	---	---	---	21	45
80-10	---	48	52		---	---	---	59	31
90-1	4	48	48		68.09	---	---	10	82
90-2	5	91	4	---	378.82	383.46	1.35	70	30
91-1	7	86	5	2	204.32	209.07	1.11	38	49
92	2	94	4	---	238.19	266.19	1.17	49	20
93	1	96	3	---	364.14	360.44	1.07	47	53
94	1	99	---	---	455.24	477.35	0.86	51	34
95	10	84	5	1	321.28	335.86	1.49	46	51
96	2	97	1	---	294.09	291.00	0.94	39	55
97	4	41	55		---	---	---	42	51
98	---	---	---	---	---	---	---	6	76
98B	TR	97	3	---	196.58	207.75	0.69	50	50
99	TR	99	1	---	338.00	332.90	0.85	38	42

APPENDIX III

Loss on ignition analyses for D'Olive Bay samples (in percent).

LOSS ON IGNITION ANALYSES FOR D'OLIVE BAY SAMPLES

Sample No.	Pct. Loss on Ignition
1-1	.32
1-2A	.61
1-2B	.94
1-3	1.53
2-1	1.25
2-2	.54
2-3	10.04
2-4	1.45
3-1	4.62
3-2	5.47
3-3	.83
3-4	3.79
4-1	5.90
4-2	4.63
4-3	3.74
4-4	.69
4-5	.53
5-1	.21
5-2	1.01
5-3	.51
5-4	.84
6-1	.36
6-2	.71
6-2A	.02
7-1	.01
7-2	.37
7-3	.54
8-1	.28
8-2	.05
8-3	.00
9-1	5.86
9-2	.86
9-3	.59
9-4	.13
10-1	.33
10-2	2.90
10-3	6.22
11-1	.59
11-2	.16
12-1	2.33
12-2	2.21
12-3	.38
12-4	.35
13-1	.31
13-1A	.28
13-2	.55
13-3	1.83
13-4	.48
14-1	.59
14-2	9.71
14-3	9.47
14-4	.72
15-1	.53
15-2	1.30
15-3	3.04
15-4	3.31
16-1	.30
16-2	2.03
16-3	.07
17-1	.31
17-1A	.42
17-2	.12
17-3	.14
17-4	.53
18-1	1.75
18-2	.12
18-3	.53
18-4	.29
19-1	.07
19-2	.78
19-3	.13
20-1	.38
20-2	6.22
20-3	5.02
20-4	5.33
21-1	1.40
21-2	.10
21-3	.42
21-4	1.21

Sample No.	Pct. Loss on Ignition
22-1	.08
22-2	.19
23-1	.24
23-2	1.09
23-3	1.15
23-4	.07
24-1	.95
24-2	.87
24-3	.03
25-1	.02
25-2	.12
25-3	.16
26-1	.01
26-2	.87
26-3	.70
27-1	3.94
28-1	.02
28-2	6.22
29-1	1.75
30-1	.48
30-1	.45
31-1	.99
31-2	1.35
31-3	.78
31-4	.18
32-1	.30
32-2	.06
32-3	6.43
32-4	.07
32-4	.38
33-1	.07
33-2	1.00
33-3	.06
33-4	.57
34-1	.89
34-2	.25
34-3	.10
34-4	.10
35-1	.37
35-2	.04
36-1	.36
36-2	.47
36-3	.96
36-4	.08
37-1	.26
37-2	1.45
37-3	.83
37-4	.23
38-1	.32
38-2	.32
38-3	.33
38-4	.59
39-1	.11
39-2	2.24
39-3	.48
39-4	.21
40-1	.40
40-2	.59
40-3	.70
40-4	2.15
41-1	
41-2	5.40
41-3	2.81
41-4	1.16
42-1	3.21
42-2	1.14
42-3	2.02
42-4	.09
43-1	2.87
43-2	.08
44-1	2.45
44-2	.10
45-1	.62
45-2	5.79
45-3	.16
45-4	.35
46-1	.39
46-2	.07
46-3	.09
46-4	.85

Sample No.	Pct. Loss on Ignition	Sample No.	Pct. Loss on Ignition
47-1	.08	48-1	3.74
47-2	.40	48-2	.13
47-3	.13	48-3	5.47
47-4	.37	48-4	.32
47-5	.07		

APPENDIX IV

Bulk density determinations for D'Olive Bay samples (in percent).

BULK DENSITY DETERMINATIONS

Sample Number	Wet Bulk Density	Dry Bulk Density
13-1A	1.31	0.71
15-1	1.57	0.77
20-1	1.54	0.73
23-1	1.64	0.76
25-1	1.77	1.38
25-2	1.15	0.51
36-1	1.14	0.43
37-1	1.15	0.45
38-1	1.20	0.53
39-1	1.47	0.74
44-1	1.23	0.46
45-1	1.31	0.68
46-1	1.30	0.61
47-1	1.41	0.81
47-2	1.48	0.85
47-3	1.50	0.93
47-4	1.40	0.85
47-5	1.47	0.92