STATE OF OHIO
Frank J. Lausche, Governor

DEPARTMENT OF NATURAL RESOURCES
A. W. Marion, Director

DIVISION OF SHORE EROSION
F. O. Kugel, Chief

DIVISION OF GEOLOGICAL SURVEY
John H. Melvin, Chief

REPORT OF INVESTIGATIONS NO. 18
(CONTRIBUTION NO. 3 LAKE ERIE GEOLOGICAL RESEARCH PROGRAM)

1951 INVESTIGATIONS
OF
LAKE ERIE SHORE EROSION

By
Howard J. Pincus,
Editor

Contributing Authors
Raymond E. Metter
Curtis C. Humphris
Richard S. Bowman
Frank J. Kleinhampl

This publication is a cooperative project of the Division of Shore Erosion and
The Division of Geological Survey. The research upon which the
publication is based has been sponsored chiefly by
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Columbus, 1953
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Howard J. Pincus
Head, Lake Erie Geological Research Program

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INTRODUCTION

By

Howard J. Pincus

Head, Lake Erie Geological Research Program
GENERAL REMARKS

Field investigations of the 1951 season con-
tinued the type of activity started in 1950 (Pincus,
Roseboom, and Humphris, 1951) by the Ohio Division
of Shore Erosion, through its Lake Erie Geological
Research Program.

Over 50 miles of shoreline were studied by six
investigators, four of whose reports follow (Metter,
Ch. 2; Humphris, Ch. 3; Kleinhampl, Ch. 4; Bowman,
Ch. 5). Although all of the work was carried out
under the supervision of the head of the program,
credit for originality and discovery resides strictly
with the author of each of the following chapters.
Each author has assumed full responsibility for the
field study of his area, for the laboratory analyses of
his materials, and for the presentation of his results.
Since much of the field work required a team
of investigators, each of the authors has indicated
his gratitude to the other members of the program
for their willing assistance and stimulating discussion
in the investigation of their colleagues' areas.
All of the program's personnel also express
their appreciation for the splendid cooperation of
Mr. F. O. Kugel, Chief of the Division of Shore Ero-
sion, whose sponsorship of the project has made these
investigations possible. Assistance has also been ren-
dered by the Ohio Division of Geological Survey,
Wildlife, and Water, by the Ohio State University's
Department of Geology, Graduate School, Develop-
ment Fund, and Research Foundation, and by branches
of the U. S. Army Engineers. To all those persons
and agencies whose names do not appear here, but
without whose aid our efficiency would have suffered
considerably, we offer our sincere thanks, and also
our hope that perhaps in some small measure the
fruits of our labors will benefit all of our people
within the near future.

It is the purpose of these introductory remarks
to present an essentially non-technical picture of the
principles used in conducting these investigations,
and to introduce the technical papers which follow.
Some of the material discussed in this chapter deals
with notions common to each of the following chap-
ters; however, each of the chapters is largely complete
by itself, so that the reader interested in only one of
the areas discussed needs only to turn to the appropriate
chapter to inform himself of the local problems in-
volved. Summary and concluding remarks appear at
the end of each chapter.

THE STUDY OF EROSION

Erosion of shorelines has often been attributed
to such factors as wave attack in conjunction with
the sweeping away of sediment by related currents,
spring-line seepage leading to slumping, frost action,
surface wash over the face of the bank, and the mechan-
ical action of lake ice.

But the processes listed are only final processes,
in that they are but the last of a series of processes
leading to erosion of one kind or another; in fact, they
may not be the only final processes operating at a
point. Further, the mere identification of a process
gives no estimate of the rate at which it is acting, or
how that rate might change, either from natural or
engineering events.

In short, the study of erosion requires more than
the naming of a process, if the aim of the study is to
comprehend the basic factors whose control might
lead to the rational control of the erosion.

Many highly successful investigations in the
physical sciences have been directed toward the under-
standing of the factors of energy and matter, and how
these are related in space and time.

Investigations of shoreline processes may be
conducted in this way also; investigations of the Lake
Erie Geological Research Program have been patterned
along just such lines, as far as possible. Of course, the
adoption of this plan of attack does not imply that
other approaches are less valid or efficient,
Tying the concepts of matter, energy, space, and time to shoreline studies, the following brief examples may suffice to show how this approach operates (Mason, 1950, and Krumbein, 1950).

"Matter", in shoreline studies, may refer in part to the materials of the bluffs, beaches, and offshore areas. It may also pertain to the masses of water, particularly as they bear upon shore processes.

"Energy", as used here, is the general term signifying such entities as waves, currents, ice push, ice expansion, surface wash. In short, we are referring to the capacity to do geological work.

The concepts of "space" and "time" aid not only in sketching patterns of the first two factors, but they enable us to make efficient studies by allowing the drawing of boundaries about these factors. In short, they help us arrive at a logical unit of study; our logical unit of study has been the "case history". The case history involves the study of the "physiographic units" (space factor), a concept proposed by Mason (1950), such study to treat variations in the first two factors during several seasons, years, or through some other period of time.

The drawing of space and time boundaries, i.e., the design of a case history study, involves arbitrary action; but such arbitrary action based on the investigator's experience provides a framework of study in which one may have confidence. Such frameworks need not be immutable, for the conduct of an investigation may show that some alteration is necessary. But such frameworks at least provide us with a target area, in place of mere fortuitous firing in the dark.

Note how successful the case history approach has been in the social and biological sciences; our geological, geophysical and engineering studies are actually in a favored position, in that many of our measurements will someday have the precision of measurements of the more "exact" physical sciences. As an incidental addition to this discussion, we cite the fact that considerable effort is expended by the personnel of the Lake Erie project in developing and improving methods of measurement.

Viewed from another point, an investigation may be known by the questions it asks. Going into a specific area, we inquire, what are the sources of sediment on the beaches, how is the sediment transported, what are the effects of fluctuations in water level, composition of bluff material, wave action from all quarters, and so forth? What are the rates at which the sediment is moved, and how do these rates fluctuate over a period of time, and from point to point along the shore?

These questions of course, all go back to our four factors of energy, matter, space, and time. And, erosion is, after all, the net removal of matter at a point within a specified interval of time.

The piecing together of answers to such questions, as applied in case history studies, allows us to build a mosaic. Such a larger view may well be worth more than the collective worth of its parts, since large-scale patterns may thus become apparent, or inconsistencies in the results of apparently comparable studies should lead to the excision of the basic errors which burden even the most efficient investigations.

Each of the chapters which follows is essentially a case history. The time factor in each has not been studied nearly enough for definitive results. But at least these studies are a beginning, and we present them as such.

FIELD AND LABORATORY PROCEDURES

Details of field and laboratory procedures are fairly completely discussed in the following chapters.

The snapper sampler (See fig. 1-1) was the workhorse of the offshore sampling operation, conducted from the research vessel. Patterned after the unit constructed by La Fond and Dietz, it proved to be a reliable, almost trouble-free collecting device.

The gravity coring rig (See fig. 1-2) was effective for short cores in clayey bottoms, but ineffective in sandy materials. Patterned after the Dietz-Emery unit, it was not equipped with a suction piston, but such pistons will be in use during subsequent field seasons.

A special type of float was constructed for measuring currents (See fig. 1-3). The float was designed by the head of the project only after Mr. Richard Bowman (ch. 5) had pointed out some of the inadequacies of the conventional type of current type float, in which the buoyant element rides at or just below the water's surface.

This new float consists of a 1" wooden member, 3-5 feet long, on the top of which is a flag, denoting the depth of the current fins, and on the bottom of which is a lead ballast for maintaining the water line of the float just below the flag. The buoyant element consists of a wooden block to which the galvanized current fins are attached. This fin-block assembly can be clamped at depths of 1, 2, 3, 4, 5, or 6 feet, thereby providing the maximum drag at precisely the
depth required. The entire unit is very stable, rugged, and efficient; its effective field of use is in shallow water, particularly within groined areas. Units capable of operating in greater depths are being constructed for future use.

Investigations of sedimentary processes generally require use of statistical methods for the handling of aggregates of data; statistical methods may be applied to both field and laboratory phases of the operation.

Recent developments in statistical methods (Fisher, 1949) have indicated that many investigations can be designed in such a way that for a given amount of effort, a certain experimental design may yield much more valuable information than is yielded by other designs. These techniques have been developed largely in response to agricultural and biological problems, but they are also applicable to some studies involving sedimentary processes.

The case histories presented in the following chapters do not employ the designs of the types indicated above; they have been patterned after the conventional type of study in this field. It is hoped that investigators working for the program during future years will see fit to adopt the most productive procedures possible.

References Cited

Figure 1-2. Gravity coring rig.

Figure 1-3. "Current Float," (Application in a specific study, Chapter 5.)
Chapter 2

SEDIMENTARY PROCESSES ALONG LAKE ERIE SHORE, FROM CEDAR POINT TO HURON

By
Raymond E. Metter
INTRODUCTION

THE PROBLEM

This paper covers a limited analysis of sedimentary processes along the Lake Erie shore line from Cedar Point to Huron, in Erie County, Ohio. (See fig. 2-1) The investigation involved a survey of the geologic setting of the area, the collection and analysis of sediment along the shore and the adjacent lake floor, the mapping of profiles, and the observation of effects of physiographical, hydrological and meteorological factors on the movement of sediment. Statistical information obtained from analyses was plotted in order to discover possible simple relationships between features of the sediments and their environments.

The study was limited in that several potentially fruitful lines of investigation such as determinations of turbidity and intensive studies of currents were not carried out due to lack of time and facilities.

EARLIER INVESTIGATIONS

In addition to extensive mapping, sounding, dredging, and current-study activities carried out by the U. S. Army Corps of Engineers as a part of their regular duties along the Lake Erie shore, other investigations have been conducted by various agencies.

The most complete program was a cooperative beach erosion study made during the years 1939-1942 under the direction of the U. S. Army Engineers as provided by the Rivers and Harbors Act of 1930 (House Document 220).

During the years around 1900, E. L. Moseley, who was then a high school science teacher in Sandusky, Ohio, made a comprehensive study of the natural history of the surrounding area. One of his more extensive projects (Moseley, 1904) involved the mapping of the filled-in ancient channels in the hard glacial clays or bedrock underlying Sandusky Bay. In his paper he also discussed botanical evidence of the age of Cedar Point, as well as great storms and other occurrences which affected Cedar Point after 1800.

Modern investigations of the sedimentary petrology of part of this area have been conducted by F. J. Pettijohn in conjunction with A. C. Lundahl and J. D. Ridge (Pettijohn and Ridge, 1932 and 1933; Pettijohn and Lundahl, 1943). These workers made use of a series of sand samples collected at half-mile intervals along Cedar Point by Charlotte Webster Barnes during the winter of 1931. Separate investigations of mineralogical variations, textural variations, and shape and roundness of sediments were made using several of the samples.

The most recent work was carried out by the Lake Erie Geological Research Program during the year beginning in the fall of 1950 (Pincus, Roseboom, and Humphris, 1951). This study was essentially a preliminary survey of the mineralogy and texture of sand taken from 20 samples collected along the shore line of Cedar Point from northeast of Beimiller's Cove to the south end of the Cedar Point jetty (See fig. 2-33).

DESCRIPTION OF AREA

GENERAL STATEMENT

The area in the vicinity of Sandusky presents a picture of submerging shore line, with large areas of marshland and drowned stream mouths. (See fig. 2-33, western half of area.) Moore (1948, pl. 1) computed by comparison of water-level gauge readings and instrument levels that subsidence in this area is .79 feet per century. He discredits the idea that the subsidence is due to isostatic adjustment as a result of the retreat of the Pleistocene ice caps, but offers no positive alternative (Moore, p. 707).

Rocks underlying the area from Cedar Point to Huron are of Middle and Upper Devonian age, and are covered by glacial drift and old lake deposits, the total thickness of cover ranging from 8 to over 50 feet. Although bedrock is not exposed along most of the shore line, there are outcrops at Sandusky, Huron,
Legend
Devonian
Dd Delaware
Dc Columbus
Ddr Detroit River

Index Map and Geologic Map of Area
(Geology Generalized after Carman, 1946)

Figure 2-1
Grand Forest Beach and Boulder Camp (See fig. 2-33), and the lithology at intervening points can be inferred.

HURON TO HURONIA BEACH

Geology

The Huron shale member of the Ohio shale underlies the portion of the shore from Huron to Huronia Beach subdivision, but is nowhere exposed. Exposures are present along the Huron River to the east, and at Oak Point to the west. Glacial till and lake sediments rising 6 to 15 feet above the lake level cover the shale, which is found at depths greater than 6 feet. Walls, rip-rap, and other protective structures obscure the cross section of the bluffs fronting residential areas, but there is an excellent exposure along the edge of a large cultivated area east of Huronia Beach (See fig. 2-33).

The bluff along the lake in the area of Huronia Beach is 7 to 8 feet high, and lower portion shows an excellent section of varve-like laminated clay. The laminated clay is buff-colored at each end of the 1000-foot-long bluff, but is gradational to gray in the central portion. Clay laminations are separated by light layers of silt. The clay is overlain by 3 or 4 feet of buff silt and fine-grained sand. Ground water has caused many large concretionary-like structures to form in this sandy zone, producing spherical or ellipsoidal shells of sand slightly cemented by iron oxide. Wind and wave action removes the uncemented inner sand, leaving a series of pockets 1 to 4 feet in diameter along the bank. (See fig. 2-3,5) Near the eastern end of the bluff, the pockets are in two, or even three tiers, the lower tier containing the larger structures. In addition, cylindrical concretionary structures extend into the clay from above, following old roots or crevices.

The bluff is topped by 1 to 2 feet of yellow sandy soil.

Nature of Shore

During the summer of 1951 at both Huronia Beach and Huron there were many sections along the shore where the water lapped directly against the base of bulkheads or rip-rap, preventing the accretion of beach sediment. Small beaches have formed eastward of the groins in this area and small beaches have formed at minor irregular indentations in the coast. A small sand beach is present at the park in Huron. The long central portion east of Huronia Beach has what appears to be a good beach, for there is a strip of clean sand 15 feet wide between the lake and the bluff. However, this sand is no more than 5 or 6 inches deep, and extends no more than a few feet out beyond the water line. (In these discussions, the term "water line" refers to the average water level.)
Figure 2-4. Diagrammatic cross section of shore east of Huronia Beach.

Figure 2-5. Diagrammatic cross section of shore at Camp Boulder.
line during the summer of 1951. This was at an elevation of around 573 feet.) The sand at this location often is covered by a thin layer of red-violet or black sand, due to high percentages of garnet, magnetite or ilmenite. Both rounded and angular shale pebbles are plentiful in the region of Huronia Beach.

Erosion

Erosion has been rather severe in this region. It occurs most rapidly during times of severe storms from the north or northeast, when large waves directly attack the unconsolidated material in the bluffs along the shore. Erosion of the adjacent lake bottom may possibly occur at any time, since longshore currents were observed even on relatively quiet days during the summer of 1951.

Other factors contribute to the erosion of this and other areas. Surface water during heavy rains has been observed to cut notches in the tops of the bluffs as it flowed over the edge in small rivulets. Ground water running along more pervious layers issues from various heights on the bluff face, causing sapping and general weakening of the material, thus making it more susceptible to further wave attack. Frost action causes pebbles and cobbles in the till to become loosened. Chemical decay of materials probably plays little part in areas of rapid erosion, although it may in places where the same surface is exposed many months.

The push of ice in the winter has been described as very destructive in some years, although of minor importance in the winter of 1951-1952. The ice edge pushing against the bluffs causes undercutting and weakening, with consequent rapid erosion during spring storms. Ice has been observed by local residents to shear off chunks of the till bluff as it is piled against the shore by strong winds.

The various agencies listed above probably present a total effect which is less than that of the storm waves alone. The strength of the large waves is tremendous, and they have been observed to move large stone or concrete structures weighing many tons. The bluffs have been seen to retreat further in a single storm than in a period of many months previous to the storm.

The U. S. Army Corps of Engineers’ beach erosion study started in 1939 showed that between 1877 and 1939 the average shore line retreat in this area was 206 feet (House Document No. 220, p. 13). In Huron, a strip nearly 300 feet wide has been lost along the shore. In addition, the 6-foot depth contour advanced 201 feet shoreward, the 12-foot depth

Figure 2-6. Concretions in place in the Huron shale at Boulder Camp. Water level is at elevation of about 571 feet, as compared to average of over 573 feet during the summer of 1951.

Figure 2-7. Sideritic concretion and glacial grooves forming crag and tail on horizontal surface of Huron shale near groin at foot of steps at Camp Boulder. Striae here strike about S. 60° W.
contour advanced 142 feet, and the 18-foot contour, 174 feet. The reason for the variation in the rates of advance is not certain, but the shallower depths are more affected by wave action, and just west of Huron it was noticed on at least two relatively calm days during the summer of 1951 that there were very strong currents where the lake was 15 to 20 feet deep.

In recent years protective structures have been constructed which have arrested the rate of erosion, but severe storms still cause damage.

**OAK POINT**

**Geology**

Oak Point is a promontory on which Boulder Camp and North Palm Beach are located. (See fig. 2-33) It is a promontory because the top of the Huron member of the Ohio shale here for many yards rises to an elevation of over 571 feet, which is only slightly lower than the average Lake Erie level. (U. S. Lake Survey records show that since 1942 the monthly mean lake levels have varied between elevations of approximately 571 feet and 574 feet.) Aerial photos show the shale near the surface of the lake, conspicuous as dark areas near the shore. (See fig. 2-33) From shore the shale was seldom seen during 1951-52, but the large sideritic concretions characteristic of the Huron shale (Kindle, p. 199) protrude 1 or 2 feet above the top of the shale in many cases, and often the tops of the concretions are visible above the water—hence, the name "Boulder Camp." (See fig. 2-6)

It has been known for some time that the Huron shale crops out in this general area. E. M. Kindle (1912, p. 199) proposed that the term Huron shale be limited to "those beds of Ohio shale exposed on the Huron River, at Rye Beach and elsewhere, in which spherical concretions occur." No shale was observed by the author at Rye Beach during 1951-1952, and it is likely that Kindle may have been referring to the area a few hundred yards to the east.

The shale in this area is overlain by 8 to 10 feet of brown to gray compact glacial till. (See fig. 2-5) The till contains many erratics from pebble size to boulders, but is mainly a stiff, dense clay. The material is sandier near the surface. It is hidden at many frontages by bulkheads and rip-rap.

On September 27, 1951, at about 5 P.M., the water dropped to 571.5 feet. As a result, the upper surface of the shale was exposed in several places and hundreds of the concretions became visible, sitting in place in the shale. (See fig. 2-6) An interesting feature observed was that the tops of many of the concretions have been beveled off and show

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**Figure 2-8.** Rectangular joints in the Huron shale at Camp Boulder. View N. 60° E. Bedding planes are approximately horizontal.

**Figure 2-9.** "Pocket beach" of pyrite nodules near Camp Boulder. The nodules lie on the Huron shale north of limestone rip-rap, and are usually covered by water.
Stripes due to glacial action. One concretion about 3 feet in diameter exposed just west of the series of groins on the eastern half of the Boulder Camp shore showed a large crag and tail effect, with 4-inch deep grooves on each side of the tail. (See fig. 2-7) The shale is scarred by many striations, the general trend being N, 60° E.

The shale is broken by an extensive, apparently vertical, rectangular joint system. (See fig. 2-8) The stronger set trends approximately N, 60° W.

Nature of Shore

The beach at Camp Boulder is quite narrow, and high water covers the entire beach. The beach materials consist of a thin layer of pebbles, predominantly shale, lying on the clayey till which has been beveled down by wave action.

On September 27, at the time when the water was quite low, "pocket beaches" of pyrite concretions were exposed. These ellipsoidal or mushroom-shaped concretions average 2 to 3 inches in diameter, and have been eroded out of the Huron shale. They gather parallel to the shore a few yards out under the shallow water in small pockets up to 10 feet long and 3 or 4 feet wide. As many as a bushel of them may be in each group. (See fig. 2-9) After severe northeast storms a few of these concretions may be found thrown up on the beach at the foot of the bluff.

Another feature noted at the same time was a belt of shale fragments averaging 6 to 8 inches in diameter about 10 yards wide, running parallel to the shore a few feet out from normal water line. In this belt, the angular fragments had been deposited in great numbers. Instead of lying nearly horizontally in shingle fashion, these fragments stand nearly vertically in closely-packed rows. The planes of these fragments follow no universal orientation, but combine to form patterns of swirls and pinwheels. (See Fig. 2-10) The phenomenon was evidently caused by the swirling lake waters as translation waves race across the shallow depths covering the wide, flat shelf formed by the Huron shale. A similar arrangement of ice fragments was reported by R. S. Bowman (personal communication) to have formed in a shallow area in western Sandusky Bay during the winter of 1951-52. In both cases, the cause seemed to be the action of waves over a flat, shallow bottom.

Erosion

This promontory has resisted erosion, and old surveys show that the shore line has retreated very little in comparison to adjacent areas (House Document No. 220). However, due to high water, erosion has been quite active at Boulder Camp during recent years. The waves beat directly against the till cliffs, undercutting them and causing much slumping. In the period from October, 1951, to March, 1952, the bank retreated about 8 feet near the center of the area. (See fig. 2-11,12) Whenever large waves strike on the shore here, the water is an extremely dirty yellow for many yards out, indicating that the till is being carried away in suspension.

Protective Structures

Along the east side of the Boulder Camp shore line a series of groins has been built, and sand has accumulated on the eastern side of each. Rip-rap has been banked against the bluff along the western bluff bordering the camp. During the winter of 1951-1952, the owner of Boulder Camp built a wall of concrete blocks out about 30 yards from shore, three feet thick and about 4 feet above the shale. In spite of the wall, high waters and storms in March, 1952, caused extensive erosion along the shore behind the wall. Rip-rap and groins have also been used east of Boulder Camp as protection against erosion.

Figure 2-10. Close view of shale fragments (Boulder Camp). This area is usually submerged.
GRAND FOREST BEACH TO RYE BEACH

Geology

Huron shale is exposed at the eastern end of the Grand Forest Beach shore line. Here, too, concretions are exposed in place in the shale. A stiff gray to brown till has been deposited over the shale and is 3 to 4 feet thick. The till contains a profusion of angular shale fragments as well as crystalline erratics. Above the till is about 6 to 8 feet of laminated clay, capped by 1 or 2 feet of soil. The laminated clay occasionally shows cross-bedding and minor folding. (See fig. 2-13)

About 1000 feet west of Boulder Camp the shale is not exposed, but a dense, highly-contorted red-brown till is present to an elevation of about 576 feet. The till shows a thin lamination due to slight changes in color, and the extreme contortions of the material show up rather well. The surface of the till is not horizontal, but shows no marked uneveness on its upper surface. It is overlain by 6 to 8 feet of laminated clay. The till contains many erratic pebbles and cobbles. In one place there is a thin horizontal zone of small red limy concretions averaging about 1 inch in diameter.

To the west the lamination disappears, and still further west the bluffs are obscured by protective structures. At Rye Beach there is no pronounced bluff, and the land only rises 3 or 4 feet above the mean lake level. A yellow till is present here, and in some places it contains abundant erratic pebbles.

Nature of Shore

The shore materials of this area vary considerably. At the eastern end, where the shale is exposed out under the water, thick shingle beaches of angular and rounded shale fragments are present. (See fig. 2-14) In places the shingled material is piled up 4 or 5 feet high. Just east of the shale are sand beaches about 15 feet wide, but the sand apparently is not abundant on the lake floor adjacent to the beach. The sand here contains black layers of magnetite sand up to 1/2 inch thick, and pockets of black sand 2 or 3 feet square and 3 inches thick are frequently formed along the foot of the bluff at the head of the beach.

A 30-foot-long beach suitable for recreational use has been formed in a small cove about 1000 feet west of Boulder Camp. A few similar small beaches occur along the shore in this area, and the park at Rye Beach has a beach over 100 feet long. At the eastern end of the area, groins collect a greater amount of sand and gravel on their east sides (See fig. 2-15), but at the western end of the area sediment is collected in approximately equal amounts on both sides of groins.

Erosion

Erosion is quite serious in this area. The
beaches are interrupted by bulkheads, groins, piles of rip-rap, and concrete walls, but in several cases erosion in intervening areas has flanked the protected frontages to such an extent that they may soon be eroded from the sides. The shore line here retreated 21 feet between 1877 and 1939, the 6-foot depth contour retreated 36 feet, the 12-foot contour 37 feet, and the 18-foot contour 7 feet (House Document No. 220, p. 13). The irregular rate at various levels might possibly be explained by protective devices arresting erosion of the shore line, and depths greater than 12 feet being below the more vigorous wave action. It may be that the profile of equilibrium is being approached for this particular area.

CEDAR POINT

General Description

Cedar Point peninsula extends from just west of Rye Beach over seven miles to the northwest, terminating at the entrance to Sandusky Bay. Moseley (1905, pp. 210-238) adequately discussed the geologic history of Cedar Point, and evidence of recent years is in agreement with his views. He divided the peninsula into three parts: 1. a bar extending from Rye Beach to the area west of Willow Point, 2. a dune section extending from Willow Point to the head of Beimiller's Cover, and 3. the ridge or terminal section of Cedar Point. (See fig. 2-23) It will facilitate matters to discuss each of these separately.

The Bar or Barrier Beach

Geology: The long, narrow strip of sand and gravel from Rye Beach to Willow Point is a bar which is steadily advancing over the marsh to the south. (See fig. 2-16) Thus, swamp muck and peaty material are to be found at shallow depths below the bar, as well as on the Lake Erie side. A thin veneer of sand or gravel may cover the muck on the lake floor. Beneath the swamp muck are lenses of yellow, blue, and red glacial clays containing thick lenses of sands and gravels. The term "lenses" is used because of the fairly rapid changes, both horizontally and vertically, in the character of the cross section below the bar.

The Sandusky city engineers have made a series of auger bore holes in the marshy region from the new Cedar Point entrance road westward to within about 300 yards of Willow Point. The borings were made at 1000-foot intervals in nine north-south rows 1000 feet apart. The westernmost line of borings encountered bedrock at an elevation of approximately 550 feet, overlain by gravel, sand, clays, and swamp muck--approximately 25 feet of unconsolidated material. The next line of probings, 1000 feet farther east, encountered bedrock at an elevation of 545 feet, and there is no more record of bedrock elevations eastward along the shore of the peninsula. Borings at the Plum Brook Intake went down to elevations of 516 feet without encountering rock, giving a minimum thickness here of approximately 60 feet for the unconsolidated material.

It is assumed that the bedrock formation encountered by these borings is the Delaware limestone, for it is quarried near the State Soldiers and Sailors Home southeast of Sandusky (Stout, p. 866) as well as at Venice, the old Mills Creek quarry on the southwest part of Sandusky, and the old Schoepfle quarry in Sandusky (Stauffer, pp. 125-130). The quarries in Sandusky and near the state home are about 2-1/4 miles southwest of this area. The Columbus limestone is found under the Delaware in all of the above-mentioned quarries but the first. It would appear that the Olentangy shale is absent along the shore, having possibly been removed both by ancient stream erosion, and by work of the continental ice sheets of the Pleistocene. The softness of this shale would readily explain such an action. The Huron shale is

Figure 2-13. Laminated clay at Grand Forest Beach. Structure was probably caused by a current or stream cutting a channel through bottom deposits, with later deposition covering crest and trough alike. Hammer rests on till.
not involved here, for its basal portion would normally be exposed near Rye Beach. The contact of the Huron shale over the Prout limestone member of the Olentangy shale is exposed at an elevation of about 605 feet at Slate City on U. S. Route 6, 3/4 miles east of the new Cedar Point entrance. (See fig. 2-33) The northeast strike of the rocks here (Stout, p. 359) would indicate that the base of the Huron shale would be some 30 feet above the swamp muck at the Plum Brook intake, and should be at about 575 feet at Rye Beach.

The bore-hole data show variations both from east to west and from north to south. For example, near the new Cedar Point entrance road there is a lens of sand over 20 feet thick at about 500 feet elevation, but near Willow Point there is none. At an intermediate point this buried lens is over 30 feet thick. At the Plum Brook intake, mixed silt and sand was encountered at an elevation of 521 feet.

The clays show local relief on their upper surfaces, and there are definite depressions on the surface of the clay south of the peninsula. Moseley (1905, pp. 203-207) was able to trace definite channels in the clay extending northward under the bar from the mouths of streams flowing into the bay from the south. The channels are as much as 20 feet deep, but have since been filled with swamp muck. The muck is as much as 10 to 20 feet thick in most places in which the marsh now exists, as shown by the Sandusky city engineers' borings.

The bar has been breached at various times by severe storms, even in recent years. In the early 1800s, openings large enough to bring boats through would be opened up for weeks at a time, and on such occasions large quantities of sand were washed into the marsh (Moseley, pp. 219-220). The numerous irregularities on the south side of the bar have been formed in similar fashion.

Two streams flowing into the lake near Rye Beach have been choked off by bars. (See fig. 2-18) Sawmill Creek, which has two outlets, has both mouths closed by sand bars about 120 feet wide and 4 feet high—about the same dimensions of the easternmost two miles of Cedar Point peninsula. The peninsula joins the mainland west of Sawmill Creek, but the shore on east to Rye Beach more closely resembles the shore of the peninsula than areas farther east.

**Nature of Shore:** The shore along most of the bar is an excellent sand beach, but the beaches for about 1/3 of a mile west from Sawmill Creek and for about 1/3 of a mile midway between the Plum Brook intake and the new Cedar Point entrance are of gravel.

There is no cliff or bluff of any noticeable

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**Figure 2-14.** Shingle beach at Grand Forest Beach. View eastward toward Camp Boulder. Concretions in place in Huron shale are visible in the water.

**Figure 2-15.** Groin at Grand Forest Beach. More shale collects on the eastern side, although about the same amount of sand collects on each side. The shale and sand are roughly in separate layers on the eastern side.
Figure 2-16. Diagrammatic cross section of bar portion of Cedar Point.
(Based on borings by Sandusky city engineers.)

Figure 2-17. Diagrammatic cross section of dune section of Cedar Point.
(Based on borings for Sandusky water intake.)
size east of the new entrance, though small nips less
than a foot high are seen at the tops of the beach in
some places. The beach is absent just west of the
new entrance due to artificial maintainence, by rip-
rap and groins, of the shore line, but quickly widens
a few hundred feet to the west until it is 40 to 60
feet wide. It gradually narrows farther westward,
although the change is irregular, and west of Willow
Point it is only 20 to 30 feet wide. Along the latter
portion at the top of the beach there is a 6 to 8-foot
sand "cliff" which has been undercut by storm waves.
Cross bedding and absence of heavy mineral layers
in the cliff show that it is probably of dune origin.

