CHAPTER 8

THE MOTION OF SEDIMENT ALONG THE SOUTH SHORE OF LAKE ERIE

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INTRODUCTION

Much of Lake Erie's southern shoreline displays fairly uniform properties with respect to shore processes. However, detailed studies of selected strips of shore areas often reveal characteristics which are so distinctive that problems of control require special attention to local characteristics.

The purpose of this paper is to present some generalizations and some detailed comments on the motion of sediment along the south shore of Lake Erie, to outline the results of some detailed studies of small areas, and to evaluate the types of evidence used in such studies.

The term "motion of sediment", can be assigned several distinctive meanings, each meaning being fixed by the type of evidence used in inferring motion and, where possible, direction and rate. Certainly, "motion of sediment" has one meaning when inferred from long period accretion patterns, another meaning when inferred from systematic variations along the shoreline in grain size or mineralogy, and still another meaning when inferred from observations of beach drifting for a few hours. The phrase, "along the shore", as used in this context, is taken to mean any (inferred) motion, which has a longshore component, whether that motion applies to an individual particle or to groups of particles, to net displacement or to total displacement, for any specified time interval, within any specified area. Obviously, understanding of movement along the shore requires also consideration of normal components, therefore one considers also motion into and out of offshore areas, and landward movement of barrier beaches.

The effectiveness of ice as a longshore transporting agent is not here considered. On the basis of observations of ice action in several of the study areas, it is not believed that a serious error is committed by allowing this omission here.

Wind may be an effective transporting agent locally, but its total importance as such is believed to be insignificant.

In fact, wind or ice may obliterate or distort evidences of movement by water.

Comparisons of inferences drawn from several sources point up the possible differences in conclusions based upon evidence from the several sources.

THE PHYSICAL SETTING

BEDROCK GEOLOGY

From Sandusky eastward, the southern shore of Lake Erie is underlain by non-resistant rocks, mostly shales, of Devonian age; west of Sandusky, the shoreline is underlain by resistant limestones and dolomites of Silurian age (Fig. 1,2).

The lake is shallower in the western end than it is in the central and eastern portions, possibly because of differences in the resistance of the bedrock to glacial scour. The easternmost part of the basin is also the deepest, possibly because here the non-resistant rocks dip more steeply than the equivalent rocks underlying the central basin to the west; this steeper dip would have presented a greater vertical thickness of weak rock for excavation by the southwestward moving ice tongue (Carman, 1946).

Only a small fraction of the shoreline is bedrock. Bedrock is exposed along 34 miles of Ohio's 184 miles of shoreline; resistant rocks account for 11 of the 34 miles (White and Gould, 1945).

Bedrock is exposed on the lake bottom in many places, especially in the western end, where the relatively resistant Silurian dolomites and limestones appear at the surface at Catawba, Marblehead, and on the islands. So-called "reefs", which provide excellent sport fishing, are lake bottom exposures of these rocks. Shales are frequently exposed farther east, but the relief of these exposures is quite low.

The types of bedrock exposed along the shore and underwater contain, in general, very little material in the beach-building size range.

UNCONSOLIDATED SHORE MATERIALS

While the Lake Erie basin appears to have been the site of excavation by ice, many of the features of the southern shore, especially in the central and western portions, are glacial or glacial lake deposits.

Boulder Clays

Much of the bluff material is unstratified glacial drift, usually a tough boulder clay, containing mixtures of local and foreign debris. A large variety of rock types is represented in the larger fragments of these till mixtures, accounting, at least in part, for the heterogeneous assemblages of minerals commonly found in beach deposits.

The fresh boulder clay, typically blue to gray, has been oxidized to a yellowish color from the top to depths exceeding ten feet, in some areas. Possibly ten percent of the boulder clay is potential beach material, therefore considerable erosion of the bluffs is required to produce appreciable amounts of beach-building sediments. The 40-65' high bluffs from Cleveland to the Pennsylvania border are cited here as an example of the boulder clay deposits in Ohio.

The till bluffs are attacked by waves, slaking, frost action, rain wash, ice push, and sapping.

Glacial Lake Deposits

Some of the lakes preceding Lake Erie have left their mark in the form of lake bottom deposits and ancient beach ridges.

The lake bottom deposits are often found lying upon the boulder clay. In other places, where the shore relief is low, only the old lake deposits are under wave attack.

Such a stretch of low shoreline runs along the western part of the lake, in Lucas and Ottawa Counties, Ohio. Here, some areas are so low that marshes front on the lake, with barrier beaches intermittently marking their lakeward edges.

These deposits, typically silty clays, and usually patchy blue-gray and brown, contain so little sand size material that their contribution to the supply of beach material can be disregarded.

Old beach ridges mark the margins of earlier higher lakes formed as the water level rose and fell with changes in the lake's outlet during its complex history. Some of their sandy constituents may be contributed to the lake by streams cutting through the ridges, and, in time, by wave attack. The total contribution of such materials at the present time is believed to be very small (Kleinhampl, 1952).

EXAMPLES OF SHORE MATERIALS

Some of the types of shore materials observed are illustrated in Figs. 4, 8, 9, 11, 15, 17, and 19.

TOPOGRAPHY

The southern shore of the lake, for the great part of its length, lies between flat surfaces: landward, glacial deposits and the beds of the higher predecessors of the modern lake present a smooth topography, usually sloping gently to the north; lakeward, the bottom generally drops very gradually toward the lake's center, rising again gradually toward the Canadian side. The bottom relief is very gentle, regardless of the type of bottom material; bedrock bottoms are occasionally slightly irregular.