Many areas are covered with black or purple
sand. A patch of the purple garnet sand is almost
always present west of and between the westernmost
two or three of the series of groins at the new Cedar
Point entrance. The bar west of the Plum Brook in-
take contains layers of black sand that extend up
over the crest of the 120-foot-wide bar and down the
back slope, in continuous, even sheets 2 to 10
millimeters thick. (See fig. 2-20)

Erosion: Erosion along this strip is not so ob-
vvious, for the retreating shore is merely one side of
the wide, sandy beach which is migrating southward.
However, the tendency of the bar to move southward
is relentless, and the old Cedar Point road, which
turned northwest along the shore at the location of
the Plum Brook intake, finally had to be abandoned
in 1919, and the bar in that area has advanced almost
100 yards since then. The new road has on occasions
been severely damaged just west of the entrance by
strong northeast spring storms. A series of groins has
been built here, and rip-rap placed along the cliff,
but the groins in the center have failed to collect
much sediment. (See figs. 2-21,22,23)

The Dune Section

Geology: The portion of the peninsula from
east of point of Woods to the head of Beimiller's Cove
may be considered an independent unit in that the
bedrock and overlying clays rise up close to the sur-
face, and were here above lake level for centuries.

Sand dunes have accumulated in this area, rising as
high as 15 to 20 feet above the level of the lake.

Moseley (p. 222) reported one dune 27 feet high.

Test holes drilled in preliminary work for the
Sandusky water plant intake pipe show that bedrock
is at about 551 feet elevation just southeast of Point
of Woods. Earlier probings showed that bedrock is
at about 560 feet between Big Island and Cedar Point,
and at one place in Beimiller's Cove it is at 563 feet.

Overlying the rock is 8 to 10 feet of blue, red, and
yellow clays, so that at Point of Woods the upper sur-
face clay is at about 565 feet of elevation, and in

Figure 2-18. Bar cutting off mouth of Sawmill
Creek at Rye Beach.

Figure 2-19. Eastern end of Cedar Point peninsula
as seen from Rye Beach (foreground, left). Note how
the bar portion has advanced inland, while the rip-
rap at Rye Beach has reduced erosion.
Figure 2-20. Typical laminae of black sand found along Cedar Point. (Taken at beach of Dune section.)

Figure 2-21. View northwest at center section of groins west of the Cedar Point entrance road. Little sediment has been collected. The groins are about 20 feet long. The lake level at the time of the picture was about 574 feet.

Figure 2-22. View southeast at western end of series of groins shown in figure 2-21. Sand has collected to a greater extent on the western sides of the groins.

Figure 2-23. Groin at the eastern end of the series shown in fig. 2-22. More sand has collected on the eastern side.
many places at Beimiller's Cove and in the bay to the south the clay is as high as 568 feet. There is a slight rise in the bedrock just north of the peninsula, and cross sections show that clays have evidently been plastered upon this rise by the glacier, the highest point of the clay being to the north, under the peninsula. (See fig. 2-17)

The dune section of the peninsula was, for a time, a point of land continuous with Big Island. During the Kirkfield stage of Lake Algonquin, the level of Lake Erie fell to as low as 540 to 550 feet in elevation (Leverett, p. 98). Again, during the time of Lake Nipissing the level of Lake Erie fell to around 560 feet in elevation (Leverett, p. 102). At both times there was a bridge of land from Big Island to the dune section of Cedar Point. The channels Moseley (p. 204) found in the clay of Sandusky Bay were formed during this time, as the streams flowed straight northward across the lake clays to discharge into the lowered lake. Thus, it is possible that sub-aerial erosion sculptured the surface of the clays now covered by sand.

On the north side of Beimiller's Cove there is evidence that a sand ridge has been here for thousands of years. An excavation made during the summer of 1951 exposed the interior of a ridge 20 feet high, which rises steeply from the northeast side of the head of the cove. The ridge is covered by a heavy growth of large trees and a soil zone almost a foot thick. At first glance one might call the ridge a dune, but the cross section shows that the ridge has definitely been built up by aqueous action. Banks of black sand as thick as 1 to 2 centimeters extend for as much as 100 feet across the ridge, smoothly rising slightly to the crest and dipping down the other side in straight, even planes—just as do the black layers in the bar east of the Plum Brook intake. Many of the lower black layers are truncated by overlying ones, and the relationship suggests that the ridge moved south as it got higher. (See figs. 2-24, 25, 26, 27) Microscopic examination of the sand from the ridge shows nothing to suggest that it is a dune.

The author believes that this ridge was formed as a bar immediately subsequent to the Elkton stage of glacial lake Lundy (Leverett, p. 100) as the lake level dropped from around 620 feet to 540 feet in elevation. Leverett (p. 98) lists a higher St. Clair and Rouge stage of Lake Algonquin during which Lake Erie was at about 590 feet and a lowest stage of 580 feet. The top of this ancient bar is approximately 590 feet in elevation, and the lake level was probably over 580 feet (as it would have been during the St. Clair and Rouge stage). Moore's calculations of crustal sinking in this area probably do not affect these calculations too much, for the rate of sinking

Figure 2-24. View westward at excavated section across an ancient bar north of Beimiller's Cove on Cedar Point.

Figure 2-25. Laminations of bar extend completely over the crest. Lower laminations have been truncated by upper ones, forming an angular unconformity. Visible laminae are rich in heavy minerals.
Figure 2-26. Close view of exposed section in ancient bar on Cedar Point. Note linearity of heavy mineral laminations. Height of section is about 5 feet.

Figure 2-27. Close view "angular unconformity," in ancient bar. Lower beds were on the south side of the original bar, and upper beds were on the north side of the later bar.

Figure 2-28. View northwest from western area behind a wall which was built parallel to shore about 30 feet from the rip-rap on Cedar Point north of Beimiller's Cove. A wide beach has collected. This picture was taken in August, about six weeks after the wall was built.

Figure 2-29. View southeast from eastern end of area behind same wall and on same day as fig. 2-28. The supply of beach material has been depleted, due to prevailing currents from the west during July and August.
north of Detroit, where the St. Clair and Rouge beaches were defined (Leverett and Taylor, pp. 496-500) is only .08 feet per century less than that at Sandusky (Moore, pl. 1.).

The spit on the south side of Beimiller's Cove is of fairly recent origin, and old maps show two islands in this area which have since been incorporated into the spit.

Nature of Shore: The shore in this area is a continuation of the excellent beach which is found along most of Cedar Point. High water of recent years has caused it to be narrower in places. Efforts to maintain the position of the present shore line by artificial divides have caused depletion of the sand at some points. For example, on July 3, a wall 120 feet long was built parallel to shore north of Beimiller's Cove. By August, there was a beach to the west and none to the east. (See figs. 2-28, 29), for the currents during those months were almost exclusively toward the east.

Erosion: Erosion is not serious in this area, and at the western portion the shore line has remained at nearly the same position since 1877 (House Document 220). In order to maintain the highway along the top of the sand bluff at the head of the beach, apparently successful protective devices have been built.

Ridge Section

Geology: West of Beimiller's Cove the bedrock and clay is at much greater depth. Probing by various engineering surveys show that rock is over 30 feet below the surface in most places. At the Cedar Point park powerhouse, clay was 26 feet below lake level and rock 46 feet below (Moseley, p. 223). Further west the depth of bedrock has not been definitely established. This portion of the peninsula is a true spit, although the end has now been anchored down by the Cedar Point jetty.

The ridge section of Cedar Point is actually a series of storm ridges of sand which have been progressively built up toward the north. Moseley (p. 231), by use of botanical evidence, estimated that the oldest (southernmost) ridge in this area was formed during severe storms shortly after the year 1400. He was able to show that each of the younger ridges had been built by specific severe storms during the last half of the Nineteenth Century, and assumed that the older ones were formed in similar fashion. A large triangular area containing four more ridges has been built up since 1905, when the northernmost ridge was about even with the south end of the Cedar Point jetty. (See fig. 2-33)

The hollows between successive ridges are

Figure 2-30. View southeast of marsh between the youngest two ridges at the western end of Cedar Point. Lake Erie is beyond the ridge to the left.

Figure 2-31. Bar which has moved toward the shore at the western end of Cedar Point.
swampy in some cases, and the northernmost one contains a marsh in which the water stands 2 or 3 feet deep. (See fig. 2-30)

**Nature of Shore:** The beach in this area is excellent, and has been utilized as a resort area. A dune about 8 feet high has been built up along the eastern portion, but the western end has only a low storm beach. Low bars form just off shore and move landward from time to time, adding to the accumulation. (See fig. 2-31)

The accumulation of sediment east of the jetty, and the fact that the Cedar Point spit was formed before the jetty was built, indicate that there is a general westward movement of sediment, even though for short periods there may be eastward movement.

**Erosion:** In spite of the increase in size of the part of the spit above water, there has also been a considerable amount of sediment loss offshore. Between 1877 and 1939 the 6-foot depth contour moved landward 174 feet, the 12-foot contour 378 feet, and the 18-foot contour 15 feet (House Document 220, p. 13). The 18-foot contour passes by the base of the north end of the jetty, which explains its minor change in position. The cause for erosion at this point could be due to a combination of dredging operations for the Sandusky harbor channel, and the moving of sediment in toward shore faster than it can be replenished. A complete current study near the end of the jetty could also give possible information as to the cause.

**FIELD AND LABORATORY METHODS**

**FIELD METHODS**

In addition to the geologic reconnaissance of the area, the investigation entailed various specific procedures in the field and laboratory.

**Collection of Samples**

**Shore Samples:** Lines of samples perpendicular to the shore were taken at intervals of approximately one quarter of a mile from Rye Beach westward to the end of Cedar Point, and at various points east of Rye Beach. (See fig. 2-33) Samples in each line were taken at the shore line, the crest of any berms present, and at the crest and foot of the foredune or storm beach, if present. (See fig. 2-32)

On the Cedar Point peninsula several excavations were being made by construction workers, and samples were taken from various layers in the exposed section.

The samples were taken in most cases by use of a beach drive sampler (Pincus, Roseboom, and Humphris, p. 6) and were stored in labeled Mason one-pint fruit jars. Each sample was indexed to a corresponding data sheet on which was recorded such information as stratification, time of day when taken, and profile of the beach at that locality. Samples were collected by hand in cases where only a thin layer or a pebble count was desired. Thin laminae of sand rich in heavy minerals were collected by careful horizontal slicing with a pocket knife.

Location of shore samples was recorded by pricking small holes in aerial photographs of the area. Careful study of landmarks made possible the location of points with probably no more than 6 to 10 feet of error.

A major criticism of this method of sampling is that in the final result the analyses deal with a mixture of the laminations in the beach material, thus not showing results of specific depositional characteristics (Emery and Stevenson, p. 223).

Collecting samples from individual laminae from each location would be a formidable task, and collecting material laid down simultaneously at different locations would be impossible for one field investigator, and difficult for more than one. The method here used does result in a type of generalized picture of each locality sampled. Surface layers, especially on higher points, could have been disturbed by wind, but this actually involves only a very small part of the total sample.

**Shallow Water Samples:** In near-shore waters less than five feet deep a check-valve sampler (Pincus, Roseboom, and Humphris, p. 5) was used, and samples were stored in the same manner as the shore samples. In cases where the sediment was too coarse for the one-inch diameter of the check-valve samples, collection was by hand or, in very shallow water, by the beach drive sampler. A piston was used to extract the core from this sampler in order to reveal any laminations which might be present in the sediment.

On the Lake Erie side of Cedar Point the check-valve sampler was carried to the sampling locality by a person wading out from shore. Samples were taken at depths of approximately 5, 3, and 1 1/2 feet, at the plunge point, and at the crest of the bar, if present. (See fig. 2-32) Location of samples was
made by Brunton compass triangulation from two shore stations occupied successively by a second person while the collector remained in position. The off shore samples were taken perpendicular to the shore line, and aligned with the series of shore samples. (See fig. 2-33)

In Sandusky Bay and in the marshy area to the east, the check-valve sampler was manipulated from a flat-bottomed row boat, and locations were estimated closely by careful inspection of the aerial photographs. Samples were not collected at equal, predetermined intervals in this area. (See fig. 2-33)

Depths from which samples were collected were referred to the water level at the time of collection. The corrections for fluctuating lake levels were determined during most of the summer by two staff readings daily at the State Dock in Sandusky. Since core samples represents a depth of at least 6 inches, the sediment collected represent an average of depositional conditions for several depths, so that precision greater than six inches in actual elevation of samples was not believed to be required.

**Deep-Water Samples:** Sediment samples taken from the lake bottom at depths greater than five feet were obtained by means of a modified LaFond and Dietz clamshell snapper-type sampler (LaFond and Dietz, p. 34). Samples were taken in locations at predetermined distances along a given range, or by indications of a change in the nature of the bottom as indicated by the type of echo on the fathogram.

Location determined by sextant were later plotted on a base map by means of a three-arm protractor (Pincus, Roseboom, and Humphris, p. 6), since use of aerial photographs was unsuitable for positions far from shore.

Samples were stored in the same manner as mentioned above. If no sample could be obtained after three or four attempts in a given location, it was recorded that the bottom was bedrock. This was apparently confirmed at several locations by the character of the echoes recorded on the fathogram.

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**Figure 2-32.** Diagrammatic representation of typical sample locations along Cedar Point.
LAKE ERIE SHORE
CEDAR POINT TO HURON
LOCATION OF SHORE AND BOTTOM SAMPLES

Figure 2-33
Mapping of Profiles

Plane Table: Profiles perpendicular to the shore line were mapped by plane table and alidade along the Lake Erie shore from the new Cedar Point entrance roadway to the Cedar Point Jetty. (See fig. 2-33) The plane table was set up at the approximate location of samples which had previously been collected along the shore line, and rod stations were located in a series from the crest of the foredune or storm beach to the greatest depth to which the rodman could wade. Thus, profiles were obtained to correspond to the rows of samples which had been collected along the same beach.

Fathometer: Profiles were mapped at depths greater than five feet by use of the Raytheon type 1373 Fathometer, Jr., which was part of the research vessel's equipment. The profiles were mapped either on ranges parallel to shore or perpendicular to shore. The boat was run at constant speeds along linear tracks, and two persons took frequent simultaneous horizontal angle readings with sextants to give locations corresponding to marked intervals along the continuous fathogram which was produced. Positions were later plotted on a base map by means of a three-arm protractor and the portions of the fathogram between stations were interpolated to present a continuous profile of the lake bottom along the track run.

Hydrological and Wind Observations

Each time that work was done in the field, observations were made of wave and current direction, frequency and size of waves, and wind direction. No complete current study was made, but floats thrown out from shore were observed to find the direction and approximate speed of the longshore currents. Wave height and frequency were estimated by eye as the waves impinged on groins or pilings out in the water, or as a wave rose and fell along the handling pipe of the check-valve sampler. In the latter method, the measurements of amplitude were correct to within an inch, but by the first method may have been as much as 6 inches in error. Wave direction was determined roughly by pointing a Brunton perpendicular to an approaching wave front.

LABORATORY METHODS

General Statement

The samples were taken to the laboratory in the collecting jars and dried in an oven. They were later analyzed mechanically, mineralogically, and for carbonate totals. Much of the mechanical analysis was done during the summer at Sandusky, but most of the laboratory work was completed during the school year in the Lake Erie Geological Research Program laboratory in Columbus.

Mechanical Analysis

Approximately 60 grams of sediment was separated by a Jones splitter for each sample composed of material ranging from silt to pebble size, and was analyzed for Wentworth grade size distribution by sieve analysis. A Ro-Tap was used according to the procedure described by Krumbein and Pettijohn (p. 140-141). Elutriation by pipette (Krumbein and Pettijohn, pp. 166-168) was used to analyze sediments of grain size smaller than 1/16 millimeter in diameter.

A disadvantage of computing weight percentages for each grade size is that minerals vary in density, but the percentages of heavy minerals were found to be quite small in most cases. The heavies were more abundant in the finer grades. (See Fig 2-43).

Carbonate Analysis

Carbonate percentages were determined by computing weight loss due to leaching by a 10 per cent solution of hydrochloric acid (Pettijohn and Ridge, 1932, p. 77). Approximately 20 grams of unsieved material from each sample was subjected to digestion in an acid bath for at least 8 hours. The remaining sediment was washed three times, dried in an oven, and any loss of weight noted was assumed to be due to leaching of carbonate minerals. Later mineralogical analyses bore out that carbonates were the only detectable acid-soluble minerals present in measurable quantities.

Mineralogical Analysis

Procedure: Heavy mineral separations by bromoform solution (Stow, pp. 48-49) was carried out for the three finest sieve grade fractions (1/16-1/8, 1/8-1/4, and 1/4-1/2 mm) of selected samples. Three size grades were used for heavy mineral analysis in order to get a more comprehensive picture of various mineral frequency variations (Krumbein and Pettijohn, p. 473). The bromoform was purified by washing in water three times, and this produced a solution of density greater than 2.86 (pure bromoform...
density: 2.89). Weight percentages were calculated, portions of the heavy fractions were mounted in Lake-side plastic (index 1.545), and grain counts were made of the various heavy minerals present.

Grains were counted in random fields in the case of smaller grade sizes, or by systematic traversing by use of the mechanical stage in the case of larger grade sizes. Counts of 100 grains were made for the larger grade sizes, but 200 grains were counted in the case of the smallest size.

The light fractions from the separations were examined under the binocular microscope for grain rounding and surface frosting. Mineralogical analyses were made for samples from each end and from the center of the area studied.

Discussion of Errors Involved: There are many steps in the entire procedure of making mineralogical analyses of sediments which are subject to errors, and these have been pointed out by various authors (Krumbein and Pettijohn, Chap. 14-18). The problem of obtaining representative portions of the various grade size fractions was approached by using quantities of sediment which had been obtained by careful quartering or by use of an Otto microsplit. Such procedure was also used in obtaining the small amounts of material necessary for slide mounts. Even so, the fact that magnetite or other magnetic minerals were present makes it probable that there was a tendency toward aggregations.

In counting a predetermined number of grains on a slide, there is again introduced a sampling error. Various workers have counted numbers of grains varying from 50 to the entire heavy fraction of the sample. Sindowski (1949, p. 5) summarized the procedures of many German workers, and concluded that 200 grains should be sufficient in most cases.

The probable error (Krumbein and Pettijohn, p. 18) grows proportionally smaller with increasing numbers of grains counted. These relations have been summarized graphically (Krumbein and Pettijohn, p. 472). Although the per cent of error is quite large for minerals with low frequencies of occurrence, the trends of the heavy mineral patterns as plotted in this study are believed to be affected to only a minor extent.

TREATMENT OF ANALYTICAL RESULTS

MECHANICAL ANALYSES

General Statement

Size analyses were made using the Wentworth size classification, but for convenience in using standard statistical procedures, results of size analyses were recorded in terms of Krumbein's phi (\( \phi \)) scale (Krumbein, 1934).

Cumulative distribution curves were plotted, using Wentworth grade phi values as abscissas, and weight percentages of the various size grades as ordinates. From these curves were calculated the following statistical measures:

<table>
<thead>
<tr>
<th>Statistical Measure</th>
<th>Symbol</th>
<th>Pages in Krumbein &amp; Pettijohn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phi Median</td>
<td>( M_{\phi} )</td>
<td>233-234</td>
</tr>
<tr>
<td>Phi Quartile Deviation</td>
<td>( QD_{\phi} )</td>
<td>234</td>
</tr>
<tr>
<td>Trask's Sorting Coefficient</td>
<td>( S_0 )</td>
<td>232; 234-235</td>
</tr>
<tr>
<td>Phi Quartile Skewness</td>
<td>( SK_{\phi} )</td>
<td>237-238</td>
</tr>
<tr>
<td>Phi Quartile Kurtosis</td>
<td>( K_{\phi} )</td>
<td>238</td>
</tr>
</tbody>
</table>

Application of Statistical Data

All statistical results were tabulated, and appear in the appendix of the master's thesis on which this paper is based. This thesis (Metter, 1952) may be consulted in the library of the Ohio State University. Values of phi medians (\( M_{\phi} \)) and sorting coefficients (\( S_0 \)) for Lake Erie bottom samples (for depths 5 feet or greater) have been plotted on an outline map of the area. (See figs. 2-34, 35, 36)

Graphical representations of linear trends of various statistical quantities of beach samples have been plotted (See figs. 2-37) for samples taken along the crest of the storm beach or dunes along Cedar Point. (See fig. 2-39) Profiles along the Cedar Point Lake Erie shore have been plotted with phi median (\( M_{\phi} \)) and sorting coefficient (\( S_0 \)) values indicated at the sample locations. (See fig.2-38)

CARBONATE ANALYSES

Carbonate percentages were compiled and are tabulated in the appendix if the unpublished thesis (Metter, 1952) on which this paper is based. A map showing carbonate percentages was constructed for bottom samples (See figs. 2-34, 35, 36), and graphs were constructed showing linear variations along the beach and dune crests. (See figs. 2-39, 41) Values of per cent carbonate vs. phi median were plotted for samples analyzed, using separate symbols for dune, beach, and bottom samples. (See fig. 2-40)

HEAVY MINERAL ANALYSES

General Statement

Although over 20 mineral species were
Figure 2-34. Per Cent Carbonate in Bottom Samples.

Figure 2-35. Phi Medians of Bottom Samples.

Figure 2-36. Sorting Coefficients of Bottom Samples.
identified and almost every sample examined contains more than 10 different heavy minerals, some mineral species were found consistently to occur much more frequently than others. These same minerals are more abundant in all three size grades examined: 1/16-1/8 mm, 1/8-1/4 mm, and 1/4-1/2 mm. (Grains thicker than 1/2 mm are difficult to identify microscopically, and most of the samples collected contain little material finer than 1/16 mm. Thus, study of these three size grades constitutes a study of the major portion of the readily identified heavy minerals of the sample.) Hornblende, garnet, magnetite-ilmenite, augite, and diopside each constitute over 10% of the total heavy minerals in the most of the sample studied. Hypersthene and zircon in most cases comprise 5 to 10% of the total heavy minerals, while rutile, titanite, and actinolite-tremolite are frequently present in quantities averaging 2 or 3%. The rutile and titanite are seldom observed in the 1/16-1/8 mm size grade.

Also frequently observed are tourmaline, enstatite, blue-green amphibole (probably arfvedsonite), apatite, and epidote. (See Appendix--Heavy Mineral Analyses, Metter, 1952)

Most of the minerals are observed to have different degrees of roundness, although the apatite is

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Figure 2-37. Statistical Measures of Water Line Samples.
Cedar Point Beach Profile

Showing Locations of Samples and Data Derived from Mechanical and Carbonate Analyses

Scale

Vertical Exaggeration: 4 X

Feet

Idealized Profile

Shoal in (C. 16.5)

Adapted from U.S. Army Corps of Engineers "Manual of Procedure in Beach Erosion Studies"

Note: The samples were collected during a period of four weeks during June and July of 1951. The profiles were mapped by plane table and slide in August, 1951. There were shifts in positions of bars during the intervening time.

R. E. Matter

Figure 2-38
Fig. 2-38. Cedar Point Beach Profiles (continued)
Figure 2-39. Statistical results of mechanical and carbonate analyses of dune samples.
Figure 2-40. Per cent carbonate vs. phi median.
almost always well rounded, and the garnet subangular to angular (Pettijohn, 1949, p. 52).

**Representation of Data**

Results of mineralogical analyses have been tabulated in the appendix previously cited, and detailed descriptions appear on p. 78 & 79 of the unpublished thesis (Metter, 1952). Graphic representations of linear variations along the shore have been plotted for the 1/16-1/8 mm and 1/8-1/4 mm grade sizes, and the same was done for six of the shore profiles. (See figs. 2-42, 43) Insufficient data have been obtained to do the same for the 1/4-1/2 mm grade size due to scarcity of heavy minerals in this grade size for many samples.

In addition, frequencies of the more abundant heavy minerals were plotted on outline maps for the three size grades analyzed for various bottom samples. (See figs. 2-46 thru 65) Heavy mineral percentages were plotted for the 1/16-1/8 mm and 1/8-1/4 mm size grades. Such devices make it easier to visualize areal variations of pattern for any one mineral. Actual grain counts were plotted, it being kept in mind that allowances must be made for sampling errors when one is interpreting the data (Krumbein and Pettijohn, pp. 469-480).

**AREAL PATTERNS AND INTERPRETATIONS OF MECHANISMS OF TRANSPORT**

**SIZE DISTRIBUTIONS**

**Phi Medians**

Study of figure 2-35 reveals that phi medians of the samples increase in value away from shore (i.e., median grain size decreases away from shore). This is in agreement with the theoretical considerations of fluid mechanics as discussed by Inman (1949, p. 67). Settling velocity, roughness, velocity and threshold velocity were computed for spherical grains with a specific gravity of 2.65 and were plotted on double log paper, with grain diameter in millimeters as the independent variable (Inman, p. 56). Some fundamental characteristics of movement for different grain sizes were deduced from the curves:

1. Fine sand, with an average diameter of about .18 mm (2.5 phi value) is most easily moved, being subject to transport at relatively low velocities by surface creep, saltation, and in suspension.
2. Grains of diameters greater than .18 mm tend to travel by rolling and sliding, and also require higher velocities for initial movement.

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**Figure 2-41. Per cent carbonate in beach samples collected along water line.**
Figure 2-42. Mineral Species Percentages in Heavy Mineral Fractions of Samples Collected along Water Line.
Figure 2-43. Mineral Species Percentages in Heavy Mineral Fractions of Samples Collected along Water Line.
Figure 2-44. Heavy mineral percentages in 1/16 - 1/8 mm size grade of bottom samples.

Figure 2-45. Heavy mineral percentages in 1/8 - 1/4 mm size grade of bottom samples.

Figure 2-46. Per cent augite in 1/16 - 1/8 mm heavy minerals of bottom samples.

Figure 2-47. Per cent diopside in 1/16 - 1/8 mm heavy minerals of bottom samples.
Figure 2-48. Per cent garnet in 1/16 - 1/8 mm heavy minerals of bottom samples.

Figure 2-49. Per cent hornblende in 1/16 - 1/8 mm heavy minerals of bottom samples.

Figure 2-50. Per cent hypersthene in 1/16 - 1/8 mm heavy minerals of bottom samples.

Figure 2-51. Per cent magnetite-ilmenite in 1/16 - 1/8 mm heavy minerals of bottom samples.
Figure 2-52. Per cent zircon in 1/16 - 1/8 mm heavy minerals of bottom samples.

Figure 2-53. Per cent zircon in 1/8 - 1/4 mm heavy minerals of bottom samples.

Figure 2-54. Per cent augite in 1/6 - 1/4 mm heavy minerals of bottom samples.

Figure 2-55. Per cent diopside in 1/6 - 1/4 mm heavy minerals of bottom samples.
Figure 2-56. Per cent garnet in $\frac{1}{8}-\frac{1}{4}$ mm heavy minerals of bottom samples.

Figure 2-57. Per cent hornblende in $\frac{1}{8}-\frac{1}{4}$ mm heavy minerals of bottom samples.

Figure 2-58. Per cent hypersthene in $\frac{1}{8}-\frac{1}{4}$ mm heavy minerals of bottom samples.

Figure 2-59. Per cent magnetite-ilmenite in $\frac{1}{8}-\frac{1}{4}$ mm heavy minerals of bottom samples.
Figure 2-60. Per cent diopside in $\frac{1}{4}-\frac{1}{2}$ mm heavy minerals of bottom samples.

Figure 2-61. Per cent augite in $\frac{1}{4}-\frac{1}{2}$ mm heavy minerals of bottom samples.

Figure 2-62. Per cent garnet in $\frac{1}{4}-\frac{1}{2}$ mm heavy minerals of bottom samples.

Figure 2-63. Per cent hornblende in $\frac{1}{4}-\frac{1}{2}$ mm heavy minerals of bottom samples.
3. Grains with diameters less than .18 mm if once put into suspension will tend to be transported in suspension rather than by surface creep. Inman found these results to be in agreement with laboratory experiments under controlled conditions.

A consideration of the transportation of sediment by wave action of medium strength led Inman to the conclusion that fine sand would be moved backward and forward as a wave passed, having a net change in location of zero. Coarser material would move shoreward with the rapid surge associated with the wave crests, and finer material would tend to be in suspension. Increasing intensities of wave conditions would cause a corresponding increase in the size of the sediment having a net transport of zero (Inman, p. 67).

These considerations seem consistent with the patterns observed in figure 2-35. Near the western end of Cedar Point the shore profiles (fig. 2-38) are gentler than to the east, and the waves lose much of their strength farther out from shore. Thus, the median diameter of sediment which is relatively stationary should be smaller at a given distance off shore at the west end than for the same distance off shore at a position farther to the east. The increase in grain size near the end of the Cedar Point jetty is probably due to currents leaving or entering Sandusky Bay, for strong currents have been observed in this area on various occasions. Observations were too few in number for any conclusions to be drawn as to general directions of flow. Similar variations are not present near the end of the Huron west pier. The factor of supply of sediment probably enters the picture here. There is an abundance of sand just west of the entrance to Sandusky Bay, and a sand bar extends most of the way across the mouth of the bay. Currents from the west or from out of the bay thus have a nearby source of sand-sized material. At Huron, jetties to the east cut down the supply of sand which can round the end of the west pier. A study of the sediments transported by the Huron River has not been made by the author, nor has an investigation of currents near the end of the west pier been carried out. The Huron River flows in a bedrock channel through much of its lower course, and may not carry much sand-sized material. If the prevailing currents were from the east, the above speculation would be plausible.

Near the center of the area the sediment near shore is coarser than to the east and west, possibly because of the nature of material being eroded from the lake bottom here. The increase lakeward in value of phi median is most rapid near shore, probably

Figure 2-64. Per cent hypersthene in $\frac{1}{4}-\frac{1}{2}$ mm heavy minerals of bottom samples

Figure 2-65. Per cent magnetite-ilmenite in $\frac{1}{4}-\frac{1}{2}$ mm heavy minerals of bottom samples.
due to the steeper bottom surface slope and consequent falling off in effects of wave motions.

Phi medians indicated on the profiles in figure 2-35 show a general decrease in size of material in both directions away from the water line. It is here that the agitation of water is particularly strong, due to the breaking of waves, and, in the light of Inman’s work, it can be shown that the very fine material is carried away in suspension, the fine sand is moved back and forth up the beach by the swash and runoff, and the coarser material can be rolled no farther shoreward, particularly if there is a sharp scarplet at the plunge point. On the profiles of figure 2-38 it can be seen that the coarsest material is found at the plunge point in most cases.

Phi medians of sediment from along the water line show an irregular trend, but definitely indicate a decrease in size of material at the western end of the peninsula, as has been observed by others (Pettijohn and Ridge, 1932; Pincus, Roseboom and Humphris, 1951). Toward the east the progression is very irregular. It is doubtful if this should be classified as a variation series (as was done by Pettijohn and Ridge) for the source of the sediment seems to be both from the bluffs along the eastern part of the area and from the lake floor along the entire area, with more coming from the latter source. (See sections on erosion in Description of Area.)

Phi medians of dune crest samples (fig. 2-39) are only indicated westward from the new Cedar Point entrance, for there is no ridge of any size east of the entrance. Here again the trend is toward finer material westward, with an exception at Point of Woods (sample 379). It is possible that there has been artificial disturbance of the sand at this point. It should be observed that rise of phi median values at the western end is accompanied by a falling off in the height of the ridge.

Other Statistical Measures

Sorting: Trask (1932) defined values of So less than 2.5 as indicating a well sorted sediment, and values greater than 4.5 indicate a poorly sorted sediment. On this basis it can be said that sediments over the entire area studies are well sorted, with only a few exceptions. A study of figure 2-37 shows that sorting of sediments along the water line is better as the median grain size decreases. Since the median diameter never gets smaller than a phi value of about 2.5 this is in agreement with the hydrodynamic considerations of Inman. (Since the coarser and finer materials are more difficult to move, and since the very fine material is removed in suspension, bottom sediment tends to be better sorted as its median diameter approaches .18 mm (Inman, p. 61).

A study of sorting along beach profiles (fig. 2-38) indicates that the sorting is poorest near the water line, especially on the initial down-slope of the steeper profiles. The slightly higher values for samples 324 and 329 are probably due to the daily operation of the Cedar Point park sand-sweeping machine. Sorting along the dune crests is good and shows little variations. (See fig. 2-39)

Kurtosis: No systematic relationships seem to exist between kurtosis (peakedness of curve) and phi medians or sorting coefficients, which have been plotted. (See figs. 2-37, 39)

Skewness: In the series of beach samples along the water line (See fig. 2-37) there is an increase in skewness toward the larger grain size of the frequency distribution curve of size grades for samples with poorer sorting, and also for samples having higher phi median values. Negative values of skewness indicate a skewness toward the larger sizes, in this case. Dune sands show almost no skewness. (See fig. 2-39)

Carbonate Percentages

Bottom samples show a nearly linear increase in carbonate content as the phi median of the sediment increases from about 2. This systematic covariation possibly results from a common cause. The carbonate increases as the water deepens off shore (See fig. 2-35), with a notable rise in percentage north of Beimiller’s Cove on a line from the end of the Cedar Point jetty parallel to shore. This is possibly due to the Delaware limestone being near the surface here. (See section on Cedar Point Dune area.)

Dune and beach samples show no such general systematic variation. (See figs. 2-39, 41) This may be due to the fact that sands on the beach have been subjected to a thorough washing by the swash, with much accompanying scouring action as the grains rub against one another, the net result being that much carbonate present would be clastic. Samples taken along the water line show a reciprocal relationship of phi median and carbonate content (See figs. 2-37, 41). The carbonate totals along the water line vary considerably, and increase markedly near the Cedar Point entrance (where limestone rip-rap has been placed) and also at Rye Beach (also where rip-rap and cement structures have been placed). Some
erratic variations may have been caused by shell fragments which were occasionally more abundant due to new broods of young snails hatching out. Samples containing noticeable quantities of small shells were not analyzed for carbonate.

Carbonate in dune crests varies from 1 to 2%, but is high in sample 305 near the western end of Cedar Point. (See fig. 2-39) The cause is not apparent. The ridge is about 5 feet lower here than to the east, and the phi median is higher, so that the conditions of deposition are apparently not the same as on the dunes farther east.

**MINERALOGICAL PATTERNS**

**Bottom Samples**

A summary of patterns of distribution of specific heavy minerals (figs. 2-45 thru 65) is tabulated below.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>1/16 - 1/8 mm</th>
<th>1/8 - 1/4 mm</th>
<th>1/4 - 1/2 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zircon (Figs. 2-52, 53)</td>
<td>Increases toward shore, with increase near dune section of Cedar Point both near near and off shore.</td>
<td>Pattern similar to 1/16-1/8 mm.</td>
<td>No definite pattern recognized.</td>
</tr>
<tr>
<td>Magnetite-ilmenite (Figs. 2-51, 59, 65)</td>
<td>Highest off shore along central portion of the bar section of Cedar Point, but near shore at the west end of the bar section. High near C. Pt. jetty.</td>
<td>Highest off shore in central part, but near shore to east and west.</td>
<td>No definite pattern, but possible higher near shore.</td>
</tr>
<tr>
<td>Hornblende (Figs. 2-49, 57 57, 63)</td>
<td>Higher percentage off central portion of bar, and at both eastern and western ends of area. At east end, higher than percentages for larger two grade sizes.</td>
<td>Higher at west end, and in central part of area. At west end has higher percentages than other 2 grades in some cases.</td>
<td>Increase in percentage toward the west.</td>
</tr>
<tr>
<td>Garnet (Figs. 2-48, 56, 62)</td>
<td>Most abundant off shore in central part and near shore at dune section of Cedar Point. At east end these values are higher than for the two larger grades.</td>
<td>Most abundant off shore in central part of area. In center, values for this size are greater than for other sizes.</td>
<td>High at west end. At west end the values for this size are higher than for the 2 smaller sizes.</td>
</tr>
<tr>
<td>Hypersthene (Figs. 2-50, 58, 64)</td>
<td>More abundant off shore and at extreme western end of Cedar Point.</td>
<td>No definite pattern recognized.</td>
<td>Central portion possibly has higher percentages.</td>
</tr>
<tr>
<td>Augite (Figs. 2-46, 54, 61)</td>
<td>Possibly more abundant near dune section.</td>
<td>Higher at each end of area, but slightly more at east end.</td>
<td>No definite pattern recognized.</td>
</tr>
</tbody>
</table>
A reciprocal relationship exists between percentages of hornblende and magnetite-ilmenite for all three size grades. This was also noted in the 1950 investigations of the Lake Erie Geological Research Program for areas west of Cedar Point (Pincus, Roseboom, and Humphris). The garnet pattern is somewhat similar to the one for magnetite-ilmenite. Hypersthene more resembles hornblende in its aerial pattern. Many factors are involved in these patterns. Differences in density and shape are important. Theoretical considerations usually deal with spherical grains, but hornblende is more often elongate, while magnetite and garnet are more nearly equidimensional. Frequency variations of percentages of various minerals do not necessarily mean an actual variation in total quantity of that mineral, for the total amount of heavy minerals in an area may be small.

The patterns of hornblende, magnetite-ilmenite, diopside, and garnet suggest a central source. Assuming a central source as the principal contributor of heavy minerals, it appears that hornblende and hypersthene are more likely to be carried far over shallow depths, such as are found at the western tip of Cedar Point, while magnetite-ilmenite moves outward from the source to less extent. This agrees with the findings of Pettijohn and Ridge (1933). Another fact in favor of a principal central source is that here the 1/8-1/4 mm size grade contains as much or more heavy minerals than the 1/16-1/8 mm size grade, while the 1/16-1/8 mm size grade elsewhere has greater total heavy mineral content. The total heavy mineral percentages were calculated as proportion by weight of total sample, and the increase in magnetite in this central area may have distorted the picture, since its density is much greater than that of the other heavy minerals.

For the minerals of the 1/16-1/8 mm size grades, two or three relationships are apparent. (See figs. 2-42, 43) Garnet and magnetite-ilmenite bear a reciprocal relationship with hornblende, augite, and diopside. The garnet and magnetite-ilmenite percentages increase westward to the Cedar Point amusement park, and then fall off rapidly.

For the 1/8-1/4 mm grade, magnetite-ilmenite percentages fall off just east of the new Cedar Point entrance. Along the eastern half of the area the garnet percentages follow those of magnetite-ilmenite, but garnet extends westward farther than magnetite-ilmenite. Again, as was the case for bottom samples, hornblende, augite, and diopside are in reciprocal relation to garnet and magnetite-ilmenite.

CONTRIBUTIONS OF GLACIAL TILL TO MINERALS PRESENT IN SAMPLES

It has been shown that material varying in size from clay to boulders is present in the unconsolidated material along the shore in this area. Since almost all such material is of glacial origin, the entire assemblage, although not the same proportion, of igneous and metamorphic minerals present in the crystalline rocks to the north can be expected in the shore sediment. While it is true that some minerals are more easily destroyed in transport, and others are attacked by weathering after deposition (Sindowski, 1949), fresh material is constantly being added by the crystalline erratics of larger size which are constantly being washed out of the till and subjected to abrasive action in the surf. In addition, sediments of Lake Wisconsin tills are relatively young, and have been subjected to prolonged weathering.
The sediments from the older glacial lakes, and from moraines south of the Defiance moraine should show a more marked decrease in minerals which are less resistant chemically and mechanically to the rigors of transport and weathering.

The dark laminae of heavy minerals show the presence of many of the accessory minerals of the crystalline rocks. The relative abundance of many easily weathered minerals among these heavy fractions (See Appendix - Grain Counts of Heavy Minerals, Metter, 1952) indicates that at least some of the sediment present is relatively fresh.

It is interesting to note that the heavy minerals which predominate here are mainly minerals which are easily weathered (Sindowski, p. 8). Amphiboles, garnet, and augite are included in Class II ("Easily Weathered") of Sindowski's seven-class listing of comparative resistance of heavy minerals to weathering. His class VII is listed as "not weatherable," and includes zircon, rutile, and tourmaline. This might indicate that the source of the heavy minerals studied is probably a relatively fresh one, for many of the grains examined were angular and unaltered, but it is possible that continual abrasion during transport might have produced this effect. It appears that the sands are not coming in from out in the lake, for the material a few thousand feet out (at least, from along this area) is a very fine-grained mud. (See fig. 2-34, 35, 36) Thus, they quite reasonably could be interpreted as resulting from erosion of glacial till along the shore.

TRANSPORTATION

The Cedar Point shore line trends nearly N. 45°W., and any wind producing waves from north of N. 45°E. would impinge upon the shore in such a manner as to produce an eastward current. Waves must approach from east of N. 45°E. to produce a resultant current toward the west. This concept of the cause of direction of flow of longshore currents was borne out during the summer of 1951, when currents were observed to flow from the west on all but two of the days that the author was in the area, and on those two days, the wind was from the E.N.E.

From the above reasoning, it would follow that during the times that the waves were from N. 45°E. on around to the northwest, longshore currents would carry sediments to the east. During the severe storms usually associated with waves from the east the movement would be to the west.

The northeast storms cause much stirring up of bottom sediments, due to the enormous energy of the large waves. The action is particularly vigorous near shore, where the waves break. The agitated sediment is immediately moved along by the longshore currents. Material eroded from the till bluffs and carried out in suspension is also moved by the longshore currents.

The longshore currents flowing to the east may be rather strong at times (as was often noticed by persons operating the check-valve sampler) but there is not so much material in suspension for such currents to carry. Thus, an over-all westward movement is possible if long periods of time are considered. The reciprocal relationships of some minerals (see section on mineralogical patterns) suggest that transportation is not equal in both directions for all minerals, nor is it equal in both directions for different grade sizes of the same mineral.

Material the size of granules and pebbles can be observed to roll along the beach with the swash from each wave. Pebbles 4 or 5 millimeters in diameter were observed to move along the beach seven-inches with each breaking wave on a day when the waves were no more than 12 to 18 inches from crest to trough. It is selective sorting by the swash's run-off which causes the laminae of heavy minerals and size variations. The swash throws up a layer of sand on the beach, and the run-off carries back the lighter minerals. Swash produced by different sizes of waves possesses different amounts of energy, and thus will deposit material of different median diameters.

Waves were observed carrying pebbles and sand as they raced in toward the shore across a shallow bottom. After heavy storms, large pebbles can be found on top of the clay bluffs at the eastern end of the area, where they had been thrown by the waves.

Strong winds were observed to blow swirls of sand along the beach. Examination of light mineral separates under the microscope revealed that while the sand from the tops of dunes almost always had at least 3 or 4% frosted grains, the same was true for random samples anywhere in the area, including underwater samples. Strong south winds evidently blow sand back into the lake.

CONCLUSIONS

SOURCE OF SEDIMENTS

It seems clearly evident on the basis of investigations of the geology, and erosion, and the laboratory studies of samples, that sediment in this area has
mainly been derived by erosion of the shore and adjacent lake bottom. The erosion along this area has been extensive, and is still a serious problem. (See sections on erosion under Description of Area.) The sand and gravel lenses 15 to 20 feet below the central part of the bar portion of Cedar Point have probably been important source of the coarser-sized material.

The heavy minerals areal patterns and percentages of total heavy minerals in different grade sizes suggest a principal central source (See previous section) with more movement toward the west than toward the east. Black shale pebbles along the Cedar Point Beach increase toward the east, as would be expected if their source were the Huron shale outcrops near Grand Forest Beach (discussed in Description of Area) and the movement were westward.

North of Plum Brook intake station there is no apparent abundance of gravels and the beach immediately west of the intake is sand. Yet, toward the west a section of the beach is principally pebbles and cobbles. If the assumption of principal westward motion is correct, the source of this coarser material should have been from subsurface till west of the intake plant. A consideration of the abundance of easily weathered minerals also suggests glacial till as the source.

The higher carbonate totals north of Beimiller's Cove are probably due to the presence of the Delaware limestone, which is near the surface at this point. (See section of Dune Section of Cedar Point)

Some of the sediment is from the bar, itself, for it has probably existed in this region for thousands of years.

**SUMMARY**

The Lake Erie shore from Cedar Point to Huron is composed of glacial till and lake sediments overlying Devonian limestones and shales. The bedrock varies in depth from about lake level at Oak Point to over fifty feet below the surface at the western end of Cedar Point. Cedar Point peninsula lies along a subsurface ridge of glacial clay for most of its length, over a submerged point of land at Beimiller's Cove, and is a spit at its western extremity.

The eastern part of the peninsula is a bar which has steadily advanced inland over a marsh area. As the bar advances, till, swamp muck, lake clays, sand, and gravel are gradually exposed to subsurface erosion by the waters of Lake Erie, thus producing the bulk of the sediment which has accumulated east of the Cedar Point jetty. Sapping by springs, frost wedging, surface runoff, and ice push undermine and weaken the clay bluffs along the eastern shore line of the area, making them even more susceptible to erosion by waves. If erosion is ever successfully halted, a major source of beach materials will be cut off.

Sediment is transported by waves, currents, swash, and wind, and may be moved either eastward or westward. The greater severity of storms from the northeast causes a general over-all westward movement. The rate and manner of movement differs for sediments of unlike average diameters and mineralogical compositions. The offshore bottom profiles also affect patterns of movement and the sorting of sediments found thereon.

**SHORTCOMINGS OF THIS STUDY**

As has been mentioned above, this study has provided evidence for paths of sediment movement on the lake bottom. General movements can only be inferred from data which were accumulated over a period of many weeks, interspersed with several storms, each of which probably changed the patterns. The study is based upon fewer samples than the author would like to have used, and more extensive sampling, both areally and vertically, and at several different times of the year would be desirable for a more complete investigation. An extensive study of currents at different depths and at different times of the year should provide much pertinent information, especially as regards movements at the ends of the Cedar Point jetty and Huron west pier.
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Chapter 3

SEDIMENTARY PROCESSES ALONG LAKE ERIE SHORE, FROM MARBLEHEAD LIGHTHOUSE TO BAY BRIDGE

By

Curtis C. Humphris
Chapter 3

INTRODUCTION

LOCATION

The area under consideration is located along the eastern and southern shoreline of Marblehead Peninsula in Ottawa County, Ohio. (See Fig. 3-1, 2-1) Marblehead Peninsula forms the northern shore of Sandusky Bay, with the city of Sandusky located due south on the southern shore. The eastern shore of Marblehead Peninsula borders on Lake Erie proper, the southern shore on Sandusky Bay. The area is approximately ten miles long, extending from Marblehead Lighthouse on the eastern tip of the peninsula south to Sand Point, then west to Bay Bridge, located in the middle portion of Sandusky Bay. Kelleys Island is located approximately three miles north of Marblehead Peninsula.

PURPOSE OF THE PROBLEM

The purpose of undertaking this study was to investigate the sedimentary processes in the shore area from Marblehead Lighthouse to Bay Bridge. These studies entailed an investigation of the source of the sediment, its composition and grain size, the inferred direction and method of sediment transport, the nature of the shoreline, including bedrock geology, the topography of the offshore areas, the effects of erosion on the different types of shore materials, and the influence of existing protective structures.

Most of the field work was completed during September of 1951. In addition, the area was visited on weekends during the following winter, spring and summer (1952) in order to observe the effects of heavy storms, ice, and high water. The laboratory work was completed during the winter and spring of 1951-1952.

The problem was conducted under the sponsorship of the Lake Erie Geological Research Program, a project organized in 1950 for the purpose of comprehending the processes of erosion and sedimentation in Lake Erie.

EARLIER WORKS

One of the earliest works in this region was that by Mosely (1904). He recognized the presence of stream channels in Sandusky Bay, and commented briefly on Sand Point. Stout (1933) treated the geology of the shore of Lake Erie. In 1943, White completed a study of the geology of the Lake Erie shoreline, from the Michigan-Ohio boundary to Marblehead. This report served as the basis for House Document No. 177, a beach erosion study of the same area. The mineralogical and textural variation of beach sands along Cedar Point, an area just southeast of the area under consideration, was studied by Pettijohn and Ridge (1932-1933). The Lake Erie Geological Research Program has investigated the sediments of outer Sandusky Bay, which includes the area along Sand Point (Pincus, Roseboom, and Humphris, 1951). Bowman (Ch. 5) has studied the erosional and sedimentary processes at Willow Point, on the south shore of Sandusky Bay. Shore erosion on Sandusky Bay has also been studied by Shaffer (1951). A very recent study of sedimentary processes has been made by Metter (Ch. 2) in the adjoining area of Cedar Point.

GENERAL GEOLOGY

AREAL GEOLOGY

Structure

The two formations found in the area, the Columbus limestone and the Detroit River group, are located on the east flank of the Cincinnati Arch. Both formations dip gently to the southeast, striking approximately northeast. The more resistant Columbus limestone forms a cuesta extending into the lake (Carman, 1946). This cuesta is very noticeable at the high limestone regions around Marblehead. North of Marblehead, Kelleys Island and Pelee Island form parts of this ridge. Johnson Island, just south of Marblehead, is an extension of this same ridge.
Figure 3-1B
The area of Marblehead Peninsula, Sandusky and vicinity lies in the Eastern lake section of the Central Lowland Province (Fenneman, 1928). The Sandusky area is a youthfully dissected plain, sloping gently northward (Pincus, Roseboom, and Humphris, 1951).

The area under study is one of low relief. The western half consists of an almost flat plain. The eastern half, with the exception of Sand Point, is higher, with a more rolling topography. This is due to the fact that a more resistant formation, the Columbus limestone, underlies the eastern half of the area. A drainage divide which runs in an east-west direction, separates Marblehead Peninsula into approximately two equal portions. All precipitation falling south of this line drains into Sandusky Bay.

Sandusky Bay appears to have been formed partly by glacial erosion (Mosely, 1904). The bay, as well as several other rock valleys in the vicinity, lies essentially parallel to the main axis of Lake Erie (Mosely, 1904). Glacial grooves in the area are also approximately parallel to the bay.

After the retreat of the ice, lacustrine deposits were laid down by the glacial lakes of the Pleistocene in the bay area (Mosely, 1904). Mosely (1904) has traced the former course of the Sandusky River and its tributaries by means of buried valleys on the floor of Sandusky Bay. He has also found that no deep preglacial valley runs through the present Sandusky Bay, for at Bay Bridge, the lowest point on the bedrock surface is thirty feet below the water surface. Tributaries to the Sandusky River formed the buried valleys found in Sandusky Bay today. As the water level of the lake began to rise, the Sandusky River was backed up, so as to form marshes along both banks. Waves began to erode the shoreline, which consisted of non-resistant glacial materials. The bay formed in this manner was enlarged, both by the deepening of the water, and by action of the waves (Mosely, 1904). The southwest shore of Lake Erie can now be said to be a submerged coastline, Sandusky Bay being a drowned bay. The bay is continually growing larger, due to tilting of the Great Lake region, increase in water supply, and erosion of the banks. Large areas which were dry land one hundred years ago are now under water. It seems likely that the processes which are enlarging Sandusky Bay today will continue in the future.

The till contains at least twice, first by the Illinoian ice sheet, and later by the Wisconsin ice sheet. The till in the area is thought to be Wisconsin in age (White, 1943). Grooves and striations in the Columbus limestone indicate the ice moved in a west to southwest direction. These grooves and striations are very prominent at places where bedrock is exposed along the north shore of Sandusky Bay, on Johnson Island, and near the quarries at Marblehead.

Lacustrine clay and glacial till compose almost the entire north shore of Sandusky Bay, from Bay Bridge east to Sand Point, with the exception of occasional sand beaches and outcrops of bedrock in the middle portion of the north shore. From the east side of Sand Point to Marblehead Lighthouse, the shoreline is mainly bedrock, with till occurring locally. Johnson Island is covered by a mantle of till. It has been observed that till composes the bay floor from Johnson Island west to Bay Bridge.

The till is colored gray-brown to red-brown. At places it is mottled, and sometimes appears bluish in color. It is much darker when wet, forming a hard coherent clay. Limestone and crystalline pebbles are abundant in the till. The till is eroded easily, forming steep banks where it is unprotected along the shore.

During the Pleistocene, a series of lakes were formed by the melting of the ice. These lakes were contained by end moraines to the south and an ice barrier to the north. The lakes varied in area and depth as the ice retreated and readvanced. Lower outlets were uncovered as the ice retreated, and, in turn, were closed with readvance of the ice (Flint, 1947).

The region around Sandusky Bay appears to have been covered by glacial waters of the late Maumee, the Arkona, the Whittlesey, the Wayne, the Warren, and the Elkon (late Lundy) stages (Levett, 1915). Following the Elkon stage, a lower outlet was uncovered by the retreating ice to the east. Waters from Lake Erie flowed through this outlet, over the Niagara escarpment, and into the Ontario basin (Flint, 1947). In the Marblehead region, gravel beaches at the Marblehead Cemetery at an elevation of about 660 feet, approximately 90 feet above the present lake level, give evidence
Marblehead, is an extension of this same ridge.

**Stratigraphy**

**Columbus Limestone:** The Columbus limestone (middle Devonian) crops out in the eastern half of the area under consideration. It is exposed in the quarries and along the shore of the Marblehead area, at the extreme east end of Marblehead Peninsula. It is also exposed in the quarries on Johnsons Island. The rocks dip gently east, and strike approximately northeast. (See Fig. 2-1)

Stauffer describes the Columbus limestone as follows:

"The lower portion of the Columbus limestone consists of a rather porous massive brown limestone frequently containing a large amount of bituminous matter and very little chert, but generally having numerous cavities or pockets filled with crystals of calcite." "The upper part of the Columbus limestone, which includes about two-thirds of the formation, consists, in the main, of light gray limestone in even beds varying from a few inches to several feet in thickness." "At places it contains a considerable amount of white or light gray fossiliferous chert. The upper layers of the limestone are the thinner and often of a bluish color."

At the eastern tip of Marblehead Peninsula, the Columbus limestone is exposed along the shore as a thin-bedded gray-blue, very fossiliferous limestone. The rock breaks off in large slabs, to form a step-like surface along the shore. In this area, the Columbus limestone is approximately ninety feet thick. The following section of the Columbus limestone was taken in the Olemacher quarry, on the south side near the east end of Marblehead Peninsula. (From Stauffer, 1909, p. 133)

<table>
<thead>
<tr>
<th>Columbus Limestone</th>
<th>Ft.</th>
<th>In.</th>
</tr>
</thead>
<tbody>
<tr>
<td>9. Rather thin-bedded bluish gray limestone</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>8. Irregular layer of hard compact bluish gray limestone, not always separated from the layer below</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>7. Usually thin-bedded gray or slightly bluish limestone, quite fossiliferous</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>6. Massive gray limestone, rudely banded and very fossiliferous, the fossil occurring in streaks and pockets</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>5. Brown to gray limestone, quite fossiliferous</td>
<td>6</td>
<td>10</td>
</tr>
</tbody>
</table>

**Columbus Limestone cont.**

<table>
<thead>
<tr>
<th></th>
<th>Ft.</th>
<th>In.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Massive brown to grayish brown rock, called &quot;bottom rock&quot; by quarrymen</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>3. Layers of white chalky chert nodules</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>2. Brown limestone with no chert and few fossils</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>1. Soft gray shale in the bottom of the quarry</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

**Detroit River Group:** Lane (1908) proposed that the Detroit River group (Lower Devonian), or upper Monroe, as it was formerly called by subdivided into the following units: The Lucas dolomite, the Amherstburg dolomite, the Anderson limestone, and the Flat Rock dolomite. Only the Lucas dolomite and the Amherstburg dolomite have been recognized in Ohio (Carman, 1927).

"The Amherstburg is commonly drab or brown dolomite chiefly in thick layers, some of which are porous or have small cavities. As a whole the strata of this member are browner, thicker bedded, and more porous than in any other member of the Monroe. The Lucas is a gray to drab, banded dolomite commonly in layers of three to twelve inches and with carbonaceous partings between the layers." (Carman, 1927)

Outcrops of the Detroit River group are known along the north shore of Marblehead Peninsula west of Marblehead (Carman, 1927, p. 500). This formation has not been observed by the author, since there are no exposures in the area under consideration.

The following section of the Detroit River group, called here the Monroe limestone, was taken in a quarry on the southeast side of Johnsons Island. This section is overlain by approximately forty feet of the Columbus limestone. (Section taken from Stauffer, 1909, p. 133)

<table>
<thead>
<tr>
<th>Monroe Limestone (Detroit River group)</th>
<th>Ft.</th>
<th>In.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Rather thick layer of banded brown limestone</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>3. A layer made up almost entirely of Stromatoporasp and a few corals. The rock has a dark bluish or purplish brown color</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>2. Hard layers of gray limestone conspicuously banded</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>1. Grayish brown banded limestone in massive layers to the bottom of the quarry</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

(Carman, 1927, p. 133)
of a former beach. Workers have referred this beach to the Lake Wayne stage (Wilson, 1943). During the early stages of the glacial lakes, the Marblehead area was entirely submerged, since its highest elevation is about 670 feet above sea level (Conrey, 1930). Marblehead Peninsula appeared as an island during the Wayne and early Lundy stages. During the Elkton (lake Lundy) stage, parts of Johnson Island as well as Marblehead Peninsula were exposed (Conrey, 1930).

DESCRIPTION OF AREAS

MARBLEHEAD LIGHTHOUSE TO SAND POINT

Geology

The Columbus limestone crops out at the waterline from Marblehead Lighthouse south to the State Wayside Park. (Water level has been defined as 573 feet, the elevation of Lake Erie above sea level.) At Marblehead Lighthouse, limestone exposures up to seven feet above water level are common. The limestone breaks off into large slabs giving a stair step effect. (See fig. 3-2) The dominant set of joints strike from N. 26° E. to N. 40° E., and appear to influence erosion at Marblehead Lighthouse. Bedrock continues south along the shore until the vicinity of the State Wayside Park. At this locality, bedrock is exposed at water level. South of the Park, protective walls have been built, completely hiding the natural shore. Although not observed to the south, the Columbus limestone probably lies but a small distance below the water's surface. This can be inferred from the fact that all beaches in the area are composed of limestone cobbles, probably derived from a nearby source. A till bank, approximately twelve feet high, lies just north of the boundary between this area and the Sand Point area. Large limestone boulders and slabs cover this bank. Cobbles and boulders form a beach along the waterline at the bottom of this bank. The till consists of a brownish-red coherent clay, somewhat mottled, containing many rock fragments and pebbles. Till also occurs in the vicinity of the State Wayside Park, overlying the bedrock.

Nature of Shore

The shoreline of this area extends southward from Marblehead Lighthouse for a distance of about two miles. The northern third consists of bedrock, and several limestone cobbled beaches. Artificial structures compose the shoreline of the central area. In the southern section, the shore consists mostly of clay till protected to some extent by limestone boulder and cobbled beaches. These beaches would seem to indicate the presence of bedrock not far beneath the surface of the lake.

Erosion

At Marblehead Lighthouse, erosion appears to be controlled by a system of vertical joints, striking perpendicular to the shoreline. The water rushes up into the joints, and washes out any debris that has accumulated there. During times of heavy storms, the impact of heavy waves inside these openings might dislodge slabs of limestone. The action of water freezing and frost wedging in these joints during the winter would aid erosion also.

The area of Marblehead Lighthouse and south receives the full force of northeasterly storms. These storms generate huge waves, because of the large fetch. Waves have dislodged huge slabs of limestone from the bedrock along shore. In times of heavy storms, large pieces of limestone have been picked up from the bottom of the lake, and tossed on shore (See fig. 3-3). The total erosion in the bedrock areas do not appear to be great, however.

Effects of erosion have been considerable at the State Wayside Park area due to high water, heavy storms, and the type of shore material. Bedrock, exposed at the water's edge, underlies a thin mantle of till. This area also received the full force of storms from the northeast. During March of 1952, a large storm, together with high water, struck the Sandusky area (See fig. 3-4). At the park, the storm demolished a small shed built over a water pump. Till was stripped off for a distance of 15 feet from the water's edge, exposing the bedrock. The storm knocked down and washed away a concrete wall in front of the shed. It also caved in a thick retaining wall, and eroded a road behind the wall. During the winter of 1951-52, winds blowing from off Lake Erie piled up huge blocks of ice in this area, to a height of about twelve feet (See fig. 3-5). The push exerted by the ice moved parts of the wall built in front of the park. This ice action appears to have been a "softening up" step in the later erosion of the wall by storms. The ice jarred the wall from its original foundation, making it susceptible to destruction at a later time.
Structures

Retaining walls have been constructed at the State Wayside Park, and also nearby by private owners. Along the shore at the park, large slabs of limestone, five feet square, have been piled to form a wall. The wall has withstood storms fairly well, but waves have entered the openings in the wall, eroding the till behind it, thereby causing caving. Thick walls of rip-rap, constructed by private owners along the shore of their property, appear to be containing erosion fairly well.

SAND POINT

General Remarks

Evans (1942) defines a spit as a "ridge or embankment of sediment attached to the land at one end and terminating in open water at the other." Johnson (1919) states that a compound spit is a spit which shows a series of beach ridges. These low ridges represent the crests of beaches built by wave action along successive positions of the shoreline.

Sand Point is a compound spit, extending from the southeast corner of Marblehead Peninsula in a southeasterly direction for approximately one and one-fourth miles. (See fig. 3-1) At its narrowest point, the spit is 200 feet wide. The width increases to a maximum of three-eights of a mile, approximately one-half south of the narrowest point. The width of the spit narrows again to 600 feet at the southern tip.

A channel, connecting Lake Erie with Sandusky Bay, separates Sand Point from Cedar Point to the southeast. Sand Point is the most popular name for this spit, although it has also gone by the name of Peninsula Point, Sand Pit, and Bay Point. At the present time, the entire area is privately owned. A number of cottages have been built, the beach being used for recreational purposes.

Geology

Formation: Sand Point appears to be a typical sand spit. It has been formed by the transportation of sediment by longshore currents and beach drift in a southeasterly direction from the southeast corner of Marblehead Peninsula. Northeast winds have formed waves which strike the shore at an oblique angle, causing longshore currents. The spit has been built above water level and extended, by the action of beach drift (Evans, 1942). Beach ridges, representing successive positions of former shorelines of the spit, show that Sand Point is now a compound spit. A suggestion of a hooked spit can be noticed at the tip.
of Sand Point. This condition may be due to the action of refracted waves, which have caused material to be transported across the end of the spit (Evans, 1942).

It has been inferred by the author that most of the material for the formation of Sand Point has been derived from the outer Sandusky Bay region. This material has been transported by wave action to a point close to shore. Longshore currents then transported the sediment along the shore. The swash and backwash action of the waves, known as beach drifting, striking the shore at an oblique angle, has been a major form of transportation. In addition to this inferred source, some material may have been derived from the till banks north of Sand Point.

Clay till has been observed to form the bottom of Sandusky Bay from Bay Bridge eastward to a point approximately one mile west of Sand Point. At this locality, a thin layer of sand covered the clay till. This mantle of sand increases in thickness towards Sand Point. It would appear that clay till underlies Sand Point at an undetermined depth. Borings made along Cedar Point show that the Cedar Point sand beach is underlain by clay till and swamp muck (Metter, 1952).

A large portion of the central part of Sand Point consists of swamp, at approximately lake level. Sand beaches enclose this swamp area on all sides.

On the south and west sides of the swamp area, these sand beaches have been built up only slightly higher than the water level of the swamp. The beaches have been constructed of material transported around the tip of Sand Point, and along the western shore. Refracted waves probably caused the material to be transported around the tip, thus constructing a small hook. Longshore currents, generated by southwest winds with a four mile fetch, transported the material along the west shore of Sand Point in a northerly direction.

The construction of a small extended spit was observed by the author at the tip of Sand Point, during September of 1951. The spit extended westward, being built by material transported by a wave-generated current, flowing around the tip of Sand Point. Several days later the spit had extended itself to a small promontory, and formed a small lagoon behind it. The spit measured about 30 feet long, and six inches high. (See fig. 3-6) Another spit was observed being built along the edge of a swamp in the northwest portion of Sand Point. This spit extended to the northwest, and appeared to be enclosing the swamp.

**Offshore Bars:** Offshore bars are very prominent along the east shore of Sand Point. (See fig. 3-7) These bars can be seen at low water. In September of 1951, it was possible to walk on these bars to a

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**Figure 3-4.** View looking east, showing erosion caused by a northeast storm during March, 1951, at State Wayside Park. Till mantle formerly extended to the waterline. March 31, 1952.

**Figure 3-5.** View of same locality as fig. 3-4, showing pile up of ice, caused by a northeast wind. February 20, 1952.
point about one-fourth mile from the channel entrance into Sandusky Bay (sample locality 186). The height, shape, and positions of these offshore bars constantly change, due to the action of waves, storms, and currents.

That part of outer Sandusky Bay along the east side of Sand Point and directly southeast of it appears too shallow to provide a graded offshore profile (See fig. 3–8, 9). In order to reach this graded condition, the slope must be made steeper. There then occurs transportation of material by wave action, in the landward direction. With the continuation of this process, the formation of offshore bars to landward will result. These bars continually move towards the shore. The configuration of the end of Sand Point changes greatly by their addition and loss.

Beach Ridges and Dunes: "Beach ridges have long been recognized as prerepresenting successive positions of an advancing shoreline," Johnson, 1919, p. 404. These ridges are found along the eastern shore and near the southern end of Sand Point. They represent the crests of beaches built by wave action along successive positions of the shoreline as the spit becomes wider. Johnson (1919) does not believe that a series of beach ridges can be correlated with individual storms, as Mosely (1904) does for the ridges along Cedar Point.

Along the eastern side of Sand Point, modification by wind action has been of such an extent that many of these ridges may be classified as dunes. (See figs. 3–10, 11) Some of these dunes show cross-bedding in the upper portions. Many dunes measure twelve feet in height. Due to the action of northeast winds, the dunes advance westward.

Nature of Shore

The shoreline of Sand Point consists almost entirely of sand beaches (See fig. 3–12). The single known exception is swamp, located along the northwest shore, where Sand Point joins the mainland. (See fig. 3–13) Samples indicate that the bottom consists of organic matter and a small amount of sand.

The beach along the eastern shore, about 100 feet wide, consists of clean, white sand. To the north, the beach diminishes to 20 feet when it reaches the narrowest portion of the spit. A limestone cobble beach extends northward from this point. The sand beach also decreases in width to the south. A narrow beach extends along the west shore of Sand Point.

Flat, rounded pieces of shale, approximately one-fourth to one inch in diameter, lie along the south and west shore of Sand Point in great quantities, but are missing along the east shore. Shale fragments have not been observed in any nearby till exposures.

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**Figure 3-6.** View showing small spit being built at the southern end of Sand Point, extending northeast, about 30 feet long and 6 inches high. Water level 573 feet. September 19, 1951.

**Figure 3-7.** View looking north, showing bar 300 feet long, and 15 feet long, along the east side of Sand Point. Water level 574 feet. July 10, 1952.
The nearest outcrop of shale occurs west of Huron, in an area approximately nine miles from Sand Point. This exposure is the Huron shale member of the Ohio shale (Metter, Ch. 2). It appears that these fragments of shale have been transported by longshore currents past Cedar Point, around the Cedar Point Breakwater Light, and then swept past the tip of Sand Point and along the west shore. Deposits of "black sands" are found at many points along both shores of Sand Point, being especially prevalent along the west shore. The "black sands" consist chiefly of ilmenite and magnetite, the "red sands" chiefly of garnet. Laminations, consisting of alternating dark and light layers, can be observed in cross section. At the first jetty on Sand Point, the following banding effect was noted on the beach, ten feet above the waterline: red, black, red, brown, white, red, blackish-red. The order given is read toward the water, the bands being about six inches wide. In addition to the sorting of the "heavy" or "black" sand from the light materials, there also appears to be sorting of the ilmenite and magnetite from the garnet.

Erosion

There appears to be no appreciable erosion along the sand beaches of Sand Point. Some material may be removed by heavy storms, but the beach builds up again. The owner of Sand Point strongly believes that sand-suckers operating far off shore cause great damage to his beach. The author could find no support for this theory.

Ice is not believed to affect the sand beaches to any great extent. (See fig. 3-14) Ice push on the beach may move sand, but there is no erosion. When ice is formed along the beach, sand adheres to the ice. If the ice breaks up and floats away, small quantities of sand may be transported some distance.

During the early summer of 1952, the water level of Lake Erie was quite high (574 feet). The beach along the east shore of Sand Point was observed to have decreases appreciably in width. The waters of Sandusky Bay have encroached at places along the western shore, so that much of the southwestern edge of Sand Point has been covered with water (See fig. 3-15). A wall had to be constructed along the northwest side of Sand Point in order to protect the private road into Sand Point.

Structures

The only shore protective structures on Sand Point are two jetties located close together on the east shore, in the northern part of the area. The
Figure 3-10. View looking north, showing cluster of dunes (ridges) at south end of Sand Point. These are old beach ridges, modified by wind action. September 12, 1951.

Figure 3-11. View looking north, showing dune on east end of Sand Point, advancing westward (left of picture). March 31, 1952.

Figure 3-12. View showing laminated (dark) sand along east shore of Sand Point. The upper bank is a wave cut face. September 9, 1951.

Figure 3-13. View looking north, showing lagoon near southern end of Sand Point. September 12, 1951.
northernmost jetty, composed of large limestone blocks approximately four feet square, extends about 50 feet into the water. The beach has been built up approximately four feet higher and 20 feet wider on the north side than the opposite side. An accumulation of "black sand" was observed on the north side, about ten feet from the waterline. The second jetty was constructed like the first, extending about 30 feet into the water. The two jetties were of the same height. The buildup of sand on the north side of the second jetty as compared with the other side was not observed to be as great as that of the first jetty. This relationship appears to hold during storms also. The difference in the amount of sand collected may be due to the difference in length of the two jetties.

SAND POINT TO BAY BRIDGE

**General Statement**

The area from Sand Point to Bay Bridge, along the north shore of Sandusky Bay, covers approximately seven miles (See fig. 3-1). This long stretch of shoreline is here treated as a single area, because it is believed that processes operating over its length constitute a logical unit for study.

**Geology**

Small exposures of bedrock crop out only in the central part of the area, between localities 166 and 1203. Bedrock crops out at water level at many points in the area, but in other places is covered by till. Exposures are prominent on the hillsides and in roadcuts one-eighth mile inland from shore. Fishermen report that the bay floor off this area consists of bedrock, covered at places by a thin mantle of sand and clay. Moseley (1904) reports that bedrock is found less than thirty feet below water level in the vicinity of Bay Bridge.

The area stretching from Sand Point to the exposures of bedrock is mantled by irregular thicknesses of clay till. The till is a brownish-red color when wet, and light gray when dry. It contains numerous fragments of limestone and crystalline rock. The till banks which form the shore average about four feet in height. The Marblehead quarry region rises approximately 50 to 60 feet above the shoreline because of relief on the bedrock surface, and slopes in the direction of Sandusky Bay. The bay floor off this area at the four foot depth consists of clay covered by a thin mantle of sand.

Marblehead Peninsula is very low and flat in the area west of locality 1203 to Bay Bridge. This

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Figure 3-14. View looking north along Sand Point, showing the effect of ice push on the beach. March 21, 1952.

Figure 3-15. View of beach at the southwest tip of Sand Point, looking west. September 12, 1951.
region, and the region on to the west, was an old lake bed during Pleistocene time. The lacustrine clays deposited over this area may be observed along the shore of Sandusky Bay. These lacustrine clays have formed a dark colored, silty clay loam, which is known as the Clyde clay loam (Coffey and Rice, 1915). The subsoil produced by these clays varies in color, being usually a mottled gray to yellow. The stratification so prominent in the lacustrine clays along the Huronia Beach area (Metter, 1952) has not been observed here. These lacustrine clays represent slightly reworked glacial drift material (Coffey and Rive, 1915). They appear to contain no pebbles.

Clay till, similar to that observed west of Sand Point, underlies the lacustrine clays in most places. The banks along shore, usually composed of both lacustrine clays and till, are somewhat higher in the western area, close to Bay Bridge. Here they average about six feet in height, while those to the east average two to three feet in height. The floor of Sandusky Bay, from locality 1203 west to Bay Bridge, consists of hard clay. In the deeper parts of the bay, the floor consists of muck.

Nature of Shore

The north shore of Sandusky Bay, from Sand Point to Bay Bridge, consists of clay till, bedrock, lacustrine clay, and small sand beaches. From Sand Point to locality 166, the shore consists mainly of clay till. Small sand beaches are present at some protected points. Where the till has not been protected, it is easily eroded. In addition to wave erosion, the till slakes upon drying, and is eroded by running water and weathered by frost action (White, 1943, p. 25). Boulders in the till remain when the clay has been eroded.

Bedrock crops out at many places at water level between localities 166 and 1203. It may be inferred that bedrock furnishes the material for rocky beaches which are found in this area. A mantle of till, changing in thickness along the shore, overlies the bedrock. When the level of wave attack is raised by an increase in water level, erosion of the overlying till takes place. Exposed bedrock causes this shoreline to be more resistant than other areas.

West of this area to Bay Bridge, however, erosion is very noticeable. The shoreline consists of lacustrine clays overlying clay till, both of which are very non-resistant to erosion. The lacustrine clay is affected by running water, frost action, and slakes upon drying (White, 1943, p. 39). Erosion of these lacustrine deposits, which are much more easily eroded than till, carries the silt and clay particles to deeper water. The small quantity of sand left does not add appreciably to the beach (White, 1943, p. 39). Where there are indentations in the bank, small sand beaches have accumulated. Small deposits of "black" sands, such as were found on Sand Point, are sometimes found on these beaches. The author has been unable to relate these occurrences to any special type of wave action or other conditions.

The largest sand beach in this area, located at locality 1257, was approximately 15 feet wide and more than 300 feet in length. Limestone pebbles, shale fragments, and accumulations of "black" sands were observed along the beach.

The shoreline between the New York Central Railroad Bridge and Bay Bridge is almost entirely artificial. This shore has been built up by the addition of rocks and screenings in an attempt to stabilize the shoreline.

Erosion

The shoreline of Sandusky Bay between Sand Point and locality 166 consists mainly of low till banks, which are easily eroded, if not protected by artificial structures. The waves undercut the till at the base of the bank, causing slumping. Waves clean away the slumped material, and then resume their undercutting of the bank. Many land owners have built walls along the shore, or have dumped rip-rap at the water's edge. These protective devices appear to be working fairly well. Unprotected portions of till bank are sometimes found located between two protected areas. The amount of erosion is readily seen in these areas, for these unprotected banks have retreated as much as 20 feet in 4 years.

Screenings have been used by many owners on their shores in an effort to prevent erosion. Screening is a term applied to small pieces (about 1/4 to 1/2 inch in diameter) of crushed limestone.

It appears that this practice only slightly retards erosion. A recreational park was once located just to the west of locality 160. This entire area is now a marsh, having been flooded by the waters of Sandusky Bay.

Ice does not appear to be a large factor in the erosion of the area. (See figs. 3-16, 17) If the ice push is large enough, it may undercut the till banks, causing slumping of material to the top of the ice. The damage by ice to walls and other structures during the winter of 1951-52 was small. Heavy storms
produce the greatest erosion. Southwest storms account for the greatest damage, for Johnson Island provides protection from southeast storms. One heavy southwesterly storm causes more erosion of this area than the combined effects of all other erosional agencies during the period of one year.

The area between localities 166 and 1203 is the most resistant to erosion. Bedrock occurs at water level along this entire area. Rock beaches further protect the region, the material being derived from the bedrock. The bedrock is covered along the shoreline by a mantle of till. When the waves reach above the bedrock and rock beaches, due to very high water and heavy storms, till erodes.

In the middle of the area is a large jetty (marked A on map), which had been constructed over 90 years ago. This locality received the full force of southeasterly storms. Erosion is acute on the eastern side of the jetty, due to its exposed position. Almost 6 feet of land has been lost in the past 3 years. An attempt had been made to control this loss by the use of log pilings, but the structure washed away. The owner has now dumped rocks and screenings along the shore in an effort to check erosion. The action of ice push caused the loss of 5 feet of this large jetty during the winter of 1950-51. Damage by ice in the remainder of the area has been negligible.

There is a large erosion problem on the Sandusky Bay shore which stretches from locality 1203 westward to Bay Bridge. This is due to the non-resistant characteristics of the shore materials, lacustrine clay and clay till. The characteristics of these weak materials have been discussed previously. Where the clay banks have been exposed to wave action, much erosion has occurred. For this reason, many walls, jetties, and other structures have been constructed in the area. Sand has accumulated around some jetties, furnishing some protection. Accumulation has been greatest on the west sides of the jetties.

Erosion has been serious in the vicinity of locality 1235. There had been a sand beach here, according to the cottage owners, but it was removed long ago. Erosion became very serious when the clay banks were deprived of this protection. Approximately 15 feet of land has been lost in the past 3 years. Southeasterly storms, occurring in the spring of the year, produce much damage at this locality. Rip-rap and screenings have been dumped along the bank to arrest the erosion.

Damage has also been great at locality 1238 and westward. During one storm in the spring of 1951, 6 feet of land was lost. The owners have constructed rock walls 4-6 feet thick, and have placed screenings above the walls. Much of the screening

Figure 3-16. View of small beach, looking east, showing the result of ice push. Blocks of frozen sediment can be noticed, pushed up by southwest winds. Locality 1208, Sand Point to Bay Bridge area. March 31, 1952.

Figure 3-17. View of same locality. Blocks of frozen sediment are approximately 5 inches thick. Beach materials have been piled up by ice push to a height of 3 feet. March 31, 1952.
has seeped down through the large rocks, and has been washed away.

Cement walls have been built along the shore at locality 1241 in an effort to stop erosion. Residents of this area reported that in 1948, when the water was very low, an old road bed could be seen out in the bay about 150 feet from shore. At the present time, about 5-6 feet of water covers this road. The residents of this vicinity are of the opinion that this old road bed was in use until the early 1900's.

Along the shoreline to the west, erosion has progressed rapidly where the clay banks remain unprotected. The usual protection consists of the construction of rock walls along shore. At locality 1254, a paved road runs along the shore. A high wall, composed of huge slabs of limestone, has been built along the shore to protect the road. In times of southeasterly storms, high waves break over the wall, damaging the road.

The area between the New York Central Railroad Bridge and Bay Bridge is not affected to any extent by erosion. It is protected to a large degree from the large storms which affect the north shore of Sandusky Bay. Much of the shoreline consists of rock and screening fill.

**Structures**

Jetties and walls have been built along the northern shore of Sandusky Bay in an effort to stop erosion. These structures have met with wide ranges of success. Two large jetties, just west of Sand Point, constructed from large blocks of limestone, served as loading docks for produce grown on Marblehead Peninsula until about 1900. Small sand beaches have collected on the west side of both jetties. These beaches are destroyed from time to time by storms.

At locality 160, walls have been built along the shore, directly behind three cottages. The walls are constructed of large limestone blocks, on top of which are placed smaller stones. This construction has successfully halted shore erosion in addition to building up a small sand beach. Sand is beginning to accumulate offshore, where there formerly was only muck. West of this locality, many small jetties have small sand beaches on their west sides.

One of the largest jetties in the area lies approximately in the center of the entire shoreline. This jetty, about 120 feet long and 50 feet wide, was formerly used as a dock for lime boats. An extension of 40 feet to the west has recently been added, which gives the structure an "L" shape. Large quantities of sand formerly accumulated on the west side of the jetty. The west side now has a cobble beach.

At locality 1208 to the west, an iron jetty about 60 feet long has been constructed. Sand beaches have formed on both sides of this structure. A jetty approximately 250 feet long has been constructed at Zellers Beach, close to locality 1238. A very small beach has grown on the west side, but hardly any sand has accumulated on the east side. Small jetties and many rock walls are found to the west of Zellers Beach. Small beaches have grown largely on the west side of these jetties.

**FIELD AND LABORATORY PROCEDURES**

**FIELD PROCEDURES**

**Sampling**

Shore samples were collected by means of a beach drive sampler. A check-valve sampler was used for the collection of samples at 2 and 4 foot depths. These samplers have been fully described by Pincus, Roseboom, and Humphris (1951, p. 5-6). A snapper type sampler, of the type described by LaFond and Dietz (1948), has been used for the collection of deep water samples. Samples were stored in 1 quart glass jars.

The location of samples has been determined in several manners. Positions of deep water samples were determined by the use of a sextant, and horizontal angles. Shallow water positions were also determined in this manner. Shore positions were determined by Brunton compass, aerial photographs, and sometimes by sextant (3 point fix).

**Mapping of Profiles**

**Plane Table:** Underwater profiles were mapped along the east shore of Sand Point by use of the plane table and alidade. The profiles were taken as close as possible to certain strings of samples, extending from the beach ridge out into the water. Deep water necessitated the use of a row boat for the rodmann. Water level was determined from a water level recorded in the Ohio Wildlife and Fisheries Building at Sandusky. The depth of water was read directly from the rod, the distance from shore being measured by the alidade. Depths of approximately
Figure 3-18

Sand Point Beach Profiles

Location of Profiles on Plate

Scale

Example showing: sample locations, carbonate totals, phi medians, sorting coefficient

Vertical Exaggeration 5X
11 feet could be recorded in this manner (See fig. 3-18). 

**Fathograms:** Profiles of the bottom of Sandusky Bay and outer Sandusky Bay were mapped by fathometer. If the record shows only one or two echoes, (for a standardized sensitivity) it is inferred that the echo has been absorbed, the bottom consisting of either clay or muck. The accuracy of this inference has been checked by sampling (See fig. 3-19)

**LABORATORY PROCEDURES**

**Carbonate Totals**

Carbonate totals were run on a limited number of selected samples. The entire sample was split down to about 20 grams by use of the Jones sample splitter, and then weighed. The sample was then placed in a small beaker, and covered with a solution of 10% hydrochloric acid. When effervescence ceased, this solution was poured off. The sample was then washed, dried in an electric oven, and weighed. The loss in weight was assumed to be the carbonate content.

**Mechanical Analyses**

The entire sample was split down to a portion of approximately 60 grams, by means of the Jones sample splitter. Standard laboratory procedures, as described by Krumbein and Pettijohn, (1938, Ch. 6) were used in performing mechanical analyses.

**Mineralogical Analyses**

Rubey (1933) suggests that two fractions be analyzed from each sample, one representing the same actual grain size, the other the same relative

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**Figure 3-19**

From Fathogram of Outer Sandusky Bay

Profile Exaggeration

Horizontal 2.6 x

Vertical 100 x
MECHANICAL ANALYSES

General Statement

The mechanical analyses have been expressed in terms of Wentworth's size classification and the phi ($\phi$) scale. In the phi scale, increasing values correspond to decreasing grade size values. Frequency distribution curves have been computed for each sample, using the weight percentage as the ordinate, and the phi value as the abcissa. From this curve have been calculated the phi median ($M_d\phi$), the phi quartile deviation ($QD\phi$), the phi quartile kurtosis ($Kq\phi$), the phi quartile skewness ($\Phi SK$), and Trask's sorting coefficient ($So$) conversion chart on p. 235, Krumein and Pettijohn (1938). For a study of the above statistics the reader is referred to Chapter 9 of Krumein and Pettijohn (1938).

Representation of Data

The waterline trend of the $M_d\phi$, $So$, $Kq\phi$, and $\Phi SK$ has been computed in graphical form. (See figs. 3-20, 21) An outline map of outer Sandusky Bay has been plotted, showing the $M_d\phi$ of the bottom samples. (See fig. 3-34) The statistical results of all analyses are listed in the appendix of the unpublished manuscript (Humphris, 1952) upon which this report is based.

CARBONATE ANALYSES

A graphical representation has been made showing the trend of carbonate percentages of the waterline samples (See fig. 3-22). An outline map has been compiled for the bottom samples of outer Sandusky Bay, showing the percentage of carbonate in each sample. (See fig. 3-23) The carbonate percentage of shore and bottom samples has been plotted in connection with the underwater profiles (See fig. 3-18).
HEAVY MINERAL ANALYSES

General Statement

A total of twenty minerals in the 1/4-1/8 mm, and 1/8-1/16 mm, size classes were identified from the samples taken in the area under discussion. These minerals were hornblende, garnet, ilmenite-magnetite, hypersthene, diopside, augite, zircon, actinolite, epidote, tourmaline, titanite, apatite, monazite, sillimanite, rutile, staurolite, limonite, pyrite, hematite, and leucoxene. Hornblende, garnet, and ilmenite-magnetite were the most abundant minerals present in every sample. In several of the 1/8-1/16 mm, size fractions, the ilmenite-magnetite and garnet were predominant. Hypersthene and diopside were common in almost every sample. Augite, zircon, and actinolite varied from common to rare in most samples. The remaining minerals, epidote, tourmaline, titanite, apatite, monazite, sillimanite, rutile, staurolite, pyrite, hematite, and leucoxene, appeared as rare to vary rare. A detailed description of minerals appears in the unpublished version of this paper. (Humphris, 1952, p. 51-53)

REPRESENTATION OF DATA

The linear variation of ilmenite-magnetite, garnet, hornblende, and hypersthene in the waterline samples for the 1/4-1/8 mm, size and the 1/8-1/16 mm, grade size has been plotted (See fig. 3-24). Contour patterns have been computed from the frequencies of the same minerals in outer Sandusky Bay (See figs. 3-25, thru 3-32). The total heavy mineral percentage in the 1/4-1/8 mm, and 1/8-1/16 mm, grade sizes for the waterline samples has been plotted in figure 3-33. The number of grains of each heavy mineral in both grade sizes of the samples examined has been tabulated in the appendix previously cited (Humphris, 1952).
AREAL PATTERNS AND INTERPRETATIONS

GRAIN SIZE DISTRIBUTION

Phi Median

Phi medians of waterline samples along the entire area have been computed (See fig. 3-20). Phi medians of samples taken in outer Sandusky Bay have been computed and contours drawn (See fig. 3-34).

From figure 3-20, it can be seen that the phi median decreases (grain size increases) just west of Sand Point. West of Sand Point to Bay Bridge, the phi median appears noticeably smaller than on either side of Sand Point. It appears that the sedimentary processes acting along Sand Point are somewhat different from those acting along the north shore of Sandusky Bay. It has been inferred by the author that the source of the sediments of Sand Point lies offshore, in outer Sandusky Bay. The smaller size of these sediments can be partially accounted for by the continual abrasion undergone during transportation. Material of the size found along Sand Point (phi median of 2.5) is the most easily moved by current and wave action (Inman, 1949). Wave action appears to transport this outlying material close to shore. Longshore currents then pick up the material, and, coupled with the action of beach drift, transport it along the shoreline. In the area west of Sand Point to Bay Bridge, the bottom of the bay offshore consists of clay. The sediments composing the beaches appear to be derived from the erosion of the shore material. The shore materials in this area consist of limestone bedrock, clay till, and lacustrine clay. Fresh material, of a larger size than that found along Sand Point, can be derived directly from the materials composing the shoreline.

Contours have been drawn on the phi medians of samples taken in outer Sandusky Bay. The pattern produced by this contouring is similar to that compiled by Pincus, Roseboom, and Humphris (1951, p. 15) in investigating this area. The phi median...
increases (decrease in grain size) away from shore, as shown in figure 3-34. It appears that the sedimentary processes acting in this area have been relatively constant during the period between these investigations.

The relationship of an increase in the phi median away from shore agrees with the findings of Inman (1949). Inman (using theoretical considerations) found that those grains of approximately .18 mm size (phi median of about 2.5) are the most easily moved, being transported by surface creep, saltation, and in suspension. Grains of this size should be found along the shoreline, or near shore, as is the case along Sand Point. Inman also found that the threshold velocity increases for grains smaller than the .18 mm size. If grains of this size are lifted in suspension, there is a tendency for them to be transported by suspension, rather than surface creep. Since a greater threshold velocity is necessary to move these smaller grains, they are found in those areas far offshore, where the wave and current action is not so strong.

**Sorting**

According to Trask, a sorting coefficient of less than 2.5 value indicates a well sorted sample, a value of 3.0 a normally sorted sediment, and a sorting coefficient of greater than 4.5 indicates a poorly sorted sample (Krumbein and Pettijohn, 1938, p. 232). On the basis of these findings, all samples were either well sorted or normally sorted. (See fig. 3-20)

The relationship between sorting and phi median is indicated by figure 3-20. Along the east and west shores of Sand Point, where the phi median is largest (grain size smallest), the sediments are very well sorted, with an average So value of 1.4. From Sand Point westward to Bay Bridge, where the phi median decreases, there is a striking increase in the So value.

**Skewness**

Values for skewness of waterline samples have
been plotted. (See fig. 3-21) Skewness values along both sides of Sand Point are very even and consistent. West of Sand Point, however, the skewness values become somewhat uneven. This may be due to the increase in grain size (decrease of phi median) in this area.

Kurtosis

Kurtosis values for waterline samples have been computed. (See fig. 3-21) There appears to be a small increase in kurtosis values westward from Sand Point. No other relationships could be observed.

CARBONATE PERCENTAGE

A contour pattern has been drawn of the carbonate percentages of samples in outer Sandusky Bay. (See fig. 3-23) This pattern is very similar to that reported by Pincus, Roseboom, and Humphris (1951, fig. 12, p. 19) in their work in this same area. This pattern is also similar to the phi median pattern. It is obvious that there is an increase in the carbonate content of the sediments with decreasing grain size (increase of phi median). This trend, an increase of carbonate content away from shore, has also been observed by Pincus, Roseboom, and Humphris (1951, fig. 12, p. 19).

Carbonate percentages of shoreline samples have been plotted. (See fig. 3-22) A large increase in the carbonate percentage of the samples beginning at the western edge of Sand Point and continuing westward is clearly shown by this diagram. This increase appears to be due to two factors. The first of these factors is the presence of bedrock at places along the shore, which would supply much of the carbonate. The second factor is the use of "screenings" along the shore. These "screenings," composed of crushed limestone fragments under 1/2 inch in diameter, have been dumped along the shore at many places by land owners, in an effort to stop erosion, and build up a sand beach. This material is very fine, and after

Figure 3-23
Carbonate in Bottom Samples, Outer Sandusky Bay

Contour Interval 2%
Percentage of Heavy Minerals in Waterline Samples

Figure 3-24
being broken down further, is easily transported along the shore. Metter (1952) has reported similar occurrences along Cedar Point.

MINERAL TRENDS AND PATTERNS

Outer Sandusky Bay

Contour patterns of the percentages of ilmenite-magnetite, garnet, hornblende, and hypersthene in the 1/4-1/8 mm. and 1/8-1/16 mm. grade sizes, have been drawn from samples taken in outer Sandusky Bay. The results obtained were very similar to those found by Pincus, Roseboom, and Humphris (1951), in their study of this area. (Figs. 3-25 to 3-32)

It should be recognized that these contour patterns are but approximations, and must be studied accordingly. Small errors in the mineralogical analyses of the samples may change the contour pattern greatly. The contour pattern is affected to a much larger extent by the number of samples studied. With a larger number of samples analyzed, a more complete and accurate interpretation can be made.

A reciprocal relationship was observed between ilmenite-magnetite and hornblende in the 1/8-1/16 mm. grade size. A similar reciprocal relationship was observed between garnet and hornblende in the 1/8-1/16 mm. grade size. It would appear that ilmenite-magnetite and garnet behave in the same fashion, as they are closely related in shape, roundness, and specific gravity.

The pattern produced by the two hornblende grain sizes appear to be similar in many respects. There also was a similarity between the two hypersthene patterns, although not as distinct as that of hornblende. The ilmenite-magnetite patterns do not appear to bear any relation to each other, or to other mineral patterns. This also holds true for the garnet patterns. A larger percentage of ilmenite-magnetite was found in the 1/8-1/16 mm. size, as opposed to the 1/4-1/8 mm. size.

Figure 3-25

Ilmenite-Magnetite, 1/4-1/8 mm. size; in Bottom Samples, Outer Sandusky Bay

Contour Interval 5%
Waterline Samples

Heavy mineral percentages for the waterline samples have been plotted for the 1/4-1/8 mm. and 1/8-1/16 mm. sizes. (See fig. 3-24) The percentage in the 1/4-1/8 mm. size is fairly low and constant along both sides of Sand Point. West of Sand Point to Bay Bridge, however, the percentage is somewhat greater, a reflection of the decrease of the phi median along this area. This same relation to the phi median holds true for the 1/8-1/16 mm. size. A much larger percentage of heavy minerals in the 1/8-1/16 mm. size is found along both sides of Sand Point than in the area to the west. This is to be expected, as the sediments of Sand Point are of a smaller grain size than those along the north shore of Sandusky Bay.

Figure 3-33 shows the percentages of ilmenite-magnetite, garnet, hornblende, and hypersthene, that have been observed in the waterline samples, in both the 1/4-1/8 mm. and 1/8-1/16 mm. grade size. The reciprocal relationship between ilmenite-magnetite and hornblende which had been observed in the outer Sandusky Bay Samples, is very evident in the waterline samples also. This relationship is illustrated by both the 1/4-1/8 mm. and 1/8-1/16 mm. sizes. The abundance of garnet and hornblende exhibit this same reciprocal relationship in both grade sizes, although to a somewhat smaller degree. Garnet and ilmenite-magnetite show somewhat of a similar relationship in both grade sizes. The abundance of hypersthene appears to bear no relationship to that of the other minerals.

MATERIALS DERIVED FROM GLACIAL DEPOSITS

Clay Till

Clay till is found along the north shore of Sandusky Bay, and in some areas along the Lake Erie shore, north of Sand Point. In addition, till composes much of the bottom area of Sandusky Bay. On the breakdown of this till, a large amount of material is contributed to the buildup of shore and bottom.
sediments. In a sample of clay till taken in Ottawa County, which did not include that material larger than fine gravel, 20% of the material was larger than silt size (White, 1943, p. 24). At other localities, the till might contain a larger percentage of sand.

Till usually contains varying amounts of crystalline pebbles, cobbles, and boulders. On the breakup of these erratics, more material is made available for transport. Heavy minerals found in the sediments show that the till is fairly young. Minerals such as apatite, garnet, amphibole, and augite are known to be easily weatherable or unstable (Sindowski, 1949). These minerals, particularly the latter three, are found in abundance in the sediments. Epidote, a rather easily weatherable mineral (Sindowski, 1949) is also present to some extent. Minerals such as these indicate that the sediments are composed of relatively new material, derived from a fresh source.

**Lacustrine Clay**

Lacustrine deposits are found in the western part of the area, usually overlying clay till. The material composing these deposits is so fine that only a very small amount of it can be used for sediment buildup along the shore. Only 2% of a sample of lacustrine clay taken in Ottawa County consisted of fragments larger than silt size (White, 1943, p. 39). White has found that when the clay is eroded, "the silt and clay are readily carried to deeper water, and the sand in the material is so very small in amount that it makes no significant contribution to the beach."

**TRANSPORTATION OF MATERIAL**

Transportation of material along the east side of Sand Point towards the southern tip is accomplished by longshore currents, and by the swash and
backwash action of beach drifting. The dominant wind along this shore blows from the north or northeast. The fetch from this direction is much larger in comparison to that from the southeast. The dominant direction of shore drift is to the south, indicated by the building of Sand Point, south from Marblehead Peninsula.

Longshore currents, generated by oblique waves striking the shore, transport material along shore. Deposition occurs at those points where the current velocity is insufficient to move the material. In addition to this type of transportation, there is another important transporting agency first described by Johnson 1919, and known as beach drifting. Waves, approaching from a northeasterly direction, break obliquely on the eastern shore of Sand Point. Material is picked up by these waves, and carried up on the shore by the action of the swash. As the backwash retreats down the slope, due to the loss of velocity of the wave, the material is dropped on the shore. When the next wave comes in, this dropped material is picked up once again, and deposited a little farther down the beach. The path of a particle carried in this manner has been described by Johnson as parabolic. Johnson states that small particles will travel most rapidly, as they will describe a larger parabola than the large particles. Rosalsky (1950) believes that the coarser material is more readily retained on the beach, and is therefore more subject to beach drifting than the finer material. Evans (1939) concludes that the material falling between the .26 mm, to .60 mm, size is most easily moved. Inman (1949) is of the belief that material of .18 mm, size (phi median value of 2.5) is transported most easily. The examination of the phi medians of the samples along Sand Point agree with the findings of Inman.

There appears to be no decrease in size grade along the east side of Sand Point such as was described by Pettijohn and Ridge (1932) and Metter (1952) for along the shore of Cedar Point. Laminated sands indicate sorting at different points along the beach. The dark sands have been deposited by the swash, high on the beach. This type of sorting was
probably controlled by the fineness and high specific gravity of the heavy minerals (Evans, 1939, p. 29).

On windy days, transportation of material by wind action can be observed. This action occurs only on the east side of Sand Point, where the beach is fairly wide. Material tends to be transported inland from the beach.

The longshore currents flowing in a southerly direction along the east shore, are deflected by waves, around the tip of Sand Point. Along the west side of Sand Point, the dominant current flows in a northerly direction, due to winds from the south and southwest. Transportation along this shore occurs in a similar fashion to that on the east side of Sand Point.

Currents in the Sand Point to Bay Bridge area vary with the direction of the wind. Currents flowing to the east are observed on days of southerly winds, and westward flowing currents on days of southeasterly winds. From the major accumulation of sand on the west side of jetties along this area, it appears that the most effective longshore current is easterly. Longshore drift is the major form of transport, since there is no continuous sand beach for the process of beach drifting to function.

METEROLOGICAL AND HYDROLOGICAL OBSERVATIONS

Winds

In the area from Marblehead Lighthouse to the southern tip of Sand Point, destructive storms come mainly from the northeast and east. Since the fetch of the waves produced by winds from this direction is of great extent, the damage (by waves) produced in unprotected areas is considerable. The longshore currents in this area, produced by wind generated waves obliquely striking the shore, flow in a southerly direction.

Storms from the south and southwest produce the greatest amount of damage along the north shore of Sandusky Bay. The most destructive storms from this direction usually occur in the spring of
the year, when water level is fairly high. Winds from the west and southwest have the longest duration.

The effects of a southwest storm were observed during late summer of 1951, while standing on the southern tip of Sand Point. Lake level was low, exposing a very large sand bar southeast of Sand Point. Large waves from Sandusky Bay were observed breaking over the bar, transporting material into the outer bay area.

A wind rose is shown on figure 3-35 (from House Document No. 177, 1946).

Lake Levels

The water level of the Great Lakes is believed to be controlled chiefly by the amount of precipitation in the entire Great Lakes drainage basin. The outlet level of the lakes controls water level to a smaller degree. Approximately 1/2 of the precipitation of the region ultimately finds its way back into the lakes (Moore, 1946).

The Lake Erie drainage basin supplies only 12% of the total water supply of Lake Erie, the remainder coming from the other lakes (Moore, 1946). In order to produce high water in Lake Erie ordinarily, there must be several years of heavy precipitation in the surrounding areas. If a large amount of precipitation occurs immediately following a long dry period, the lake level is not affected to any extent, since the water is absorbed in the filling of swamps and small lakes, and in raising the water table.

The minimum lake level usually occurs during February, with the maximum occurring during the mid-summer months. The variation of the annual mean state of Lake Erie has been 3.21 feet for the past 30 years (Moore, 1946).

Winds can cause a large difference in lake level between the northeastern and southwestern ends of Lake Erie. A maximum difference of 14 feet has been observed in the water level between Buffalo and Toledo, due to the stacking up of the water at Buffalo by a strong southwest wind (Moore, 1946).
High water levels have been recorded by each of the Great Lakes during the spring of 1952. Heavy precipitation in the drainage areas is thought (by some investigators) to be the chief cause of the high water.

**SHORTCOMINGS OF THIS STUDY**

For a more complete understanding of the sedimentary processes operating within the area, additional samples should be collected and analyzed. Ideally, these samples should be collected simultaneously. Samples should be taken periodically, to observe any changes in the sedimentary processes, as to transportation, grain size, and heavy mineral content. Samples should also be taken immediately before and after each storm, to observe what effect there was on the sorting, transportation, and deposition of the sediments.

Due to a limited field season, it was impossible to make any current studies, either along the Lake Erie shore, or along the north shore of Sandusky Bay. It seems that these studies would prove most profitable along both of these areas. These current studies should be made at different depths, and at varying distances from shore. Studies should be conducted in each area for each of the different wind directions.

Turbidity measurements, taken along the entire area, should prove of great value in future studies. Such measurements would be invaluable for recommendations as to the length of jetties, since they would show the distance from shore in which the major portion of the materials are transported.

**SUMMARY AND CONCLUSIONS**

The north shore of Sandusky Bay, together with the Lake Erie shore from Marblehead Lighthouse to Sand Point, represents a submerged shoreline. Sand Point is a compound spit, built in a southerly...
direction from the southeast tip of Marblehead Peninsula. Beach ridges at the southern end of the spit attest to its growth.

Erosion along the north shore of Sandusky Bay is serious. Except for an area of resistant bedrock, the entire shoreline consists of weak and easily eroded lacustrine clay and clay till. In these unprotected areas, erosion is very serious. Erosion will continue in these areas in the future unless protective structures of some type are constructed. At some localities, walls and jetties have been built in an effort to control erosion. These structures have been moderately successful, except at times of heavy south and southwest storms. These storms prove to be the most destructive erosional agency in this area.

Jetties in this area have accumulated only a small supply of sand. This is understandable, since it is believed that this sediment is derived from erosion of the shore materials. The supply of this material is very limited. It is safe to assume that no beaches will be formed by the building of additional jetties, due to the limited supply of material.

The present beaches will remain stable, unless a new supply source is located.

Except for the area around the State Wayside Park, erosion is not a major factor in the area from Marblehead Lighthouse to Sand Point, since much of the shore is composed of bedrock. The greatest damage to this area is caused by storms from the north and northeast. There is some indication of ice push, but ice is apparently not a major factor in erosion.

Erosion along Sand Point appears to be less than that which occurs along the mainland areas on either side. Heavy storms may remove some material from the beach, but it is rebuilt quickly.

Samples taken along Sand Point indicate that the sediments are of a smaller grain size (larger phi median) than those west of Sand Point. The source of these sediments is thought to be the area of outer Sandusky Bay, much of the material having been transported from the Cedar Point area. Material appears to be transported along Sand Point by the action of longshore currents, beach drift, and some-

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Hypersthene, 6-16mm size, in Bottom Samples, Outer Sandusky Bay

Contour Interval 27

Figure 3-32
Percentage of Ilmenite-Magnetite, Hornblende, Garnet, and Hypersthene in \( \frac{4}{16} \)-mm. and \( \frac{1}{8} \)-\( \frac{1}{4} \)-mm. grade size of Waterline Samples

West to Bay Bridge | West side of Sand Point | East side of Sand Point

Figure 3-33
times wind. The dominant current along the east shore of Sand Point, generated by north and north-easterly winds, flows in a southerly direction to the tip of Sand Point, where it is deflected around the tip. Along the west shore of Sand Point, the current is controlled by south and southwest winds, and flows north.

In the area west of Sand Point, the grain size of the sediments is somewhat larger than the sediments of Sand Point. These sediments are derived from erosion of the shore materials. Transportation along the Sand Point to Bay Bridge area occurs mainly by longshore currents. The current in this area varies in direction with the prevailing wind, but appears to be dominantly eastward.

Heavy mineral studies show that the abundance of ilmenite-magnetite and garnet is inversely proportional to hornblende, both in outer Sandusky Bay and in the waterline samples. A greater percentage of heavy minerals is found in the 1/8-1/16 mm.

A decrease in grain size, away from shore has been observed in bottom samples of outer Sandusky Bay. There is an increase in carbonate content, with decreasing grain size.

Trends in grain size, carbonate content, and mineral occurrence, noted by Pincus, Roseboom, and Humphris (1951) are very similar to those observed in this study. The dominant processes of sedimentation do not appear to have materially changed during the interval between these investigations, at least as reflected in the attributes of the sedimentary products.

It appears likely that the conditions of erosion and sedimentation observed in the Marblehead Lighthouse to Bay Bridge area will continue unchanged in the near future.

Figure 3-34
Phi Medians of Bottom Samples, Outer Sandusky Bay
Contour Interval .5%
Figure 3-35

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Chapter 4

SEDIMENTARY PROCESSES ALONG LAKE ERIE SHORE, FOUR MILES EAST OF LORAIN TO HUNTINGTON BEACH PARK

By

Frank J. Kleinhampl
INTRODUCTION

PURPOSE

The purpose of this study is to provide information on sedimentary processes, especially as applied to shore erosion, along a selected portion of the south shore of Lake Erie. The conclusions presented should be accepted as preliminary estimates only since portions of the work have been no more than reconnaissance surveys.

METHOD OF INVESTIGATION

After a preparatory field and library survey of the geology of the area, samples of sediment and bedrock were collected and analyzed in order to interpret sedimentary processes. The results of the analyses were studied in the light of theoretical considerations of other studies.

LOCATION OF THE AREA

The 9-1/2 mile long strip surveyed for this report extends from four miles east of Lorain, Ohio (just north of the intersection of Ohio Highway 301 and U. S. Highway 6) to Huntington Park, west of Cleveland (See fig. 4-1). The area is approximately bounded on the south by the present backshore of Lake Erie, extending into the lake for a distance of 1-1/2 to 2 miles (See fig. 4-1).

PREVIOUS WORK

Earlier detailed studies of sedimentary processes in this area are not known to the author. Stout (unpublished manuscript in the files of the Ohio Geological Survey) discusses the general geology of the shore of Lake Erie, but in little detail. House Document No. 502, 1950, a beach erosion study provided for by Section 2 of the River and Harbor Act of July 3, 1930 and supervised by the U. S. Army Corps of Engineers, deals with the Cleveland-Lakewood area. Although not bearing directly on the shoreline west of Huntington Park, the report contains some observations on the nature of the bedrock west of this point. Another U. S. Beach Erosion Board report deals with the shoreline between Vermilion and Sheffield Lake, Ohio. The eastern limit of the study, Sheffield Lake Village, adjoins the western limit of the present study. U. S. Lake Survey, U. S. Army Corps of Engineers, has determined depths along offshore traverses, spaced approximately 1,000 to 1,500 feet apart, nearly normal to the shoreline in the area studied. These data have been used in preparing offshore profiles (See figs. 4-1, 2).

FIELD WORK

Most of the field work took place in September, 1951. The work consisted of sample collecting, making beach profiles, and observing and recording the effects of wind waves and storms upon the shoreline. During the winter of 1951-52, ice conditions in the area were surveyed. A number of sections were measured and specimens of bedrock were collected for the purpose of thin-section analysis. In June, 1952, samples were collected offshore in depths ranging from 8 to 45 feet. Field methods are considered in the section on "Field and Laboratory Procedure."

LABORATORY WORK

Laboratory analyses were conducted in the winter of 1951 and spring of 1952. Each sample required approximately 6-1/2 hours for a sediment size and mineralogical analysis. A description of the procedures used can be found in the section designated "Field and Laboratory Procedure."

DESCRIPTION OF THE AREA

The area studied lies in the Eastern lake section.
LORAIN TO ROCKY RIVER  
OHIO  

Figure 4-1A  

LEGEND  

- - - - Depth + cross section  
- - - - Exact path fathometer  
- - - - - - - - - - - - - - - Uncertain  

A-1  B-2  

Reference nos.  
Highway  

Scale  
1" = one mile  

RS-  Rock Specimen Number  
P-No.- Profile Number Location  

GEOLOGIC BREAK, AVON AREA  

\[ L^2 = 8 \text{ miles} \]
Figure 4-1B

CROSS SECTIONS
LORAIN TO ROCKY RIVER
VERTICAL 1" - 10'
HORI Z. 1" - 5/32 MI.

- See Fig. 4-1A for location of sections.
Figure 4-1C

---

CROSS SECTIONS
LORAIN TO ROCKY RIVER

VERTICAL 1" - 10'
HORIZ. 1" - 5/32 MI.

- See Fig. 4-1A for location of sections
Figure 4-2A (continued)
Figure 4-2 B

PROFILE FROM A-1 TO K-4

SEE FIG. 4-1A FOR PROFILE LOCATIONS

VERTICAL SCALE

VERTICAL EXAGGERATION 20X

HORIZONTAL SCALE
Figure 4-2 B (continued)
of the Central Lowland Province (Fenneman, 1946).

Avon Point, the prominent headland between Lorain and Cleveland, Ohio, marks the approximate center of the study area and lies well within the Central section of the Lake Erie basin (Carman, 1946, p. 279). The significance of this will be discussed later under "Hydrological and Meteorological Considerations."

The soils along the shoreline within the study area are both sandy and clayey, the latter type consisting of what appears to be both a till and a residual soil. The author has been unable to differentiate between these soils except in a few instances. It has been inferred that till occurs where extremely thick and very compact clay or where erratic pebbles in clay are found. This type material was most extensive along the shoreline. Further discussions of the soil types may be found in the sections containing detailed descriptions of the area.

The beach ridges, which lie south of the study area, compose a part of the old glacial lake plains (collectively termed the Erie Plain). They disrupt an otherwise flat topography that is much as 17 miles wide west of Rocky River. The entire drainage of these lake plains consists of streams which head on an escarpment which forms the southern boundary of the Erie Plain. The streams flow directly into Lake Erie (Cushing, Leverett, and Van Horn, 1931, p. 15-21). Cahoon and Porter Creeks are the largest streams in the study area, and they lie at approximately the eastern boundary. They have similar gradients of from 20 to 40 feet per mile, as determined from the topographic maps of the region.

**Glacial Deposits**

At least two ice advances covered the area in the vicinity of Avon Point. Late Wisconsin deposits, however, have buried deposits left by earlier ice advance (Leverett, 1902, p. 352-3). Upon the retreat of the ice, glacial lakes began forming at successive levels as different outlets were alternately blocked or opened by retreating or advancing ice or by the ice depositing or destroying barriers of glacial debris.

The following table, composed from the text of Leverett and Taylor's history of the Great Lakes (1915), shows the glacial lakes which covered the Avon Point area. The only glacial lake deposit recognized by the author which is still present in the area is that of Lake Elkton. This is further discussed in the section of the paper describing the geology of the shore from Avon Point to Huntington Park.

**TABLE I**

The glacial lakes that covered Avon Point and their levels compared to the level of present Lake Erie.

<table>
<thead>
<tr>
<th>Glacial Lakes Covering the Avon Point Area</th>
<th>Levels</th>
<th>Glacial Divisions (from Flint, 1947, p. 256-7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Maumee (middle stage)</td>
<td>775-85 feet</td>
<td>Cary substage</td>
</tr>
<tr>
<td>Lake Arkona</td>
<td>695-710 &quot;</td>
<td>Cary substage</td>
</tr>
<tr>
<td>Lake Whittlesey</td>
<td>735-40 &quot;</td>
<td>Mankato substage</td>
</tr>
<tr>
<td>Lake Wayne</td>
<td>660 &quot;</td>
<td>Mankato substage</td>
</tr>
<tr>
<td>Lake Warren</td>
<td>680-85 &quot;</td>
<td>Mankato substage</td>
</tr>
<tr>
<td>Lake Elkton</td>
<td>620 &quot;</td>
<td>Mankato substage</td>
</tr>
<tr>
<td>Lake Erie</td>
<td>570-75 &quot;</td>
<td>(From U. S. Army Corps of Engineers Lake level records)</td>
</tr>
</tbody>
</table>
Bedrock

The bedrock in the study area has been covered by deposits of till, lacustrine silts and clays, and residual soils. It crops out only along the lake shore in cliffs and along stream channels. According to Newberry (1874, p. 207), the bedrock is covered by as much as 35 feet of till; however, in some places the till has been washed away and weathered shale forms the surface. Only the Ohio shale is exposed in the lake cliffs of the study area.

The rocks of the Lake Erie region dip very gently to the south, and the outcrop pattern of the several rock units along the lake has a trend that roughly parallels the shoreline. West of Lorain the outcrop belt swings to the south across central Ohio. In the vicinity of Avon Point, the rock outcrops exhibit minor folding and faulting. Folding has occurred along both north-south and east-west axes.

INTRODUCTION TO THE DETAILED DESCRIPTION OF THE AREA

Water Levels

Water level readings obtained from the United States Lake Survey, U. S. Corps of Engineers' gauging station at Cleveland, Ohio, show that the maximum variation of water levels for the days of observation was 0.83 feet. The average maximum daily fluctuation was only 0.24 feet, the average of the lowest daily readings was 572.97 feet above mean sea level, and the average of the daily maximum readings was 573.20 feet. The fluctuation of level was most erratic on the last day of observation, September 27, 1951. The level varied on this day from a low of 572.50 at 8 A. M. to a high of 573.11 feet at noon. Because of the generally steeply sloping foreshore, a variation of as little as 1/2 foot causes no large difference in the amount of foreshore area placed beneath the water. Waves over two feet high surge over most of the protective structures when the lake level is between 572.5 and 573.5 feet; consequently, the effectiveness of the structures must not be altered appreciably. A level of 573 feet has been assumed here (except where otherwise noted) because general conditions are nearly the same along the beaches whether the lake level is at 572.5 or 573.5 feet.

During June, 1952, when offshore samples were collected, water level records for the collecting days show a maximum fluctuation of 0.5 feet, but the general lake level was 2 feet higher than in September, 1951. Daily fluctuation was never greater than 0.25 feet. The error of locating positions with the use of a sextant, described more fully in the section dealing with field procedures, and the errors of sampling may be of such a magnitude as to offset the small error of 2 feet in general elevation, especially in water over 20 feet in depth, where most of the offshore samples were taken.

Division of the Area

Figure 4-1 shows the division of the area by the author into locations denoted by a letter and number, as A-1 or B-3. Letters and numbers progress from west to east. Letter changes have no special significance. These designations are used throughout the paper, although very prominent features are designated by their proper names.

OHIO HIGHWAY 301 (A-1) TO MIZPAH COUNTRY CLUB (A-3)

Geology

The shoreline between A-1, where a northern extension of Ohio Highway 301 abuts the lake, and Mizpah Country Club (A-3, Cleveland Beach) consists of a gray-brown clayey till bluff 11 to 13 feet high. The age of the till is unknown to the author. The bank has a height of 11 to 13 feet from A-1 to A-3 with but two exceptions. At A-2, Jordan's Boat Rental, the till bluff is only about 5 feet high, and again at A-3, the bluff disappears for a few feet, almost immediately rising to its former height. No information has been obtained on the bedrock topography beneath the till.

Just east of the Mizpah jetty, shale appears at the base of the bluff and rises very gradually to the east. The shale here has been called the Huron by Newberry (1874, p. 213) and is the Cleveland or Chagrin according to a beach erosion report by the U. S. Army Corps of Engineers (House Document 502).

At A-3 the clay bank is composed of very compact clay containing a few pebbles consisting largely of shale smaller than one inch.

Beaches and the Lake Bottom

Figure 4-3 shows the shore at A-1 in 1951. The sand is clean, and the beach uniformly wide (about 30 feet). The shingle portion of the beach almost covers the base of jetty B. (A shingle beach
is here defined as one composed mainly of pebbles and cobbles.) There are no groins immediately to the west of A-1. At the time observed, the water was about 1-1/2 feet deep at the base of the wall protecting the clay bluff to the west. The waves generated by a northwest storm three days before the diagram was prepared were unopposed as they approached the structures in figure 4-3.

The position of the shingle beach may possibly be explained using the conclusions reached by Grant (1943, p. 48). Great turbulence of the water due to storm waves imparts an upward velocity component exceeding the settling rate of all but the largest particles. The particles are not deposited until they have been moved laterally to more quiet water, i.e., water in which settling velocity is greater than the upward velocity component.

The shingle material of the beach, occurring in some abundance between A-1 and B, had been tossed up by the waves and stopped where energy requirements for movement had not been met by the energy in the backwash of the waves. A higher and steeper beach would have been accompanied by altered conditions, for the backwash of water would have had more energy; of course, the wave energy must have been sufficient to move the water up the more energy-consuming slope.

Considerable energy is lost if much uprushing water is lost through seepage into the upper portion of the beach. Great turbulence near the shore end of B removed any fine material that had been carried up with the shingle. The occurrence of so much shingle on the lee side of B cannot be explained satisfactorily by the author.

Around the north-south deflector wall between A-1 and B, sand was piled about two feet higher than at the submerged "t's" of either A-1 or B. Profiles 1 and 2 (See fig. 4-2) are located at the western end of the study area. They depict the near-shore profile in 1951.

A series of short groins lie just east of A-1 and B. Very little accumulation had taken place here. Possibly most of the sand that could have been captured by these had been caught by the much longer groins at A-1 and B.

A small beach occurred on both sides of the 141 foot groin at Jordan's Boat Rental (not shown). At the time observed, there was more sand on the west side than there was on the east; however, both sides were about 35 feet wide. The east beach was composed largely of a high ridge of shingle along the base of the low bank.

A short jetty between A-2 and A-3 had not collected beach sand at the time observed.

A sand beach had been developed about 200 feet west of A-3, maintaining almost a constant

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Figure 4-3. Plan showing the development of a shingle beach after a Northwest storm.
The width of 35 feet to A-3. The beach was wider on the east side of the Mizpah groin (not shown). Its width decreased from 75 feet, along the east edge of the groin, to zero (i.e., meeting the bluff) 600 feet farther east.

A bedrock bottom was inferred from a fathogram made off A-1. Because of repeated fruitless attempts to obtain a sample in the area, inferred as possibly having a bedrock bottom from the fathogram, it was concluded that the bottom was fairly certainly bedrock. Boulders too large to be picked up by the snapper may possibly lie on the bottom. The irregular topography of the bottom in this area is apparent in the profile in figure 4-2.

At A-3 the near-shore bottom is by far the most gentle in slope and relief in the study area west of Avon Point (See figs. 4-1, 2).

It has been inferred from echo-sounding and generally unsuccessful attempts to collect samples that the bottom is practically bare shale from A-1 to C-12. A profile prepared from a fathometer run made off the Cleveland Electric Illuminating Co. plant matched a profile prepared from Appendix 14, U. S. Army Engineer Beach Erosion Studies. Thus contours have apparently changed very little within the past four years. This is to be expected where the bottom is bedrock.

Figure 4-2A shows a number of profiles, number 3 of which was taken 138 feet west of the groin at A-3, and number 4 is located just east of this same groin. Sand was observed on both sides and along the full length of the 198 foot groin. It can be seen from profile 3 that a bar may exist on the west side of the groin. The water deepens slowly then shoals about 95 feet from shore, finally deepening gradually farther out. Along the east side of the groin the water was 5-1/2 to 6 feet deep; just 8 feet east of the groin this trough had disappeared, and the bottom rose abruptly to within one foot of the surface. Shepard, Emery, and LaFond (1941, p. 344) state, "Rip currents are frequently found running seaward along piers and groins. The slight deflecting influence of a pier evidently plays an important part in localizing these currents." The deep trough previously mentioned had probably developed from rip currents that occur when large waves break onshore. The author did not observe the currents.

Erosion and Protective Structures

Owners of land along this portion of the shore line do not consider erosion to be a very serious problem. Groins, although not all trapping sediment, are apparently protecting the till bluffs. At a two- or more-foot lower stage of water, erosion will cease to be of any concern because wave action will be spent offshore away from the bluffs.

MIZPAH COUNTRY CLUB (A-3) TO C.E.I. PLANT (D-1 TO D-5)

Geology

The shale that crops out just east of A-3 continues to rise to the east due to slight warping of the shale strata along a north-south trending axis. Minor folds appear on the larger warp (See fig. 4-2B), and just east of C-1, till lies above truncated beds of shale.

Figure 4-4. A diagram illustrating beach terminology used in this study.

(From Brown, 1939, p. 11.)
Very minor folds and minor faulting occur as far east as the C.E.I. plant (D-1).

Till from 6 to 7 feet in thickness overlies the shale from B-1 to B-4 in a contact of little or no visible relief. From B-4 east to the C.E.I. plant, the till is 0 to 5 feet thick. Figure 4-2B consists, in part, of a general section from A-1 to the western limit of the study area (K-4), showing the character of the bluff and the nature of the beach deposits as they appeared in 1951.

Sections measured at B-1, B-5, and C-2 are discussed at the end of the section on erosion and protective structures.

Beaches and the Lake Bottom

A sand beach area very similar to (and really a continuation of) that at A-3 extended approximately to B-2. It was not, however, as wide as the one at A-3. A greater volume of sand lay on the west side of B-1 than on the east. This relationship was true also for vicinity of the groin at B-2, although here more shingle occurred in proportion to the sand than at B-1 (profiles 5 & 6, fig. 4-2A).

Very narrow shingle beaches were observed farther east, but only next to groins or within indentations in the sand bluff. The coarsest shingle always lay against the base of the cliff with some minor variations lakeward, but in general, the smaller fragments lay on the lower berm. (Note: the beach terminology is that of the U.S. Beach Erosion Board, a simplified version of which appears on page 11 of Shore and Beach, volume 7, number 1, for January, 1939, in an article by E. I. Brown entitled "Beach Erosion Studies." For convenience, the key diagram accompanying the article is reproduced in figure 4-4.)

Offshore echo-sounding data have been interpreted as indicating the same irregular bedrock bottom discussed in the area to the west. A sample of clay was obtained about 1-1/4 miles offshore. (See figure 4-1).

Erosion and Protective Structures

The section of shoreline from A-3 to D-1 is more subject to erosion, largely because it is not so well protected by bulkheads and groins as the area immediately to the west. Erosion by lake waters is rather negligible at this time; it is doubted whether even large storms will cause much property loss.

The author has noted that most land loss during the period studies results from the action of frost-wedging in wintertime, and by sapping caused by groundwater pouring from spring-lines, especially during periods of thawing following much snowfall. Drainage problems are especially important.

Measured Sections

Section measured in the grounds of the West Shore Club (B-1). This section was taken at a point in the bluff facing the lake just east of the cement walk that leads to the water. It bears N., 6-1/2° E., of the northeast corner of the West Shore clubhouse and lies 119 feet along this bearing.

The section is very near the westernmost exposure of the Ohio shale in the area of study. The beds are horizontal.

<table>
<thead>
<tr>
<th>TOP</th>
<th>Ft.</th>
<th>In.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Soil zone, brown, sandy</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4. Till, sandy, gray-brown,</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>contains many shale pebbles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Shale, like unit 1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2. Shale, silty, gray-black,</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>thinly laminated and resistant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Shale, black, weathers rusty brown, very fossil, some clay layers present</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

Total thickness exposed in bluff 11 0

Base--Beach level of June 9, 1952 (575.0 feet)

Section measured east of B-5 in the large gully 180 feet east of H.S. Compton's house (B-5). The section was begun at the water level along the west bank of the gully.

The beds dip 10° S.

<table>
<thead>
<tr>
<th>TOP</th>
<th>Ft.</th>
<th>In.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Shale, appears highly weathered, gray-black, papery, largely covered by loose rock rubble</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>2. Shale, black, papery, weathers rust-yellow (limonitic staining), contains some silty shale layers</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>1. Sandstone, fine-grained, gray, blocky, stains red from overlying shale</td>
<td>0</td>
<td>8</td>
</tr>
</tbody>
</table>

Total thickness exposed in bluff 12 8

Base--Water level for June 9, 1952 (574.8 feet)

* Units from which material has been taken to make thin-sections. The thin-sections are discussed in a later section.
Section of the lake bluff measured in the grounds of the 103rd Q, V, L housing development. The section lies 185 feet along a line bearing N. 68° W. from the flagpole on the south side of the large white community house. It is on the western side of the small creek that flows into the lake, and is directly across from the cement steps that lead to the beach.

Figure 4-5 illustrates this section. The beds are horizontal.

<table>
<thead>
<tr>
<th>TOP</th>
<th>Ft.</th>
<th>In.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Soil zone, very sandy, light-colored (Dekalb?)</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>3. Shale, black, papery, cut by many joints (two systems) into blocks, otherwise like unit 2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>2. *Shale, black, papery, in general well-consolidated, a few vertical joints of two systems occur, shale becomes more weathered towards top</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

1. Siltstone, gray, resistant, forms ledge at lake level

| Total exposed thickness in bluff | 0 | 5 |

Base--Water level of June 9, 1952 (574.8 feet)

C.E.I. PLANT (D-1 TO D-5) TO AVON POINT (G-6)

Introduction

From D-1 to G-6 the shoreline is quite similar to one just described. The differences are due in part to the long impermeable groins at the C. E. I. plant, and in part to absences of till in the lake bluffs. Newberry (1874, p. 207) says that the till has been washed away in many places and that the soil has been derived from the decomposition of underlying rocks. The soil from A-1 to G-6 is classified as Volusia and Trumbull clay loams by Coffey and Rice (1915, map). According to them, the two soils are inseparable in

Figure 4-5. A section of the lake bluff at the allotment of the 103rd Q, V, L (C-2). The very fissile nature of the black shale is well-shown here. Only a very small soil zone exists. Taken June 9, 1952, water level was 574.8 feet.

Figure 4-6. The shoreline east of Moore road (near E-2) is illustrated here. Although many alternate black and light blue-gray bands of shale occur, the whole of the lower portion of the bluff seems nearly equally resistant to erosion. The source of the beach material is the shale, which accounts for the paucity of sand. Taken June 9, 1952, water level was 574.8 feet.
Lorain County. They have both been produced by the weathering of sandstone and shale fragments de-
posited by the glaciers. Coffey and Rice do not men-
tion the presence of any residual soils. At least some of the soils are possibly residual, because well-
zones, thin soils, lacking erratic rock fragments have been observed.

The shale exposed in the lake cliffs in Avon township, which includes the entire shore line from the C. E. L plant to Avon Point, is the Olmsted shale member of the Cleveland shale, according to Cush-
ing, Leverett, and Van Horn (1931, p. 36).

Geology

The bank within the grounds of the C. E. L plant is largely composed of fill. Because of its re-
meteness from the water and its protection by an elaborately spaced groin system, little of this material now enters the lake. About 300 feet beyond E-1 the bluffs once again front immediately on the lake. Figure 4-6 is a view looking east along the shoreline from the foot of Moore Road. The base of the cliff here has been very uniformly eroded and smoothed. No really resistant strata are present except for that projecting from the bluff about 7 feet above the beach. The shale has an exposure of 12 feet at E-4, and is overlain by a thin, clayey mantle. Except for a break in the bluff at Avon Village Park (F-5), the shoreline remains as a continuous bluff with only a few indenta-
tions to Avon Point.

Sections measured at the foot of Moore Road and at F-6 appear at the close of the discussion on erosion and protective structures for the shore line between D-1 and G-6.

Beaches and the Lake Bottom

The extensive groins at the C. E. L plant have caused sand to accumulate along the western side of D-2 (profile 7, fig. 4-2 B). The beach fronted on the lake for about 200 feet, and was widest where the sand had piled up against the west side of D-2. A smaller beach had formed against the east side of D-2.

At E-1 a series of semi-permeable jetties had been constructed, and not much sand had accumulated, although shingle formed a beach about 40 feet wide. Farther east, many short groins are found. They are usually less than 50 feet long and are made of either sandstone blocks or concrete. These have trapped some coarse beach materials, but sand is lacking. The beaches are shingle-types, and stone counts show that the more resistant, gray, silty layers of the local bedrock furnish most of the shingle. These pebbles have an average roundness of 0.6 (Krumbein, 1941, plate 1). Probing with a steel rod showed the beaches were veneers over the shale bedrock. At E-1, shingle, generally admixed with a very small amount of sand, ranged between 2 to 5 feet in thickness.

At Avon Lake Village Park (F-5), a series of many short groins had been recently replaced with fewer and longer groins. The high (15 foot) shale bank had been graded and protected from erosion by covering its lower portion with crushed stone and concrete.

An interesting beach pattern was developing at the time of observation. The largest portion of each small beach between any two of the long groins was composed of shingle becoming coarser to the east. Fine sand was accumulating along the east side of each of the groins east of F-5. The accumulation was widest at the swash. The beaches themselves were much wider and a few feet higher on the east side of each groin.

Wind and waves were from the northwest, produ-
cing a general longshore drift to the east. Most of the waves' energy was being expended along the por-
tion of beach immediately west of the structures. The wave pattern is shown in figure 4-7. Bottom topography between the groins was not mapped; however, the slight refraction of the waves implies a fairly rapid sloping of the bottom lakeward to provide a minimum of bottom interference to the waves.

Apparently, that portion of any wave (labelled A) is ineffective in its action on the beach because the groin end interferes with it. Portion B, however, continues inward uninterrupted and occupies the suc-
cessive positions denoted by subscripts. The turbulence created at C is enough to remove the finer material kicked up by the wave and moved forward by the mass movement of the water. (Inman, 1949, p. 67).

A portion of B's energy is reflected from N in the form of a smaller wave, b. The successive position of b are marked with subscripts. This wave also has a net forward movement of water which causes some of the sand in turbulence to be carried along and deposited at D. It is not removed from D because energy requirements for movement are not met. The text referring to figure 4-3 treats energy relationships more fully.

This reasoning is given added support by the fact that just west of F-5 the waves were refracted in such a manner as to approach the shore with a parallel
front. No reflection was noted. Without reflection, according to the previous line of reasoning, there should have been no differential development of beach material. One would expect some sort of a continuous pattern. A zone of sand approximately the same width at its eastern and western limits was observed.

Further, just beyond F-6 (eastward) there is no long jetty to reflect waves to the southwest. One would expect to find again (using the above reasoning) that either the wave would be refracted around F-6 to approach the shore in a parallel manner or that it would be only partially refracted, and that a less turbulent area would be created in the pocket east of F-6. In either case, if the waves, as previously observed, are capable of causing the removal of fine sand when unobstructed, only shingle would remain east of F-6. This was the case except for some sand accumulated with the shingle in the pocket east of F-6, indicating less energy here.

Some magnetite-ilmenite had been concentrated along the berm created by the northwest storm; however, no large accumulation of sand was noted in the vicinity of Avon Village Park.

A close spacing of groins from G-1 to G-5 has resulted in the collection of some beach material consisting of shale pebbles and sand. The explanation given for the accumulation of sand at Avon Village Park can possibly be applied here also. None of the beaches along here is very extensive as compared to those at Cedar Point (Metter, Ch. 2) or at the eastern end of the study area.

Lake Erie laps directly against the cliffs from G-5 to G-7. A small accumulation of sand was found at G-6 around some stone on the base of the cliff, but this was removed within a few days by a northeast wind.

Offshore echo-sounding and sampling attempts were interpreted as showing the same bedrock bottom as that to the west. Profiles of the lake bottom off D-5, F-1, F-5, and G-6 are found on figure 4-1 B.

**Erosion and Protective Structures**

This area is rather well-protected by walls and groins, and, although no large beaches can be expected

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Figure 4-7. The wave pattern developed at the Avon Village Park groins during Northwest storms.
to develop without the artificial dumping of sand, the shoreline will probably stand up quite well under attack by waves. The greatest danger lies where weak shale horizons appear at the level of wave attack. Water issuing from springlines may cause some loss of property, although the author has not observed any losses from this cause.

Slightly more sand might be expected to accumulate behind the groins at E-1 if they were made impermeable, but the cost might not be balanced by the gains.

Sections taken at the foot of Moore Road and at Avon Village Park follow.

Measured Sections

Section of the lake bluff measured at the foot of Moore Road which lies near the east end of the Avon Lake business district. The section was measured along the west side of the cut in the outcrop 124 feet from the north end of the road and in line with it.

The shale here dips 7° S. It appears to be more massive than the shale at Avon Village Park.

TOP

<table>
<thead>
<tr>
<th></th>
<th>Ft.</th>
<th>In.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Soil zone, sandy, light-buff color</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>3. Shale, black, paper-shale, weathering gray, some limonitic stains present</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>2. Shale, gray, silty, noticeably laminated, more resistant than unit 1, limonitic stains present</td>
<td>0</td>
<td>4-1/2</td>
</tr>
<tr>
<td>1. *Shale, black, thinly laminated, weathering gray, has intermittent light and dark blue-black bands, well-jointed</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Total exposed thickness in bluff</td>
<td>20</td>
<td>2-1/2</td>
</tr>
</tbody>
</table>

Base--Water level of June 9, 1952 (574.8 feet)

Section measured at the extreme eastern limit of Avon Lake Village Park at the shore end and along the centerline of the private groin 105 feet east of the most east mark groin (F-6).

AVON POINT (G-6) TO HUNTINGTON BEACH (D-4)

Introduction

A shale cliff, overlain by till continues almost without interruption along the shoreline from G-6 to K-4. A very important change in the character of the cliff occurs between H-3 and H-5, but the cliff then reverts to the typical sequence of till over shale.

Geology

The soil, as classified by Lapham and Mooney (1905, p. 685-714 and the accompanying soil map), from Avon Point to H-3 along the lake cliff is the Dekalb clay. It contains small, thin shale chips, and is an extremely heavy, clayey soil. The Dekalb clay appears to be more nearly a residual soil than any of the other types in the area. According to Lapham and Mooney, it originated from the degrading effects of glacial lakes upon the Erie (Chagrin) shale, and from later atmospheric exposure. The Dekalb clay resumes its position along the cliffs fronting Lake Erie just beyond K-4. From H-3 to K-4 the soil is Dunirk fine sandy loam.

The sheer shale bluff from G-6 east is overlain by 1 to 6 feet of clayey material (probably Dekalb clay). At G-7 the shale has an exposure of only 6 or 7 feet in the bluff. At G-8, 18 feet of shale is exposed and 6 feet of clay overlies it (See fig. 4-8). The cliff has been cut back at Vineyard Beach Park (C-10) by a small creek that flows into the lake at this point. Figure 4-9 is a westward view from G-10, East of G-10 the cliff is very high. Deep indentations mar the shoreline to H-3.

The shale exposures in the cliffs from Avon Point east are composed largely of Chagrin shale, according to Cushing (Cushing, Leverett, and Van Horn, 1931, p. 33). For purposes of definition, Cushing's report will be used for its designations of the outcrops appearing in the lake bluff east of the Lorain-Cuyahoga county line.

Cushing describes the Chagrin shale west of Cleveland as having an inconspicuous shaly cleavage, and as weathering rapidly to a soft, sticky clay.

Shalily sandstone beds, sometimes 6 inches thick, occur frequently. These contain much silvery mica and marcasite, the latter occurring as concretions throughout for formation. Thin beds of black shale are interbedded with the more common blue shale and gray sandstone beds.

Two general sections measured by the author at Vineyard Beach Park (G-10) and at Cahoon.
Memorial Park, in Bay Village just east of the study area, follow the discussion of erosion and protective structures.

A very important change in the lithology of the lake cliff occurs between H-3 and H-5. A steeply sloping bluff of sand with much brownish, very plastic clay replaces the shale almost completely about 500 feet east of H-3, and at H-4 a fine sand at least 12 feet thick overlies the shale. A large portion of the bluff farther east is covered with vegetation, but the best exposed section at H-5 discloses the same clay and sand (See fig. 4-10).

The soils map of Lapham and Mooney (1905) shows Dunkirk fine sandy loam covering this area. Lapham and Mooney (1905, p. 703) describe the subsoil of the Dunkirk fine sandy loam as being yellow and considerably heavier in texture than the overlying soil, with clay usually evenly distributed among the fine sand grains. The Dunkirk soils are glacial lake deposits. They have been formed from sediment deposited on lake bottoms or in lake beaches. According to Coffey and Rice (1915, p. 94-99), the material is of glacial origin and has been reworked by streams, waves, and wind. Because of the variability of environment in this region during the glacial epoch, the bottom, beach, and delta deposits may all exist within one small area. Between H-3 and H-5 the sand was very fine, and appeared to be bottom deposits reworked somewhat by wind (Leverett, 1931, p. 80-1). According to Leverett, this material is the sediment of the bottom of Lake Elkton.

The clay underlying and partially mixed with the sand resembled till. It could be a combination of till, glacial lake clays, and weathered Chagrin shale. In the areas where the slopes are not covered by vegetation, the material has slumped enough to remove any laminations that might be present. In general, the color of the material does not greatly resemble the clay of the weathered Chagrin, and the author concurs with Leverett's contention that the material is till (Leverett, 1931, p. 81).

Beaches and the Lake Bottom

Only very minor accumulations of beach material were found along the shoreline from G-6 to K-1. Figures 4-8 and 4-9 are typical views of the shoreline from G-6 to H-3.

A small beach containing minor amounts of sand and much shingle was found at Vineyard Beach Park (G-10). The sand here formed a veneer a few inches thick over the shale. The shingle on the west side of the 108 foot groin at G-10 was 4 feet higher than that on the east side. Probing disclosed shale cropping out at a higher level on the west side.

Figure 4-8. Taken just east of Avon Point, at G-9. Illustrative of the character of practically the entire shoreline from Avon Village Park to Huntington Beach Park. In places the overburden is not so great, and the cliff becomes much higher farther east, but water laps against it for almost the entire length of the study area. June 9, 1952, water level was 574.8 feet.
Sand covered the lake bottom off both sides of the groin in water about 3 feet deep (profile 9, fig. 4-2A).

Only shingle beaches appeared for the next mile towards the east. These were found in some of the indentations of the shoreline. A beach of this type at G-11 contained no sand, even offshore, along the 100 foot groin. A local resident said that sand had existed until the groin had been built.

Sand was collected off the west side of a groin at G-12, but none occurred off the east side.

Small amounts of sand had been accumulating between many intermittently-spaced, short groins from H-3 to H-5 (See fig. 4-1 B).

Wide sand beaches occurred between long (250 to 300 feet) groins at Huntington Park (K-1 to K-4). In general, the widest and thickest beaches appeared on the west sides of the groins.

A rather complicated bottom topography existed between the groins. The deepest water was on the east side of the longest ones, but deviations from this general pattern occurred. Figure 4-2 A, profile 10, shows a typical profile of the Huntington Park near-shore area.

The beach on the east side of the K-4 groin was made up of less sand than the other beaches, but contained shingle.

The bluff to the east of K-4 remains unprotected by groins or walls. Porter Creek has cut through the bank 200 feet east of K-4, and except for this indentation, 40 feet bluffs rise along the east shore.

The Ohio beach erosion study sheet of Huntington and Cahoon Parks (Sheet 4 of 4, Appendix 14, Ohio Beach Erosion Study, 1948) show that two groins, 2800 and 3400 feet east of K-4 respectively, had no accumulation of beach material on either side. This is probably indicative of a small sand supply for the area if the structures are properly designed. The groins at Huntington Park may capture all the available sand.

A bedrock bottom with perhaps locally a very thin veneer of sediment has been inferred from echo-sounding and sampling offshore as far east as H-3.

The previously discussed methods of interpreting the character of the bottom were used here and throughout the entire offshore area. A gradually sloping shelf of rock extends out about 2,000 feet from shore, where the water depth had been about 14-16 feet deep in June, 1952. A sharp increase in the slope occurs to a depth of 26 feet, after which the bottom slopes gently to the limits of the offshore sounding traverses (See fig. 4-1, 2).

At H-3 to as far east as Cahoon Creek, the bottom slopes gradually from the shore out, without abrupt breaks. The profiles are concave upwards. Sand lies off this area, with increasing abundance to the east. Here, it occurs as isolated patches, probably due to the sediment filling lows in the irregular bedrock bottom. Farther east the profiles indicate that much of the bedrock is covered by sediment, more closely approaching an equilibrium profile.

**Erosion and Protective Structures**

In general, rapid erosion is occurring all along

![Figure 4-9](image-url)

Figure 4-9. A view of the cliff west of Vineyard Beach Park (G-10). The tremendous mass of shale in the center of the picture has fallen because a weak layer in the shale has been eroded by wave action. Loss of land along here is mainly due to sapping. Taken June 9, 1952, water level was 574.8 feet.
the shoreline from G-6 to K-4.

Water is about 8 to 10 feet deep close to the bluffs, and bottom interference, producing wave refraction, does not take place except under severe storm conditions. Thus an equality of exposure of the cliffs to wave attack does not occur.

Certain laminae in the shale cliffs are very susceptible to erosion. This is well illustrated at Vineyard Beach Park (C-10), where the high water of June, 1952, has removed a lamina of the shale only 10 inches in thickness for as much as 6 feet back from the cliff face. The shale cliff, thus undermined, has been collapsing in huge sections (See fig. 4-9). The cliff as a whole is fairly resistant to erosion, but weak layers within the zone of wave attack require protection by some type of structure.

At Z-1 (See fig. 4-1 B) a large concrete wall has been constructed to prevent northeast waves from further cutting into the cliff (See fig. 4-11). This wall need not have been built so high, but certainly no harm can result from such height. The main force of the waves is concentrated well below the top of this wall.

From H-3 to K-1 the shoreline is protected from direct wave attack by many short groins. The exceedingly high water (574 feet) of the spring of 1952 has covered many of these structures, lowering their effectiveness; however, the greatest amount of erosion here is caused by slumping of the till banks, only indirectly due to wave attack. Heavy rainfall, infiltration, and saturation of the clay by water from waves breaking against the shore during storms, cause the material to become plastic. Large sections of the bluff then disappear through flowage of the clay, with consequent sapping.

More vegetation on the slopes in this section, better control of drainage waters, and grading of the bluffs seem to be required. The lost, if carried out in some places, would result in the removal of all level land north of the main east-west highway, but the value of this property for home sites has been decreasing rapidly anyway.

A lowering of the lake level would probably assist only slightly in decreasing erosion along this portion of the shoreline: the longer-term erosion by slumping and caving is the major factor. The lake waters seem to remove the material falling down from the bluffs to deeper water and on to Huntington Beach, on the east.

Measured Sections

Section measured at Vineyard Beach Park in Avon township, Lorain County, 102 feet west of the groin and in the shale bluff above the log cribs being used to protect the bank. (See figs. 4-9, 12).

Figure 4-10. This excellent exposure of the Dunkirk soil zone was found just west of Huntington Park (H-5). The light band just beneath the surface marks a subsoil of yellow, sandy loam. Beneath it lies a fine sand intermixed with clay. Taken June 16, 1952, water level was 574.8 feet.

Figure 4-11. The extent to which man sometimes goes to protect property is seen in this photograph taken at Z-1. The wall protects an indentation that opens in an east-northeast direction. A much lower, less expensive wall would have sufficed. Taken June 16, 1952, water level was 574.8 feet.
The beds are nearly horizontal.

**TOP**

5. Soil zone

4. Shale, gray, silty, thinly laminated, rather non-homogeneous as to silt content, much pyrite disseminated throughout, weathers rusty brown, becomes less resistant towards the top, weathers to a clayey consistency near the top, contains a few resistant gray siltstone layers throughout, but these occur most frequently near the base of the unit

3. *Shale, blue-gray, contains siltstone flags, fairly massive shale*

2. Siltstone, gray with many darker gray shale bands

1. Siltstone, gray, with few dark gray shale bands

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<tr>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
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Total exposed thickness in bluff: 16 feet 11 inches

Base--Water level for June 9, 1952 (574.8 feet)

**FIELD AND LABORATORY PROCEDURE**

**FIELD PROCEDURE**

**Collection of Samples**

**Sampling Procedure:** In the collection of samples, the grid series method described by Krumbein and Pettijohn (1938, p. 14) has been followed. It was necessarily modified because of the lack of near-shore sediments in many parts of the study area. This lack was especially noticeable east of Avon Point. Here, shore samples could only be collected where water was not lapping against the cliff face. The collecting was dependent to a large degree upon the existence of protective structures, because it was only usually in the vicinity of these that beaches were found.

In general, samples have been collected at closely-spaced (1/8 to 1/4 mile) intervals along normals to the shoreline, and on each normal four-foot and two-foot depths, at the water line, the crest of the first berm, and at the base and crest of any other berms present.

An attempt was made to obtain offshore samples wherever the quality and number of echoes on a fathogram were interpreted by the author to indicate the presence of unconsolidated material on the lake bottom.

The section was only approximately measured by observing it from a distance and gauging the thickness of the various units. Some evidence of minor folding and faulting was noted just east of the measured section.

The beds are almost horizontal.

**TOP**

4. Soil zone, brown-red in color

3. Shale, blue-gray, clayey, poorly consolidated, interbedded with siltstone flags near the top, followed by a clay-shale interval, then siltstone ledges again occur within the lowest 12 feet

2. Shale, blue-gray, many siltstone ledges

1. Shale, alternating blue-gray to black, fairly resistant

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<td>6</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

Total exposed thickness in bluff: 42 feet 0 inches

Base--Water level of May 11, 1952 (574.5 feet)
The location and designation of each sample appears on figure 4-1 A, 1 B.

A series of spot samples of bedrock was taken at intervals along the cliffs in the area (Krumbein and Pettijohn, 1938, p. 13). Thin sections were made of the most typical of these. Most of the specimens were obtained at or very near the water line, from rocks contributing directly to detritus, through disintegration by wave action. Their location and designation may be found on figure 4-1 A.

For all samples obtained on the beaches except pebble counts, a drive sampler was used (Pincus, Roseboom, and Humphris, 1951, p. 6). In essence, this is a pipe which is driven into the ground and from which cores 3 to 6 inches long can be easily obtained.

Cores were stored in pint mason jars to which labels were attached giving all the information necessary for later identification. Additional data, such as hydrological and meteorological observations, were recorded on sample collection sheets.

Below the water line, samples were taken with a check-valve-type sampler (Pincus, Roseboom, and Humphris, 1951, p. 5).

Samples collected in water too deep for wading were collected with a modified La Fond and Dietz clamshell snapper-type sampler lowered over the side of the 26 foot research vessel. (La Fond and Dietz, 1948, p. 34-37).

Errors in the plotting of the shore and near-shore sample points are probably no greater than 10 feet. Sample collection sheets accurately locate the points to within about 1/2 foot. The field maps used are drawn on a scale of 1 inch to 833 feet, and by pacing from the sample point to known features, such as groins, and taking bearings where necessary, errors in location were kept low.

Position of offshore samples were determined with a sextant, by turning horizontal angles on three known shore points. The error of location for these samples is considerably larger than that for shore samples, perhaps as large as 200 feet.

The Bathometer

The bathometer (echo-sounder) not only fulfilled its primary function of mapping lake bottom to pography, but it also proved very useful in providing a quick, rough means of determining the type of bottom.

In every case where three or more strong echo traces appeared, sampling attempts brought nothing to the surface. Only one echo trace was attributed to a clayey bottom, three strong echo traces with possibly a faint fourth, to a hard bottom. It proved rather difficult at times to distinguish between a sand or a bedrock bottom, especially when the former produced three traces. In these cases the sampler would be lowered. Two or three traces with one or two appearing only very faintly was found to signify a sandy bottom. A distinction between the sharpness of echoes could not be made with assurance.

Bathometer traverses are indicated on figure 4-1 A.

Meteorological and Hydrological Observations

It should be noted that for the period of sample collecting in the summer of 1951, the winds were consistently from the west and northwest until the last two days of collecting, when a shift occurred to the northeast. The predominance of westerly winds was of great importance in allowing sampling under fairly uniform conditions. For conventional control of the investigation, all samples should be collected simultaneously. Because similar conditions prevailed during most of the collecting, the validity of comparing results from one portion of the shoreline to another is high.

Erosion of the shore is intimately tied to meteorological and hydrological conditions. The amount of precipitation in the Great Lakes' watershed directly affects water levels, but high or low lake stages may not occur for several years (Moore, 1946, p. 59).

Seasonal changes occur on the Great Lakes, the maximum stage level for any year being reached in mid-summer, after the spring break-up of ice and snow. Spring rains have a greater effect on lake levels than those in the late summer. This is because most of the late summer precipitation enters the ground to supplement the diminished water supply.

A recognized storm path parallels the northeast-southwest elongation of Lake Erie; consequently the lake is frequently subject to winds of high velocity (See fig. 4-13). Winds generate practically all the waves on the lake, and it is their length of unbroken traverse over the water (fetch), and their duration and velocity that determine wave heights offshore. In shallow water, the bottom modifies the waves. In the Avon Point area, which is affected by the same weather occurring at Lorain, Ohio, (See fig. 4-13) the predominant strong winds are from the southwest, west, northwest, and northeast. Those from the southwest do not cause any damaging waves in this area. The winds from the other directions, having fetches
of from 50 to 200 miles can and do develop damaging waves. The occasional northeast storms, because of their long fetch over deep water develop some of the largest waves. According to Moore (1946, p. 61), the storm stages do most of the damage and are beyond the control of man.

A general longshore drift to the east was observed during the period of west and northwest winds. From the index map (See fig. 4-1 A), it is evident that west and northwest waves will strike the shore in such a way as to produce the eastward movement. Northeast winds, however, would probably produce a westerly current alongshore. Newberry (1873, p. 196) notices an eastward drift by observing the turbid Cuyahoga River water as it entered Lake Erie.

The author noticed from air photos of Rocky River's mouth that turbidity seems to be drawn out to the west rather than the east (U. S. Dept. of Agriculture, Production and Marketing Administration, photographs for Cuyahoga County, Ohio, flying completed May 20, 1951, photograph designation PZ-5G-32).

The author has seen the results of frost wedging and has concluded that erosion from this source is relatively insignificant during normal winters. If much freezing and thawing would occur, however, some measurable damage might occur.

Ice, during the winter of 1951-52, coated groins and piers, affording protection to them when the lake

**Figure 4-13. Wind diagram for Lorain, Ohio.**

**NOTES:** Figures at end of bars indicate average yearly percentage of occurrence of wind in the direction and intensity shown for the period of January 1, 1938 to December 31, 1947.

Length of bar denotes duration in average days per year.

Wind data based on records of the United States Coast Guard at Lorain, Ohio.
itself was ice-free and whipped by storm waves.

The author has not noted ice pushing against
banks or protective structures. A pressure ridge, from
4 to 6 feet high, had formed a few hundred feet off-
shore and extended, with many discontinuities from
A-1 to K-4.

The author's findings for the winter of 1951-
52 indicated little ice damage for that short time
period. House Document No. 502 (1950, p. 19) con-
tains the statement that ice has a net beneficial effect
over a long period of time on the lake shore.

LABORATORY PROCEDURE

Introduction

The unconsolidated material has been analyzed
for its particle size distribution, carbonate content,
and for the mineralogical content of the heavy mineral
fraction of a number of different size grades.

Thin-sections of bedrock have been examined for
their mineralogical composition and texture in the
search for relations to the unconsolidated samples.

Mechanical Analysis

After the unconsolidated samples had been
dried and reduced to a convenient amount by the use
of a Jones sample splitter (Krumbein and Pettijohn,
1938, p. 45), they were analyzed according to the
procedure described by Krumbein and Pettijohn (1938,
p. 140-141) to obtain a Wentworth grade size distri-
bution.

The sediments finer than silt were analyzed by
elutriation as described by Krumbein and Pettijohn
(1938, p. 166-69). These results, however, may not
be comparable with those of sieving (Sindowski, 1949,
p. 3).

The grain size distribution obtained is an aver-
age that may or may not be representative of the
whole beach. It is not characteristic of any single
instantaneous set of depositional conditions, however,
because the original sampling was in the nature of
channel samples (Emery and Stevenson, 1950, p. 220-
23).

Carbonate Analysis

Hutton's method of carbonate analysis (1950,
p. 640) was used with some modifications to deter-
mine the per cent of carbonate minerals in the sedi-
ments. Approximately 60 mL of 10 per cent HCl
was added to 25 gram samples. The supernatant
liquid was decanted and 30 mL of HCl was again
added to ensure complete solution of all the carbon-
ates. After a second decanting, the residue was
washed and filtered to remove the soluble chlorides
formed by the addition of the acid. The residue was
then dried in an oven and the per cent carbonate com-
puted from the loss in weight of the sample.

Mineralogical Analysis

Heavy Mineral Separations: The heavy min-
eral separation of the 1/4-1/8 and 1/8-1/16 mm
size grade fractions was carried out as described by
Stow (1940, p. 48-9). Bromoform of a density of
2.86 was used. The use of this liquid is very conven-
ient because, although expensive, it is easily recover-
ed and its low viscosity (0.068 poise) permits rapid
filtration and sedimentation.

Choice of Size Fraction: Most workers in
Germany analyze the 0.25 to 0.1 or the 0.20 to 0.10
mm. fraction for medium sands and the 0.20 to 0.05
or the 0.20 to 0.02 mm. fraction for fine sands, marls,
and clays (Sindowski, 1949, p. 5). Sindowski found
(1949, p. 7) that in the case of sands the 0.20 to 0.10
mm. fraction gives good average values if the modal
size lies within the 0.3 to 0.2 mm. range. In gener-
al, this condition is met in the samples analyzed in
this study. Rubey (1933, p. 26-29) gives reasons for
the use of both fractions having the same actual
limits in all of the samples compared, and fractions
with the same relative position within the distribu-
tion curves of different samples.

The 1/8-1/16 mm. size fraction used satisfies
Rubey's requirement for a fraction having the same
actual limits in all the samples compared.

The author agrees in principle with Rubey's
second requirement, having selected the 1/4-1/8 mm.
size fraction which is in almost every case the modal
class. Because the size frequency distribution curves
of different samples may be displaced along the
graph's abscissa (the size variable is along the abscis-
sa), the modal class of any two samples may differ
in grade size, although the curves have identical
shapes. A coarser modal class will have proportion-
ately less heavy minerals than a finer class (Rubey,
1933, p. 3-29).

Comparisons between fractions that occupy the
modal class, where the degree of sorting is approxi-
mately the same, eliminate essentially all the varia-
tions of heavy mineral proportions that are caused
by different settling velocities (Rubey, 1933, p. 29).
Grain Counts:  Three hundred grains were counted in slides made from samples located at 1/4 mile intervals wherever possible. In some instances only 200 grains were counted, although relatively few of these short counts were made.

A count of 300 grains was adopted on the basis of the error chart of Krumbein and Pettijohn (1938, p. 472). According to it, minerals which occur with a frequency of 5 per cent or less are subject to large relative errors in counts of less than 200 grains. The probable error diminishes at a low rate for counts above 300 grains.

Krumbein and Rasmussen (1941, p. 10-20) show that the laboratory error is large for minerals occurring infrequently in numerical counts of 300 grains. For an accuracy within 10 per cent, it is necessary to have a mineral frequency of 9 per cent in a 300 grain-count. These authors distribute the laboratory errors as follows:

Laboratory error of splitting and sieving......................... 1.0±0.5%
Laboratory error of bromoform separation.......................... 3.5±1.0%
Laboratory error microsplitting, mounting and counting........... 10.5±2.0%

They believe that the counting error is very significant. The method of counting is discussed in the next section.

Sindowski (1949, p. 4) tabulated the counts used by nine workers in Germany. The least number of grains counted is 100, the most is 500. He has shown that a count of 200 transparent grains is sufficient if many separations are made from the same bed.

Notations in Counting: A list of the more common minerals found in the grain counts and their relative frequency may be found in Appendix I of the unpublished thesis (Kleinhampl, 1952) on which this report is based.

The heavy mineral splits were reduced to a number of grains suitable for mounting on slides by the use of the microsplit devised by Otto (1933, p. 31). Some of the samples were mounted in Canada balsam and some in Lakeside plastic.

In counting grains of the 1/4-1/8 mm. fraction, each grain was counted as it appeared within the upper semi-circle of the field. This work was greatly facilitated by the use of a mechanical stage. The opaque grains were counted first in the 1/8-1/16 mm. fraction. This was then followed by a count of the rest of the grains. Great care was taken necessary to avoid counting thick amphiboles as opaque grains. The counting of grains is a long, tedious process, and short-cuts were used wherever possible. To obtain an interference figure on every grain was found to be out of the question. The general pattern of identification as given by Russell (1940-41, Tables for the Determination of Detrital Minerals) was found to be very satisfactory. The procedure consists of noting in order, first, the color and pleocroism; then, successively, the relief; shape, as determined by cleavage and crystal form; the approximate birefringence; and the extinction angle. In relatively few cases were interference figures sought.

Mineral descriptions may be found in Appendix II of the unpublished thesis (Kleinhampl, 1952) from which this paper was written.

Thin-Section Analysis

The purpose of preparing thin-sections of the bedrock along the shoreline was to attempt to search for possible relations to beach materials.

The type of material sampled and the locations from which the material came follows in Table 2:

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</tr>
<tr>
<td>3</td>
<td>Gray Siltstone</td>
<td>Vineyard Beach Park</td>
</tr>
<tr>
<td>4</td>
<td>Black Shale</td>
<td>Avon Lake Park (F-6)</td>
</tr>
<tr>
<td>5</td>
<td>Black Shale</td>
<td>Foot of Moore Road</td>
</tr>
<tr>
<td>6</td>
<td>Black Shale</td>
<td>103rd O. V. I. (C-2)</td>
</tr>
<tr>
<td>7</td>
<td>Black Shale and</td>
<td>West Shore Club</td>
</tr>
<tr>
<td></td>
<td>Gray Siltstone</td>
<td>(B-1)</td>
</tr>
</tbody>
</table>

The locations are marked on Figure 4-1 A. The particular units from which they were obtained are marked with an asterisk in the appropriate accompanying measured sections. Only the sample at Cahoon Park was taken from a location for which there is no section. The location is, however, only 178 feet east of a section measured in a bluff at Cahoon Park. Beds are almost horizontal here with only a slight eastward dip.

A number of siltstone samples were studied in...
sections cut transverse and parallel to the bedding. The former provides a study of variation in time as opposed to the latter which shows areal variations. The development of mica and the relationship of detrital particles to the matrix may be observed in sections parallel to the bedding (Milner, 1929, p. 283).

The greater proportion of samples studies were shale. The bedding and longitudinal cross-sections of some minerals could be observed in transverse sections, but due to the extreme fineness of the grains it was decided that sections parallel to the bedding would reveal more. Milner (1929, p. 301) states that sections parallel to the bedding should be studies because they reveal mutual relationships of the constituents as they lie along one bedding plane and the relative proportion of detritus to shale-substance. The latter was considered very important by the author.

A detailed description of the thin-sections examined may be found in Appendix III of the unpublished thesis (Kleinhampl, 1952). The shale thin-sections examined all contain clay, which is the predominant mineral matter, quartz, pyrite, and carbonaceous material. Numerous accessory minerals are present, as zircon and amphiboles, but they are too small to be readily identified. The average size of the quartz and pyrite grains is well below sand size, but some grains of quartz are as large as 0.05 mm, and some pyrite grains as large as 1 mm. These are very rare.

The siltstones examined are very homogeneous and exhibit no laminations, although pods or lenses composed of coarse material (about 0.2 x 1.0 mm, in size) occur frequently. The material comprising the groundmass is mainly equigranular quartz (from 0.008 to 0.30 mm, in size) with a carbonate as the cementing material. Pyrite occurs disseminated throughout the examined sections. Accessory minerals are quite numerous and varied, but these are all smaller than sand in size. The only grains which are of sand size occur in the pods, but even here they are comparatively rare.

**GRAPHIC REPRESENTATION OF LABORATORY DATA**

**INTRODUCTION**

Some standard statistical values for each of the samples collected have been calculated, and some of these have been used as an aid to the interpretation of sedimentary processes in the area discussed in this thesis. A tabulation of the following measures can be found in Appendix I (Kleinhampl, 1952) 1 -phi median, 2-Trask's sorting coefficient, 3-phi quartile kurtosis, 4-phi quartile skewness, and 5-the mode.

The definitions of these measures, their merits, and their significance are quite thoroughly discussed by Krumbein and Pettijohn (1938, p. 212-267).

Because quartile measures are easily determined from the analytical data, and because these measures are widely used in sedimentary analyses (Krumbein, 1938, p. 229), this procedure has been adopted here. The results of the mechanical analyses have all been expressed in phi (δ) units, (Krumbein, Pettijohn, 1938)

The percent carbonate and pebble counts, as determined for some of the samples, also appear in Appendix I (Kleinhampl, 1952).

**STATISTICAL VALUES OF WATER LINE SAMPLES**

The following statistical values of the water line samples collected are show graphically on figure 4-15: phi median (Mδ), Trask's sorting coefficient (S0), phi quartile kurtosis (Kqδ), and phi quartile skewness (SKqδ). Percent of carbonate present in the total sample is also shown, both for the water line and the 4-foot depth samples.

Figure 4-14 illustrates the range of percent carbonate with phi median values for water line, less-than-6-foot depth, and more-than-6-foot depth samples. The latter two are both termed "bottom samples," but are differentiated in the graphs.

**PROFILES**

In addition to the longshore graphs of statistical measure, see fig. 4-2 A for profiles normal to the shoreline. These are drawn for each locality where a number of analyses were available from samples taken at different portions of the beach and near-shore area. Sample numbers, phi median, sorting coefficient, and percent carbonate values are given wherever this information is available.

**MINERALOGICAL VARIATIONS**

The percent of heavy minerals by weight in the 1/4-1/8 and 1/8-1/16 mm, size fractions has been plotted for water line samples (See fig. 4-16).
Figure 4-14. Per cent carbonate vs. phi median.
Trace minerals (zircon, rutile, monazite, titanite, wollastonite, and tourmaline) are not plotted because of the large sampling errors involved. The percent of heavy minerals in each of these same fractions in corresponding samples at the four-foot depth does not appear on the graph because the variations are very similar to those of the water line samples. The phi median values for the water line samples analyzed and graphed in this manner have been superposed on the diagram. A later discussion is based upon this average and the phi median values.

ANALYTICAL RESULTS AND THEIR INTERPRETATIONS

PERCENT CARBONATE VS. PHI MEDIAN

From the graph (See fig. 4-11) it is apparent that most beach samples have a phi median value between 1.5 and 2.0. These samples show a range in carbonate content from about 4 to 6 percent—a range that can hardly be considered significant because of errors incurred in sampling and analysis. In a few beach samples with larger median diameters, the percent carbonate is somewhat higher.

The beach samples have been studied as a longshore series to see if a progressive change in carbonate content occurs along this stretch (See fig. 4-15).

The less-than-six-foot depth bottom samples also are all clustered about one phi median value (2φ), ranging in carbonate content from 4 to 6 percent. A few samples have as much as 10 percent carbonate, but none much below 4 percent. Here too, the data have been examined for recognizable longshore variation, for no trend is apparent from figure 4-14.

A decided variation of percent carbonate with respect to phi median can be seen by taking as a frame of reference all the samples—beach, shallow, and deep water. The deep water samples all have smaller median diameters than either the shallow water or beach samples, and as a group they have more carbonate, ranging from about 6 to 8 percent.

In summary, the graph shows a range or variation of percent carbonate that is of doubtful significance for the samples with a phi median of 2.0. There are few samples of larger or smaller phi median values, and no trends are postulated from the few that are plotted. Where there is an apparently non-accidental increase in phi median values, the carbonate percentages increase slightly.

A study of thin-sections of the local bedrock disclosed much carbonate cement in the gray siltstones that occur with some degree of abundance along the shore. This carbonate is composed of very minute grains, mostly of silt size. The removal of some of this by erosion and its transportation to deep water is probable because of its minute size.

Figure 4-15 shows the longshore variations of carbonate percentages with respect to longshore variations of phi median values for water line and 4-foot depth samples. No trend can be discerned from this except for a possible decrease in the magnitude of the fluctuations of carbonate percentages to the east. The value of the carbonate in these samples can be seen, again, to very inversely with phi median values.

TEXTURAL CHANGES OF WATER LINE SAMPLES

Inman (1949, p. 57-70) renders a very fine treatment of the mechanics of the sorting of sediments, and some comparisons and verifications of his conclusions can be made from the Avon Point study. Much of the discussion that follows is based upon Inman's paper.

Sorting and skewness are probably functions of the median diameter of a sample. It appears that under the conditions specified by Inman, samples with a median diameter near 0.18 mm, are best sorted, and that sorting becomes poorer for both larger and smaller median diameters.

Sand with a median diameter near 0.18 mm, is hydrodynamically unique in that the threshold velocity is least for this size and increases both for finer and coarser sediments. Thus, sand of 0.18 mm, is most easily moved, and transportation may be by surface creep, saltation, or suspension. Grains with a diameter larger than 0.18 mm, will be moved initially by rolling or sliding, and grains with a diameter less than 0.18 mm, will have a tendency to be transported in suspension.

From a study of figure 4-15, it is apparent that where the phi median of any sample is around 2 (the nearest approach to a median grain size of 0.18 mm), the degree of sorting is quite high, while where the phi median values are very low, the sorting becomes
poorer. Stetson and Upson (1937, p. 57) say that 1.25 is an average value for the sorting of beach sands, and that 1.45 is an average value for well-sorted, near-shore sediments (perfect sorting = 1).

Bottom sediments in the process of transport tend to become progressively better sorted as their median diameter approaches 0.18 mm, if currents causing the transport have a friction velocity gradually decreasing in the direction of transport. Figure 4-15 shows that, in general, the median diameter of the samples is near 0.18 mm. Thus, progressively better sorting should be expected in the direction of transport if optimum current conditions exist and if there are no other complicating factors. But sorting is good for nearly all the samples, and large trends are not apparent.

In the vicinity of A-3 and E-2 the samples are very coarse, probably because of very recent additions from the till and shale bluffs. Here, the material is poorly sorted, while just to the east of these points, the samples have much better sorting and finer median diameters.

It does not seem possible to account for the large fluctuations that occur in the plot of phi median values versus sorting. The recent additions of material from erosion and the presence of jetties seem to cause local fluctuations in an otherwise unchanging pattern of statistical measures. The great length of jetties at the C. E. L plant in Avon Lake appears to have a disruptive effect upon near-shore processes of sedimentation. A highly detailed study of this area is suggested.

The extreme uniformity which occurs in the graphs of phi median, sorting coefficient, phi quartile kurtosis, and phi quartile skewness is significant in itself. Very regular conditions of transportation, with possibly very minor fluctuations of competency or current directions are indicated. It might be, however, that addition of material from the cliffs to the beaches obscures trends due to currents. The source of supply of the sediment must also be fairly uniform in composition and texture. Some irregularities exist at the location of long groins, such as by the C. E. L plant, where interference with the longshore currents exists because of 1,000 foot groins.

Figure 4-15 shows the median diameters and sorting coefficients of some samples obtained from the Dunkirk soil material at H-4. This material is somewhat finer and about as well sorted (So=1.4-1.5) as the beach samples. The mechanical analyses of these subsols verifies those performed by the U. S. Bureau of Soils. (Lapham and Mooney, 1905, p. 704).

Russell (1939, p. 33) has divided sorting into two types. That which occurs at a particular locality or site of deposition has been termed "local" sorting by Russell, and that which involves an assortment of particles in the direction of transport, "progressive" sorting. Inman (1949, p. 61) says that in the absence of movement by surface creep, the great differences in settling velocities of very fine sediments act over large lateral distances as an effective sorting agent. For this reason, clays and silts derived from the deposition of suspended material may be better sorted than coarser sediments with median diameters up to that of fine sand. Reference to the tabulation of statistical values for the deep-water samples (Appendix I, Kleinhampl, 1952) shows that these samples are all poorly sorted. The sediments are possibly transported offshore by rip currents (Shepard, Emery, and La Fond, 1941, p. 337-369) or other lakeward-moving currents in which the progressive sorting action may be poor. They are also probably agitated by large waves which often reach 7 to 10 foot heights during large storms in this portion of Lake Erie.

The statistical measures taken from the profiles normal to the shoreline (See fig. 4-2 A) show the same uniformity from east to west as shown by the water line sample values. Only a very slight difference exists between samples (for which phi median values were taken) at the plunge point and just below and above it. This is best shown in the tabulation of phi median values (Appendix I, Kleinhampl, 1952). This difference, according to Inman, should be expected (1949, p. 48).

TOTAL HEAVY MINERAL PERCENTAGES IN TWO GRADE SIZES

A tabulation of the total heavy mineral percentages found in each of two grade sizes can be found in Appendix I (Kleinhampl, 1952, unpublished). The exact significance of this information is not known. Rasmussen (1941, p. 98-101), however, noted that a greater percentage of heavy minerals occurred up on the beach than at the water line. His explanation follows.

An explanation of the greater percentage of heavy minerals on the upper part of the beach may be attempted by consideration of heavy mineral densities. Because of its greater density a heavy mineral particle has a settling velocity equal to that of a larger particle of quartz or feldspar (the predominant constituents of the beach sand). The speed of an incoming wave diminishes rapidly as it rushes upon a
Figure 4-15. Phi median, Trask's sorting coefficient, phi quartile skewness, phi quartile kurtosis, and per cent carbonate of water line samples.
shallowing beach so that for any given mass there is a certain point at which all particles of that weight settle out (neglecting shape and surface area, which are important, but are not contradictory to the simplified picture given here). The magnitude of velocity of the water returning on the ebb is much less because of friction losses, and because of volume loss in sinking into the sand. Therefore for any given point the water can move only particles of somewhat smaller settling coefficient than it deposited on its inflow. Thus it will remove quartz and feldspar of a given size on the return more easily than heavy minerals of that size. Consequently there may be a greater percentage of heavy minerals of a given size on the higher reaches of the beach than on the lower.

The explanation very nicely accounts for the contours of heavy mineral percentages paralleling the shoreline, and he states that the linear pattern may be the rule in heavy mineral weight variations along beaches. Rasmussen also sets forth the idea that in a line normal to the shoreline there is a decrease in the total heavy mineral percentages towards the water (based on observation) and that the percentages rise in the zone where the sand grades into silt (a hypothesis). Figure 4-2 A gives values for the percent of total heavy minerals in the 1/8-1/16 mm size fraction for a few samples in profiles normal to the shoreline; however, the results are inconclusive, possibly because of the lack of variation in phi median values for the samples.

Figure 4-16 illustrates the longshore variation of heavy mineral content (by weight percent) for water line samples in the 1/4-1/8 mm, and 1/8-1/16 mm size fractions.

The total heavy mineral percentage for the 1/4-1/8 mm grade size is consistently less than for the 1/8-1/16 mm size, although the same variations exist in a subdued manner. The superposed phi median values tend to follow the same fluctuations as the heavy mineral percentages. Where the median diameter of a sample increases the content of heavy minerals decreases. This agrees with Rasmussen's hypothesis and shows the trend of decreasing heavy mineral content with increasing coarseness, not shown in the profiles normal to shore, because of lack of variation in the phi median values. In some instances the presence or absence of magnetite-ilmenite in the total heavy mineral content is the most important factor; it appears to control the total percent of heavy minerals by weight.

This is illustrated at points B-4 and B-5, (See fig. 4-16) where all of the heavies except pyrite-limonite decrease in their frequency of occurrence (by mineral count). The absence of the high density minerals accounts for the decrease in the percent of the total heavy minerals by weight. Apparently the phi median values here are greatly influenced by the light mineral constituents which tend to produce a coarser sediment (Emery and Stevenson, 1950, p. 223 and Rasmussen, 1941, p. 98-101). In general, the coarsest sands are the most poorly sorted (Inman, 1949, p. 51); this leads to the conclusion that much new material has been added here, probably from the shale cliffs which front directly on the lake at this point. The water has not had time to sort thoroughly this material. The more direct exposure to the full force of waves at this point is probably another contributing factor to increased coarseness.

The unknown factors introduced by the groins at the C. E. I. plant could have influenced the phi medians, sorting coefficients, and percent of total heavy minerals by weight. It may be that the interference produced by the groins has effectively reduced current velocities, allowing accumulation of light grains of size near 2 phi.

In the vicinity of Avon Point, a wide departure exists between phi median values and the heavy mineral totals. Rather than the usual pattern of a decrease in the total heavy minerals with an increase in coarseness, a reversal appears. The sediments are, in general, quite fine but the percent of total heavy minerals is also low. The trend of the shoreline here is felt to be an influence; to the west the trend is west-southwest, while to the east it is east-southeast. In figure 4-16 the frequency of occurrence of both garnet and magnetite-ilmenite decreases very greatly with respect to the total heavy minerals, while that of hornblende increases. The large decreases in the former pair of very dense minerals is reflected in the drop of the percent by weight of total heavies. Normally, these two increase where phi median values increase for samples collected in the study area (Pincus, Roseboom, and Humphris, 1951, p. 13). Apparently eddy currents exist in the vicinity of the headland and are strong enough to carry in only small sizes of light minerals. The assumption has been made that the currents are directed inshore. This implies that transportation by suspension is the dominant type of movement.
Figure 4-16

HEAVY MINERAL COMPOSITION, 1/4 TO 1/8 MM FRACTION

HEAVY MINERAL COMPOSITION, 1/8 TO 1/16 MM

PERCENT OF HEAVY MINERALS IN THE 1/4 - 1/6 AND 1/8 - 1/16 MM FRACTIONS
HEAVY MINERAL SPECIES VS. 
TOTAL HEAVY MINERALS

A very large variety of heavy minerals is present in the samples of sediments collected in the Avon Point area. At least 17 different minerals, with some varieties of these, occur in any one sample, although only about 6 minerals occur frequently enough to be used for study purposes.

A few similarities can be noted between the 1/4-1/8 and 1/8-1/16 mm. heavy minerals fractions (See fig. 4-16).

In general, magnetite-ilmenite varies directly with garnet, and both of these vary inversely with hornblende (Pincus, Roseboom and Humphris, 1951, p. 12-13). No particular relationship is noted between magnetite-ilmenite and limonite-pyrite. In some instances these two appear to be directly related to one another and at other times they bear a reciprocal relationship towards one another. Therefore it cannot be said that limonite-pyrite is formed wholly from magnetite. This is augmented by the observation that much limonite and pyrite appear to exist in the shale while magnetite-ilmenite does not (at least not in sand-size grains), and some of the clinker may have become limonite-pyrite. In the 1/4-1/8 mm. fraction, both total garnet and pink garnet have been plotted, but because one varies directly as the other, only the total garnet is shown for the 1/8-1/16 mm. fraction. Pink garnet constitutes the largest proportion of the total garnet.

A number of minerals have been omitted from the figures because no definite trends appeared or because the minerals did not occur with enough frequency to be plotted. These include augite, zircon, monazite, hypersthene and a number of others. The hypersthene pattern is similar to that of diopside, and no trend is discernible for the latter.

Within each one of the size fractions studied, no clear trends exist.

In the 1/4-1/8 mm. size grade hornblende seems to increase slightly from west to east while magnetite-ilmenite bears a reciprocal relationship to it. Limonite-pyrite may be more abundant between the western limit of the area and Avon Point.

The increase in percent of hornblende with respect to the total heavy minerals to the east does not seem to continue for the 1/8-1/16 mm. size, nor does the magnetite-ilmenite trend continue. Limonite-pyrite, however, again appears most abundant just west of Avon Point.

Pettijohn (1933, p. 92), in a study of Cedar Point sediments, attributed a longshore change in mineral composition to the ability of low sphericity minerals to outrun grains of high sphericity. His high sphericity and high density mineral was garnet; hypersthene was intermediate, and hornblende and diopside were of low sphericity and density. The tendency, he presumed, had to be due to transportation in suspension, and he concluded that the principal mode of travel was by this means.

An application of this deduction to the trends of hornblende and magnetite-ilmenite in the 1/4-1/8 mm. grade leads to the conclusion that an eastward shore drift of materials occurs largely by suspension.

The 1/8-1/16 mm. grade does not exhibit the same trend because of the smallness of the particles. According to Stokes' law, fine particles have slower settling velocities than coarse particles. Applying this to the lack of a trend in the 1/8-1/16 mm. size, it seems that the fine particles are swept along in suspension and measurable progressive sorting does not occur (Inman, 1949).

Some recognition of the rather large fluctuations in the frequency of some minerals should be made. Such fluctuation occur most markedly with hornblende, magnetite-ilmenite, and garnet in the areas just west and east of the C. E. I. plant. The wide divergence of various measurable characteristics of samples here may be of significance. It can hardly be said that all of the samples are not adequately representative of the beaches but aside from this or the influence exerted by the 1,000-foot groins at the C. E. I. plant, no simple explanation is known.

A study of the sediments composing the bluff from H-3 to H-4 discloses that their percent by weight of heavy minerals is very small compared to that of the presently forming beach materials. Garnet, magnetite-ilmenite, and hornblende occur within the heavy mineral assemblage with the greatest frequency. Their great abundance here, plus the fact that they are easily weathered (Sindowski, 1949, p. 7-8) probably means that they are too recent to have undergone much weathering, or they might possibly have been too well protected from weathering.

SOURCE OF SEDIMENTS

There are many potential contributing sources to the sediment found in this area, but only a few appear to be of significance in their contributions to sand beaches.

Analysis of the shales and siltstones (Appendix
III, Kleinhapml, 1952, unpublished) has shown that, assuming representative sampling, they probably contribute very few individual mineral grains to the sand beaches because of their extremely fine texture. They probably contribute a great deal of material to the offshore area where clay is found.

Pebble counts (Appendix I, Kleinhapml, 1952) indicate rapid diminution in size of black shale fragments, as the distance from source areas increases. These fragments compose many fine shingle beaches, indicating that the shale is a steady contributor to lake deposits. The siltstone interbedded with the shale furnishes most of the very coarse shingle found on some beaches.

The presence of so many varieties of minerals in the sands and the varieties of igneous rocks represented in pebbles along the shore implies a source containing a very heterogeneous assemblage of rock types. The till overlies much of the sand along the lake bluffs meets this requirement. A Beach Erosion Board report for the Lorain area (1949, Appendix VIII) states that the boulder clay present throughout the area furnishes some material of a size suitable for beach building. Observations of the author support this statement. Most of the till contains some sand.

Any large-scale dumping of material dredged from the Black River and Lorain Harbor areas, as occurred in 1930-31 on the east side of the city of Lorain, would probably contribute heavily to the beaches west of the C. E. I. plant at Avon Lake.

Offshore deposits as contributors to the beaches are of no significance because from the west end of the area to as far east as H-3 (See fig. 4-I A), only large deposits of clay exist, and these are found sporadically and only in relatively deep water (about 30 feet) where it would be difficult for currents to carry the material up to the beaches over steep bottom slopes.

The Black River, in Lorain, has been ruled out as a source of sediment to the areas both east and west of Lorain Harbor because of the presence of breakwalls and a large settling area (Beach Erosion Board, Appendix VIII, p. 13). Both Porter and Cahoon Creeks, however, head in an area where old beach ridges exist. These streams are located at the eastern extremity of the study area, and, although small, they have gradients of from 20 to 40 feet per mile. In times of heavy rains these streams could carry some sand and gravel size material to Lake Erie.

The largest single source of sand in this area is believed to be the Elkton Lake bottom material just west of Huntington Park. The mineralogical studies made do not furnish as much support for this hypothesis as do the mechanical analysis of samples from along the water line and in the bluff material. A more detailed mineralogical study is needed here. A decrease in the size grade of the mode occurs for water line samples in the Huntington Beach area as compared to the mode farther west. The change corresponds to modal values determined for the bluff material. Much of the extremely fine material from these bluffs seems to be carried offshore in the Huntington Park area.

The contribution of material brought to the Lake from Rocky River’s drainage basin is not known. Certainly in times of severe northeast storms some material from this source could enter the study area.

SHORTCOMINGS OF THIS STUDY

The emphasis of this study has been placed upon three items: the size distribution of water line and off-shore sediments, the heavy mineral content of the sediments, and the composition of the bluffs as they relate to the sediments. Avenues for further investigation are: 1- A detailed current study, 2- A detailed areal study around the C. E. I. plant at Avon Lake, 3- A detailed areal study from Huntington Beach to Rocky River.

The quantity and type of sediment contributed by the river is unknown.

A study of the topographic and geologic maps for the region shows that besides passing through drift and Chagrin shale materials, Rocky River also passes through an area containing some of the Dunkirk soils derived from glacial Lake Elkton. This might make differentiation of contributors in this area quite difficult.

A shortcoming in the collection of data lies in the fact that sampling was spread over a fairly long time interval, and, although wind and wave conditions were similar throughout most of the study, some beach differences might possibly have developed. Another series of samples should have been taken after a period of strong east to northeast winds.

Any studies of the effectiveness of groins must be made in greater detail, and use should be made of the general information available on the area (Krumbein, 1949, p. 27).

ECOLOGICAL RELATIONSHIPS

The lack of any sediment over a large part of the near-shore lake bottom in the western portion
of the area is plainly detrimental to plant life. This scarcity of plant life is probably reflected, to a smaller degree in the amount of fish life.

Butler (1951, p. 8-11) states that pure sands restrict both the numbers and varieties of animals, and that pure muds so restrict the number of animals that they may, in some cases, be reduced to a zero. Optimum conditions for life exist where a bottom consists of sand mixed with mud.

The study area contains the extremes of bottom types mentioned by Butler; consequently, animal life should be greatly restricted in number and variety.

**SUMMARY AND CONCLUSIONS**

Erosion is not too serious, in general, along the shale bluffs in the study area as compared to the erosion occurring in the area covered by glacial Lake Elkton sediments and till. To prevent erosion, the clay must be kept from being saturated with lake water and groundwater. Better surface drainage through the use of tile might help the latter condition, and increasing the amount of vegetation might help the former. It must be recognized that the existence of the excellent sand beach and bottom off Huntington Park would be endangered if erosion immediately to the west of the park were slowed or stopped. With the source of beach material eliminated, currents created by storms might remove most of the sand at Huntington Park. The material contributions of Rocky River and the shore farther east to the Huntington Park area must be known before any accurate predictions of this type can be made. The more rapid erosion of the till and sand portion of the shoreline has caused the headland at Avon Point to become progressively more exposed to the full force of east, northeast, northwest, and west storms, so that this headland is becoming more and more susceptible to attack.

Certain findings from textural and mineralogical studies made by other workers have been further verified in this study. The author has found that some established criteria of current movements and methods of transport could not be used because the continual addition of material to the lake from a source continuous in extent throughout the study area masked any trend of size or mineralogical content of moving sediments. A very close association between lithology of the cliff and beach materials has been noted, however, and the amounts of sand present in a locality served as an interpretive aid. (See fig. 4-2 B) Supply appears to balance removal throughout most of the area, and this factor also greatly aided the investigation.

The statistical measures, by their very regularity, indicate that, in general, stable beach conditions for the area are best met by a material with a median diameter of about two phi. This is of importance in any consideration as to the type of sand to be used as beach fill (Krumbein, 1949, p. 29). Longshore currents in the area are probably weak because they seem unable to remove material with a phi median value of 2 as fast as it is supplied, in spite of the supply being fairly small.

It was found, too, that extreme caution must be used in predicting current movements on the basis of sand accumulating along a groin. Reflection of wave energy may vary with different directions of approach of storm waves.

In conclusion, it can be said that a sedimentation study in a cliffed area can be extremely complicated. Martens (1939, p. 210) states that on uneven rocky shores where beaches are small and discontinuous they are extremely variable both in texture and composition because of different sources of material and varying exposure to waves,
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Chapter 5

SEDIMENTARY PROCESSES ALONG LAKE ERIE SHORE, SANDUSKY BAY, VICINITY OF WILLOW POINT

By

Richard S. Bowman
INTRODUCTION

GENERAL STATEMENT

The erosion and submergence of Sandusky Bay have been studied for many years. However, few workers have investigated the processes involved in the removal, transportation, and deposition of clastic materials in Sandusky Bay. The writer has directed his attention toward such processes now active along a short strip of the southern shore of Sandusky Bay, west of Bay Bridge. (See figs. 2-1, 3-1 B)

This investigation has been a co-operative project of the Divisions of Beach Erosion and Geological Survey of the Ohio Department of Natural Resources, and the Department of Geology of the Ohio State University. The field work took place between June 27, 1951 and August 22, 1951.

THE PROBLEM

The purpose of the study has been as follows:

1. To investigate the sedimentary processes now active along the Willow Point shore and to determine the relation between these processes and shore erosion. This in turn required information on the following: a. The type and sources of sediment deposited along the Willow Point shore. b. The modes of transportation of sediment with special emphasis on currents acting within a half mile of the shoreline. c. The effects of offshore engineering structures upon the direction and rate of movement of waves and currents.

GEOGRAPHIC LOCATION OF WILLOW POINT AREA

Willow Point is the prominent projection of land located on the south shore of Sandusky Bay, Margaretta Township, Erie County, 4.2 miles west-southwest of Bay Bridge, Ohio (See fig. 5-1). The strip of shoreline referred to in this report as "the Willow Point area" extends from .74 miles east of Willow Point to 9.1 miles southwest of the Point (See fig. 5-1).

BRIEF GEOLOGICAL HISTORY OF SANDUSKY BAY

Sandusky Bay now occupies the lower part of the Sandusky River valley (Leverett, 1931, p. 101, 102). Following a regional uplift which occurred approximately 4,000 years ago (Leverett, 1931, p. 103), waters which formerly flowed eastward from Lakes Superior, Michigan, and Huron by way of the Ottawa River, moved southward into the Erie Basin. With an increase in drainage area, the water level of Lake Erie rose from approximately 560 feet to 573 feet above mean sea level. Because of the higher lake level, the lower Sandusky River valley was flooded, producing the present bay.

Gutenberg (1933, p. 449) states that "the Great Lakes region is tilting...due to forces which tend to restore isostatic equilibrium, disturbed by the melting of ice after the Ice Age." In Lake Erie, the western end is sinking relative to the eastern end. This tilting has, therefore, caused the Sandusky Bay area to submerge, the rate of submergence having been estimated at one-half to two feet per century (Gutenberg, 1933, p. 455; Moseley, 1905, p. 235).

PHYSIOGRAPHY OF SHORE WEST OF BAY BRIDGE

TOPOGRAPHY

The local relief is very low along the southern shore of Sandusky Bay. For the most part, the land surfaces rise three to eight feet above the present mean water level. There are, however, three major low, swampy areas bordering the southern shore;
Figure 5-1.
Willow Point Shoreline
Erie Co. Ohio
their central portions are 1.3, 4.1, and 7.9 miles southwest of Bay Bridge.

Willow Point is one of these low areas. South of the Willow Point shoreline, the land surface lies below the present bay level. The swamps in the area are used as duck marshes and have been channelled to allow small boats to move about.

CLAY CLIFFS

Shaffer (1951, p. 3) has observed that all of the low cliffs along the southern shore of Sandusky Bay in Townsend Township, Sandusky County, consist of glacial lake clays (See fig. 5-8). Deposits of this type are prevalent along most of the southern shore where low cliffs exist. Commonly, wave action wears back these cliffs, forming a series of scallops ranging from a few feet to hundreds of feet in length. During dry periods the upper surface of the lake clay develops a web of small joints, or cracks, which penetrate to an average depth of eight inches. Although the clay becomes very hard when dried, it is eroded easily by waves. The vertical jointed surface quickly sloughs off with slight undercutting of the cliff, thus maintaining a vertical face on the retreating cliff (See fig. 5-9).

SEDIMENT ALONG THE SHORE

Well developed beaches are not common along the southern shore of Sandusky Bay. Sediment now being deposited along the shore is generally restricted to the central concave portions of the scalloped shoreline. Small quantities of clastic material lie parallel to the shore, forming a type of pocket beach which is seldom wider than ten feet.

Beach samples collected both east and west of the area studied (See fig. 5-1) consist mostly of quartz, cinder and some shell material. Minor constituents include magnetite-ilmenite, garnet, hypersthene, amphibole, and silicate bead, the last to be discussed later in the report. The proportion by weight of carbonate material found in samples east and west of the Willow Point area ranges from 4.82 to 54.6 per cent. (Table 2). Neither a systematic variation nor a simple trend with respect to location, was apparent in percentage of carbonate found in these samples.

MARL AND TUF A

Marl and tufa (Pettijohn, 1949, p. 308) crop out along the Kruck shore and along the western side of Little Pickerel Creek (See fig. 5-1). The marl and tufa have nowhere been observed in the same vertical section at the same map locality, but they do exist at the same horizon, separated by lake clay.

Both the tufa and marl deposits are up to one foot thick where they lie above or below lake clays containing abundant shell material. Thin layers of peat with interbedded streaks of marl are found above the main stratum of marl. Tufa is discussed later as a source of shore material.

The marl contains many ostracods, but the writer has not yet attempted to use these organisms to determine the age of the deposit. The marl is a local deposit and, therefore, is not a continuation of the Castalia bog, although it may be of similar age.

METHODS USED

FIELD TECHNIQUES

Mapping

In the present investigation, the area has been field-mapped on a scale of one inch equals two hundred feet, using telescopic alidade and plane table. In the western part of the area, where swamp borders the bay and there is no beach material, the shoreline has been drawn at the edge of swamp vegetation. In such areas, the shoreline may fluctuate horizontally as much as sixty feet, with small order (6-10 inches) changes in water level.

Profiles

Three offshore profiles of the bay bottom have been surveyed perpendicular to the Willow Point shoreline (See fig. 5-1). The plane table was placed at a previously mapped shore station, with the alidade aimed offshore and perpendicular to the line of the water's edge. The lower end of the stadia rod was placed on the bay bottom along successive positions on the line of profile. The interval between stations on the line of profile was increased as the distance from the shore station increased. Profiles were taken to one thousand feet offshore.

Offshore profiles roughly parallel to the shore were mapped with the fathometer on the survey craft of the Lake Erie Geological Research Program.


Sediment sampling devices were of three types:

1. A gravity coring rig (modified after Emery-Dietz) with a Shelby seamless coring tube (1-1/2 inch LD.), was used for sampling clay off the Willow Point shore. The impelling mechanism is a surface-triggered 250-pound lead weight. The coring rig provides a sample which preserved the vertical sequence of many layers of sediment. 2. A check-valve sampler (Pincus, Roseboom, & Humphris, 1951). 3. A drive sampler, consisting of a one-foot piece of two-inch galvanized pipe with a cap over the upper end and a bevelled edge on the lower. (Pincus, Roseboom & Humphris, 1951).

**Current Study**

The direction and rate of movement of currents were studied by setting out free floats, the successive positions of which were determined by means of triangulating with sextants from two shore stations at known positions. Sextant shots were taken every five minutes for a period of two hours.

The float consists of a block of wood supporting four 6 x 6 inch fins which form an X shape pattern in plan view. Each block is cut in half vertically so that it can be bolted to a central wooden rod (1 x 1 inch) six feet long, at any one of five positions. The fin assembly, therefore, can be adjusted to a depth of one to five feet. Strips of lead sheeting are used as ballast on the bottom end, and colored flags are tacked to the upper end to identify the depth at which the fin assembly is operating.

For studying currents off Willow Point, the three groups of floats used were those with fins set at a depth of a, one foot; b, three feet; and c, five feet. By using these three float adjustments, currents at these three depths have been studied and compared. Each group consists of eight virtually identical floats which, when mapped as a unit, provide a picture of the "average" behavior of the current at the depth being studied.

**LABORATORY TECHNIQUES**

**General Statement**

The facilities of the Lake Erie Geological Research Laboratory were made available to the writer during the months of June, July, and August. Thus, the sample analyses were performed concurrently with the field work. For this reason, the writer was able to observe significant trends in sediment composition while collecting samples, and to plan an efficient field operation.

**Percentage of Tufa, Shell, and Insoluble Residues**

Some samples contain a large per cent of tufa and shell fragments. Percentage by volume and by weight have been determined in those samples high in tufa and shell materials. The analytical method used is as follows:

Weight and volume of the sample are determined, Shell fragments are then separated by hand from the tufa and insoluble residues. Weight and volume of shell fragments are then determined. Sample is then digested in hydrochloric acid, Weight and volume (by per cent) of insoluble residues (remaining sediment) are determined; these values are then subtracted from 100 to give the weight and volume (by per cent) of carbonate. Since the percentage of carbonate is taken as the sum of tufa and shell percentages, and shell percentage is known, the percentage of tufa is easily evaluated. (See Table 1 for analyses of samples.)

**Mechanical Analyses**

Sediment was shaken through 4.0, 2.0, 1.0, 0.5, 0.25, 0.125, and 0.064 mm. screens. The weight of sediment remaining in each of the screens was divided by the total weight of the sample in obtaining percentages for each class of grade sizes. (See Table 2 for analyses of samples)

**Elutriation**

Clay (finer than 0.064 mm.) samples collected in Sandusky Bay north of the Willow Point area are to be analyzed mechanically at a later date. The method to be used is that of elutriation by pipette.

**DAMAGE CAUSED BY EROSION ALONG WILLOW POINT SHORE**

**STATE SCHOOL LANDS**

The State School Land extends approximately 2,640 feet east and 2,070 feet west of Willow Point. The total extent of the shore, measured along a
TABLE I

ANALYSIS OF SHORE MATERIAL EAST AND WEST OF LITTLE PICKEREL CREEK

<table>
<thead>
<tr>
<th>No.</th>
<th>Tufa Shell</th>
<th>Insoluble Tufa Shell</th>
<th>Insoluble Percent</th>
<th>Distance &quot;A&quot; 1</th>
<th>Distance &quot;B&quot; 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% by wt.</td>
<td>% by wt.</td>
<td>% by vol.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>West</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>464</td>
<td>q</td>
<td>84.20</td>
<td>15.80</td>
<td>1.71</td>
<td>1.75</td>
</tr>
<tr>
<td>469</td>
<td>41.63</td>
<td>54.10</td>
<td>54.16</td>
<td>2.59</td>
<td>43.29</td>
</tr>
<tr>
<td></td>
<td>65.73</td>
<td>21.41</td>
<td>61.11</td>
<td>11.11</td>
<td>27.78</td>
</tr>
<tr>
<td>*72</td>
<td>83.94</td>
<td>13.90</td>
<td>79.16</td>
<td>4.16</td>
<td>16.66</td>
</tr>
<tr>
<td>441</td>
<td>79.20</td>
<td>5.49</td>
<td>72.00</td>
<td>12.00</td>
<td>16.00</td>
</tr>
<tr>
<td>468</td>
<td>32.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>462</td>
<td>88.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East</td>
<td>413</td>
<td>95.18</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Distance "A" - miles from previous sample in the direction towards Little Pickerel Creek.
2. Distance "B" - miles from mouth of Little Pickerel Creek.
* Sediment load - Little Pickerel Creek.

TABLE II

MECHANICAL ANALYSES

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Statistics in Millimeters</th>
<th>% Carbonate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.0</td>
<td>2.0</td>
</tr>
<tr>
<td>East</td>
<td></td>
<td></td>
</tr>
<tr>
<td>425</td>
<td>0.74</td>
<td>0.20</td>
</tr>
<tr>
<td>413</td>
<td>0.27</td>
<td>1.42</td>
</tr>
<tr>
<td>414</td>
<td>0.57</td>
<td>0.20</td>
</tr>
<tr>
<td>462</td>
<td>1.99</td>
<td>1.08</td>
</tr>
<tr>
<td>468</td>
<td>0.04</td>
<td>2.89</td>
</tr>
<tr>
<td>463</td>
<td>0.0</td>
<td>22.07</td>
</tr>
<tr>
<td>401</td>
<td>6.81</td>
<td>13.39</td>
</tr>
<tr>
<td>441</td>
<td>1.93</td>
<td>13.39</td>
</tr>
<tr>
<td>472</td>
<td>17.78</td>
<td>13.71</td>
</tr>
<tr>
<td>411</td>
<td>16.28</td>
<td>23.82</td>
</tr>
<tr>
<td>469</td>
<td>0.04</td>
<td>2.89</td>
</tr>
<tr>
<td>465</td>
<td>0.0</td>
<td>1.65</td>
</tr>
<tr>
<td>West</td>
<td></td>
<td></td>
</tr>
<tr>
<td>426</td>
<td>11.62</td>
<td>9.96</td>
</tr>
</tbody>
</table>
straight line, is about 5,280 feet (see fig. 5-1). Over a period of 125 years, erosion has reduced the original area of the School Land by some two hundred acres (F. O. Kugel, personal communication). Shoreline features east of Willow Point are quite different from shoreline features to the west of the point, although the entire shore is bordered by swampland. To the west of Willow Point, the shoreline has retreated landward much more rapidly than to the east. Along this stretch of badly eroded shore, no beach has been formed, although one hundred feet offshore sediment is moving parallel to the shoreline.

The projection at Willow Point is protecting the strip of shore to the east from waves moving toward the southeast. During northwest storms, wave action against the western shore is quite severe; to the east of Willow Point, the water is relatively quiet, especially near the beach. The reason for this phenomenon is that those waves striking the point from a northwestern direction pivot around the point and, in so doing, much of their energy is dissipated.

The beach to the east of Willow Point and all beaches in the area studied differ from the typical sand beach which lies at the foot of a rock cliff, clay bank, or even a sand dune: "beaches" in this area separate the swampland from Sandusky Bay and, therefore, are similar to offshore bars. A sedimentary deposit lying between two bodies of water is very easily attacked by erosional agents. For the most part, all beaches in the area are migrating landward in much the same manner as an offshore bar moving landward in the last stages of its cycle (see fig. 5-11). Waves quite often transport sediment over the highest beach crest, dumping this material into the backswamp. Continual transfer of sediment from the stoss offshore to the landward side of the beach causes a landward migration of beach material.

A striking shore feature to the east of the Point is a six-foot breach in the sand beach two hundred feet southeast of the inner wall. Water passing through this breach flows into and out of the backshore, depending upon the difference in water levels in the swamp and the bay. Since beaches in the area extend only a few feet above mean water level such a breach could have been developed during periods of high water.

**KRUCK PROPERTY**

**Location**

The Kruck shoreline extends from the west side of the mouth of Little Pickerel Creek to approximately 915 feet to the west. The total length of shoreline, measured along a straight line, is about 1,050 feet (see figs. 5-1, 2).

**Description of Shoreline**

The Kruck shoreline contains two small beaches, each of which lies in a small embayment. The beaches are nowhere wider than twenty-five feet. In the western part of the property, a main northeast-southwest channel connects channels a few hundred feet inland with Sandusky Bay. Small deposits of clastic material are also present on the west side of the main channel.

An offshore profile, taken perpendicular to the shoreline, shows that the bottom surface slopes gently away from the shore, becoming nearly flat eight hundred feet from the shore (see fig. 5-1, section A-A'). The vertical exaggeration on section A-A' is ten times. The water level at the time the profile was taken was 573.8 feet above mean sea level. Offshore samples consist mostly of plastic tan to gray laminated lacustrine clays.

Marl and tufa also crop out along the shore, as mentioned previously (see fig. 5-2). At present, these deposits lie 1-1/2 feet below the mean summer bay level of 573.8 feet above mean sea level. Both the marl and tufa offer less resistance to wave attack than the overlying and underlying clay. For this reason, these deposits are removed rapidly, causing undercutting of the overlying clay which is then carried into the bay.

**Increase in Water Level and Wave Action**

The water level of Lake Erie has risen an average of two feet above mean water level during 1949 (chart by Corps of Army Engineers, Cat. No. 1000). This increase has undoubtedly increased the rate of shoreline retreat due to erosion all along the southern shore of the bay. Shoreline retreat is caused by 1. erosion and 2. submergence resulting chiefly from
Figure 5-2. Block diagram showing erosion of tufa and marl along the Kruck shore, and some typical sections.
increases in water levels. In a low area such as Willow Point, submergence generally has greater effect upon shoreline retreat during a short period of time than in areas where clay cliffs border the bay. At many places along the Willow Point shore, the water's edge has advanced eighty feet due to the rise of two feet in mean water level. 

There is, however, one strip of shoreline in the Willow Point area in which the rise in water level has been especially significant in aiding the erosional processes. This strip of shore is located along the eastern part of the Kruck property. The factors contributing to this increase in shore retreat are (1) existence of tufa and marl along the Kruck shore and the vertical position of these deposits relative to present mean bay level, (2) the susceptibility of this marl and tufa to erosion by wave action, and (3) the present water level during north-western storms. The combined effect of these relations upon shore retreat is as follows:

Winds from the northwest inflict more erosional damage upon the Kruck shore than do winds from the northeast (See section on meteorological data). During severe northwestern storms, the water level of Sandusky Bay drops as much as 1-1/2 feet. Since the present bay level is nearly 574 feet above mean sea level, a drop of 1-1/2 feet places the water line midway between the top and bottom of the stratum of marl and tufa, thus allowing waves from the northeast to attack these soft deposits (See fig. 5-2).

Prior to 1943, northwest storms and the subsequent lowering in bay level would leave the water level two feet below the marl and tufa. Waves then beat against lake clays which are much more resistant to wave action.

It might be argued that prior to 1943, storms from the northeast and the accompanying rise in water level could have had an effect on the Kruck shore similar to that produced by northwestern storms today. The writer has observed that Willow Point not only protects the eastern shore of the area from northwestern storms but, in like fashion, it protects the western part of the School Lands and the Kruck shore from the destructive effects of northeastern winds. Waves traveling from the northeast have expended much of their energy before reaching the Kruck shore, and therefore inflict only minor damage on the shore.

**Currents**

According to soundings taken in Sandusky Bay (files of the Lake Erie Geological Research Program), depths are seldom greater than ten feet. In such shallow water, and especially near shore, surface and most subsurface currents apparently move in the direction of wind. One exception, however, occurs when water is moving in or out of the bay during high winds from the northeast or northwest respectively; this flow is reversed after the high winds have died down. During such periods, the direction of subsurface currents may be largely independent of wind direction.

Currents at one, three, and five foot depths were studied north of the Kruck shore following a northwest storm. Wind was from the north-northwest traveling at a velocity of ten to fourteen miles per hour. Water at all depths was moving slowly to the south and, therefore, generally parallel to the direction of wave propagation (See fig. 5-1). All other studies made in the area showed similar behavior of the currents.

Referring to the path of floats shown on figure 5-1, it is interesting to note the manner in which the three and five-foot floats suddenly changed their direction of movement. A possible explanation for the break in their paths is as follows:

Since the floats were set out following a severe storm from the northwest, water was moving back into the bay producing a westward moving current. The floats traveled in a direction essentially parallel to the direction (south-southeast) of wave and wind motion while on the west side of the outer wall. The wall functioned as a protector from the westward moving currents. Upon reaching a position south of a line drawn through the wall, the floats were carried to the west for a short distance by a current moving around the western end of the south side of the wall. This current appears to have behaved like a stream rather than a sheet. The current affected the five-foot floats the most; the surface floats were only slightly deflected. Over the greater part of the track, however, the direction of float movement (all three depths) was nearly parallel to the direction of wave propagation.

**EAKEN PROPERTY**

**General Statement**

The Eaken property borders the Kruck property on the west. The shore extends 350 feet beyond the westernmost part of the area mapped. The relief is low, much swampy land bordering the bay.

Clastic shore material is more abundant than
along the Kruck shore, but does not form as extensive a beach as that which lies east of Willow Point. Beach material is migrating southward into the swamp (See figure 5-11).

**OFFSHORE SEDIMENTARY PROCESSES**

**GENERAL STATEMENT**

The principal distinguishing characteristic of shore sediment immediately east and west of Willow Point is the abundance of tufa stems, which are restricted to the area studied. Tufa pebbles, however, occur not only at Willow Point but also as a part of the shore material to the east.

Analyses of beach samples taken a few hundred feet west of Little Pickerel Creek have an average composition of 70 per cent tufa, 7 per cent shell, and 23 per cent insoluble residue (See fig. 5-3). It should be noted that in analysing the samples, "tufa" means here all calcareous material other than shell. The actual percentage of tufa stem material is not definitely known to be greater to the east of the Point, but rather the total percentage of calcareous rock material increases.

**SOURCE AND TRANSPORTATION OF SEDIMENT**

The source of tufa stems is located along the Kruck shore and the west bank of Little Pickerel Creek between Wahl road and Sandusky Bay (See fig. 5-1). The deposit of tufa, cropping out along the Kruck shoreline, furnishes about 70 per cent of all clastic material composing the beaches along the Kruck and Eaken shore. Although tufa from the Kruck shore and Little Pickerel Creek are indistinguishable from each other, it is unlikely that much of the tufa from the Kruck shore is transported east of Willow Point, since the Kruck deposit is very small.

A large quantity of tufaceous sediment washed into Little Pickerel Creek from its western banks appears to be moving eastward upon entering the bay, being deposited along the eastern shore of the State School Lands (See fig. 5-1 for path of transport & fig. 5-3 for abundance). The transporting agent is probably a current which moves eastward during western and northwestern storms.

Figure 5-17 shows the character of samples taken east and west of Little Pickerel Creek. Since most of the coarse material (other than shell) in these

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**Figure 5-3.** Percentage relations of tufa, shell, and insoluble residue in samples collected east and west of Little Pickerel Creek.
samples consists of eightier tufa stems or pebbles, and since the writer has observed no outcrops of tufa other than those along the Kruck shore and Little Pickerel Creek, it is assumed that much of the coarse sediment in these samples comes from either Kruck property or Little Pickerel Creek. In view of this, it is interesting to note the decrease in grain size east and west of Little Pickerel Creek (Table 1).

The source of most of the tufa pebbles and cobbles deposited along the shore east of Willow Point is Little Pickerel Creek. The stream is fed by a spring located 1.8 miles west-southwest of Castalia, Ohio. The waters feeding the stream contain considerable dissolved calcium bicarbonate. With evaporation or rise in temperature, calcium carbonate is precipitated upon plants and elastic material present in the stream channel.

Samples 458 and 459, taken at the intersection of Little Pickerel Creek and Route 12, consist largely of carbonate pebbles ranging from .25 to 2 inches in diameter. Tufa pebbles can be distinguished from other carbonate pebbles by their "grape-like" surface. Tufa pebbles are also commonly pitted on the surface.

The path of transport of tufa pebbles is shown on figure 5-1. By sampling the offshore bottom this path has been determined by measuring the position and width of the tufa deposit. The sampling showed that tufa stems and pebbles are restricted to a narrow band running parallel to the western shoreline of the State School Lands. This band of sediment becomes wider east of Willow Point.

A possible reason for this sediment spreading laterally east of the Point is that the transporting agent (probably current), having passed Willow Point, continues in an eastward direction thus carrying the sediment farther from shore. Waves from the north-northwest, north, and northeast spread the sediment landward, depositing it on the beach.

SILICATE BEAD

For the past five years, the glasswool plant located on the north shore of Sandusky Bay at Gypsum, Ohio (See fig. 5-1) has been dumping waste material into Sandusky Bay. Part of this waste consists of an artificial bead which has been observed in every beach sample collected along the southern shore of the bay. The bead is a calcium silicate (personal communication, chief chemist of the glasswool plant) having a hardness and specific gravity slightly less than that of quartz. The size range is between 4.0 mm and 0.064 mm, diameter. The shape of the bead ranges from splinter to perfect sphere. The greatest inferred distance of transport is 5.9 miles. The writer has not investigated the path of transport but wishes to stress that sediment is being transported from the north shore to the south shore of Sandusky Bay. The exact mode of transport is unknown.

THE EFFECTIVENESS OF STRUCTURES

GENERAL STATEMENT

There are three principal offshore structures in the area studied. All are constructed of quarry run stone consisting chiefly of limestone and dolomite (See fig. 5-16). The following discussion will be limited to the present inferred effects of each upon sedimentary processes.

EFFECT OF OUTER WALL

The outer wall lies about 2,000 feet northwest of Willow Point on the site of the shoreline of 125 years ago (See fig. 5-1). The wall was constructed (1945) in an attempt to reclaim part of the original land of the State School Lands, a purpose which has yet to be fulfilled. Since its construction, the wall has settled until today water covers much of the uppermost portion. The wall rests on lake clay.

The outer wall has little effect upon the Willow Point shore. Waves pass over the wall very easily and, therefore, lose little or none of their energy.

It has been suggested that during northwestern storms the outer wall creates or deflects currents which inflict considerable damage upon the Kruck shore. The writer has thoroughly investigated this possibility and finds no evidence to support this suggestion. The writer submits the following relevant evidence gathered in his work in this area.

1. On August 21, 1951, during a 30 to 35 m.p.h. wind from the northwest, waves coming from the northwest retained their alignment and direction of movement after passing over the outer wall. If the velocity of any part of the wave front had been decreased, the wave front would have been bent instead of remaining linear.

2. On August 21, 1951, waves were moving southeastward with a velocity of 2-3/4 m.p.h. If a current were forming at the western limb of the wall and moving to the Kruck shore, it would have to move at an angle of 45° with the direction of wave propagation for a distance of approximately 1,900 feet. It seems
very unlikely that such a current could be maintained for this distance, considering the direction and rate of movement of the waves.

If a mass of water eddied between the outer wall and the jetty to create a current causing damage to the Kruck shore, then the path of the current in this area would have to be maintained for a distance of 1,600 feet, making an angle of $70^\circ$ with the direction of wave propagation.

3. If a current were strong enough to overcome the effects of wave motion and still inflict damage upon the Kruck shore, it seems reasonable that such a current would scour out a shallow northeast-southwest channel along the shoreline. The offshore profile taken perpendicular to the Kruck shoreline shows no channel, but rather a gentle uniform slop (section A-A' on fig. 5-1). Short cores of sediment, collected with a check-valve sampler along the Kruck shore, show that the clay bottom is not covered with more than two inches of tufaceous sediment. Therefore, the possibility of obscuring such a channel by filling with sediment during periods of calm water is eliminated.

4. As mentioned before, current studies in the area indicate that subsurface as well as surface currents deviate very little from the direction of wave propagation. During periods of higher wind, the likelihood of such deviation decreases under shallow water conditions, because the depth of the surface current increases to include the entire depth of the water. During northwest storms, the water level is lowered, thereby decreasing the depth of water between the Kruck shore and the outer wall.

**EFFECT OF THE JETTY**

A 305-foot jetty extends north of the mouth of Little Pickerel Creek (See figs. 5-1, 15). The fronts of southeasterly moving waves, upon striking the north end of the jetty, pivot clockwise through an arc of $45^\circ$. As the waves pivot about the north end of the jetty, they lose much of their energy. Figure 5-15 shows smooth water to the east of the jetty. The shore immediately east of the jetty is, therefore, protected from northwest storms.

**INNER WALL**

A nearshore wall has been constructed extending from the western end of the State School Land eastward around Willow Point (See fig. 5-16). Since waves do not pass over the inner wall during storm periods, it provides effective protection for the western shore and the northern point of the State property.

**METEOROLOGICAL DATA**

**GENERAL STATEMENT**

The energy in water waves is derived from wind. In a body of water the size of Sandusky Bay, the water's surface can be quickly whipped into a mass of heaving whitecaps by a sudden increase in wind velocity. For this reason, meteorological events have considerable influence upon sedimentary processes, and deserve special treatment in the present discussion.

The erosional effect wind may have upon the southshore of Sandusky Bay depends upon (1) wind velocity, (2) frequency of high speed winds, (3) fetch, (4) resistance of shoreline with respect to wind direction, and (5) orientation of shoreline with respect to wind direction. The relative importance of these factors may differ along strips of shore a short distance apart.

**PREVAILING AND FAST MILE WINDS**

The writer has prepared several figures relating to prevailing and fast mile winds (i.e., these winds attaining the greatest velocity over a period of twenty-four hours) from the northeast and northwest, occurring at Sandusky, Ohio (See figs. 5-4 thru 5-7).

Northeast and northwest winds were selected because (1) strong northwest winds cause a lowering of the bay level which is quite significant in aiding erosion along the Kruck shore, and (2) although north, east, and west winds may also be important as an erosional agent acting upon the Willow Point shore, the writer has observed more pronounced erosion accompanying northwest and northeast winds.

The following relationships between northeastern and northwestern winds have been compiled for the individual years 1948, 1949, 1950, and 1951:

1. For both prevailing and fast mile winds, northeastern winds occur over a larger percentage of time (the per cent of the total number of days in which the wind blew from the northeast or northwest, for a period of one year) than do winds from the northwest.

2. The prevailing winds, the average velocities (the yearly average of daily average wind speed) of northeastern and northwestern winds are nearly equal,
Figure 5-4. Prevailing and fast mile winds, Sandusky Bay, Ohio, 1948.
Figure 5-5. Prevailing and fast mile winds, Sandusky Bay Ohio, 1949.
Figure 5-6. Prevailing and fast mile winds, Sandusky Bay, Ohio, 1950.

**KEY**

- **15-20 MPH**
- **10-15 MPH**
- **0-10 MPH**
Figure 5-7. Prevailing and fast mile winds, Sandusky Bay, Ohio, 1951.
Average wind velocities from the northwest are always slightly greater. The maximum difference in average velocity for a period of one year is 1.08 m.p.h.

3. The average velocity of fast mile winds from the northwest is always greater than that for northeast by an appreciable amount. The maximum difference in average velocity for a period of one year is 8.0 m.p.h.

**REASONS FOR WIND RELATIONSHIPS**

Bodies of water often influence the path of moving air. In the Lake Erie region, winds from the north are often converted to north-eastern winds upon reaching the Lake Erie Basin. It is believed that wind over water has lower contact friction than wind over land; therefore, Lake Erie acts as a channel guiding winds along its northeast-southwest axis into Sandusky Bay, the long axis of which lies essentially parallel to that of Lake Erie. In a given period, therefore, both prevailing and fast mile winds from the northeast occur over a larger percentage of the time than do winds from the northwest.

During the winter months, nearly all winds from the northeast and northwest are gradient winds (caused by air moving from a high to low pressure area); however, during the summer about 75 per cent of all winds from the northeast are thermo winds (winds resulting from cold air, over Lake Erie, replacing warm air to the southwest). Most north-western winds, on the other hand, continue to be gradient winds throughout the summer months. Gradient winds, except in extreme cases, are faster moving winds than thermo-type winds. The yearly average velocity of northeastern winds is, therefore, slightly greater than that for northeastern winds.

The difference becomes even more pronounced for fast mile winds which are frequently from the northeast and northwest between April and October.

The velocity of wind at Sandusky occasionally differs from that at Bay Bridge during a short period of time. Although, at times, this difference in wind speed and direction is great, usually the difference of wind motion at Sandusky and Bay Bridge is small. The writer assumes that the above relationships, computed on the basis of meteorological data recorded at Sandusky, holds also for Sandusky Bay west of Bay Bridge.

**CONCLUSIONS**

The reasons for the retreat of the southern shore of Sandusky Bay (related to sedimentary processes) are as follows:

1. Present water stage; the mean water level in Sandusky Bay has risen two feet since 1943, at which time the mean water level was 572 feet above mean sea level. Since some of the land along the south shore of Sandusky Bay is very low (572-573 feet above mean sea level) with respect to mean lake level, encroachments by the water on the land are large during periods of high water level.

2. Shore material: a larger part of the Sandusky Bay shoreline consists of low cliffs composed of lake clays and till. These cliffs are worn back much more rapidly than bedrock cliffs. Since there is little shore sediment present, these cliffs are continually exposed to wave action.

3. Effects of wind phenomena; severe northeast winds cause water to pile up at the western end of Lake Erie and in Sandusky Bay. This rise in the water level allows waves to erode the shore more effectively. Northwestern storms cause water to flow out of Sandusky Bay. This lowering of the water level permits waves to strike directly against certain soft beds cropping out along parts of the southern shore of Sandusky Bay (See fig. 5–2).

4. Tilting of the Lake Erie Basin: the eastern end of Lake Erie is rising relative to the western end. Sandusky Bay, therefore, is in a submerging area, a condition in which the shoreline will continue to retreat landward.

The rate of erosion along the shore of Sandusky Bay can probably be decreased by devices which protect the shore from erosional agents; however, a thorough understanding of sedimentary processes is essential in constructing and locating these protective structures. It is hoped that the investigation of sedimentary processes occurring in Sandusky Bay will continue in order that more effective shore protective measures can be taken.
Figure 5-8. View from the northeast corner of Townsend Township, Sandusky County, looking west, showing a clay cliff recently undercut.

Figure 5-9. View from the northwest corner of Section 4, Townsend Township, Sandusky County, looking east, showing vertical clay cliffs after top layer had sloughed off.

Figure 5-10. View from the east end of the State shore looking east, showing the beach deposits located along the eastern part of Willow Point shore.

Figure 5-11. View from the Eaken shore looking east, showing "beach" deposits which are migrating southward into the back-swamp.
Figure 5-12. View from Sandusky Bay looking southwest, showing the shore along the Kruck property.

Figure 5-13. View from Wahl Road (0.4 miles south of Sandusky Bay) looking north, showing Little Pickerel Creek when bay level was 574 feet above mean sea level.

Figure 5-14. View from Wahl Road (0.4 miles south of Sandusky Bay) looking north, showing Little Pickerel Creek when bay level was 572.8 feet above mean sea level. (Taken August 21, 1951)

Figure 5-15. View from east side of the mouth of Little Pickerel Creek looking north, showing a 305-foot jetty extending perpendicular to the shore. Photographed during a northwest storm. Note the difference in character of water surface on either side of the wall.
Figure 5-16. View from the inner wall along State shore (west of Willow Point) looking southwest. Notice the difference in the character of water surface on either side of the wall.

Figure 5-17. Samples collected east and west of Little Pickerel Creek. Refer to figure 5-1 for the location of samples by number. Notice the decrease in grain size east and west of Little Pickerel Creek.
Gutenberg, G., (1933), Tilting Due to Glacial Melting, Jour. Geol., 41, p. 449-467.