In almost any profile cutting the landward plains and the lake bottom, the zone of maximum relief is the narrow shore area, in which the bluffs join the landward and lakeward surfaces. Changes in relief along the shoreline are usually very gradual.

The shoreline displays some conspicuous signs of submergence, as for example, the flooded embayment at Sandusky. Moore (1948) has presented quantitative evidence indicating submergence of Lake Erie's shores with respect to the lake's outlet.

Some areas, particularly those west of Port Clinton, where the bottoms of older, higher lakes now make up the shore, show the effects of recent submergence superimposed upon the earlier emergence.

Aspects of the topography well worth noting are the orientation and regularity of the shoreline. The orientation is particularly important when considered in connection with wind data and directions of large fetch. At Ceylon Junction, approximately 12 miles southeast along the shore from the Cedar Point jetty, the general trend of the shore changes quite markedly: to the west, the shore trends generally northwest, and to the east, it trends generally northeast.

Irregularities in the shore arise from such factors as the submergence mentioned earlier, exposure of relatively resistant rock, as at Catawba, and large-scale deposition, as at Presque Isle Peninsula, Erie, Pennsylvania.

DRAINAGE

Most of the water in Lake Erie comes from the upper lakes, through the Detroit River; only 12% of the water comes from the lake's drainage basin (Moore, 1946).

Apparently, tributary streams contribute little beach material. Some of the streams transporting sand size materials are used for commercial navigation; harbor areas are generally enclosed in such a way that upstream materials settle out in the harbor basin, not reaching the lake proper. The dredging of channels may place some of these materials into the general longshore circulation.

UNCONSOLIDATED BOTTOM DEPOSITS

Most of the lake areas studied to date are floored with clays and silty clays much like those found in the bottom deposits of the older, higher lakes. Many of the deposits in deeper water have apparently settled out of suspension very slowly, forming quite uniform layers.

Large areas of sand and gravel on the lake bottom are not common. The large Lorain-Vermilion sand and gravel area (7x10 miles) lying 6 miles and more northwest of Lorain, consists of relatively poorly sorted material, probably of glacial origin. Probing operations by the Lake Erie Geological Research Program have revealed thicknesses of 8 and 10 feet in some places. This deposit does not appear to be directly connected in any way with shoreline sand deposits in the Lorain and Vermilion areas. Exploration as far north as the International Boundary has revealed similar coarse materials, but the detailed distribution on the lake bottom is not yet known.

Other large sand deposits, like those in outer Sandusky Bay and off the west Fairport breakwater (4x10 miles), are well sorted and apparently continuous with nearshore and shore deposits. The outer Sandusky Bay deposits have been probed to depths of over 20 feet by the Lake Erie Geological Research Program.

Peaty and mucky bottom deposits often lie offshore from marshy areas. Off Magee Marsh, 18 miles east of Toledo, the barrier beach is migrating landward, exposing old marsh deposits on its lakeward side. Such deposits provide no beach building materials, except, perhaps, for small accumulations of sand blown or washed into the ancient marsh in which the materials were formed.

METEOROLOGICAL FACTORS

Southwest winds prevail in the Lake Erie Basin. However, there are sufficient west, northwest and northeast storms to utilize large fetches, thereby producing waves (Saville, 1953) capable of causing much shore damage and longshore, lakeward, and landward transportation of sediment.

Transient changes in lake level produced by pressure gradients or wind stress frequently bring vulnerable shore materials under the attack of large waves, operating over an offshore profile which dissipates very little of the wave energy.

The seasonal variation in lake levels is usually between one and two feet, the highest and lowest levels occuring in June and February, respectively. The average level for the period 1860-1952 is 572.31 feet above mean tide at New York City. The difference between the highest one-month average (574.60', April 1952) and the lowest one-month average (569.43', February 1936) is 5.17' (Saville, 1953).

GENERAL COMMENTS ON SHORE PROCESSES

The combination of wind directions, available fetches, and shoreline trends apparently add up to net generalized littoral drifts which flow to the west and to the east for given wind directions from neutral points whose positions vary with the wind directions. Neutral points have been reported (House Doc. No. 32, 83d,, Congress, 1st Session, 1953; House Doc. No. 220, 79th Cong., 1st Session, 1946) at, or in the general vicinity of the previously mentioned break in the main trends of the shoreline, viz., Ceylon Junction.

Shore materials, whether consolidated or unconsolidated, are generally very poor sources of potential beach materials. The boulder clays are usually the most prolific sources, but they are usually made up of no more than 10% of potential beach materials. Occasionally, as in the Cedar Point area (Metter 1952), beach materials may be exposed on the lake bottom as an active modern beach moves landward; or, suitable materials from older lake deposits may be exposed in shore bluffs, providing localized shoreline sources of material (Kleinhampl, 1952).

Large offshore deposits apparently must be ruled out as sources of beach materials because there is little evidence to indicate that they are contributing appreciably to nearshore and shoreline deposits.

The generalized picture of littoral drift is based upon availability of energy from different sources (Saville, 1953), and upon patterns of accretion (usually with respect to structures) and erosion, recorded over periods large enough to minimize the effects of seasonal and apparently random fluctuations.

COMMENTS ON SELECTED STRIPS OF SHORELINE

INTRODUCTION

Brief discussions follow of some of the significant features of selected areas studied by the personnel of the Lake Erie Geological Research Program. These discussions are set in the larger framework of the very competent reports prepared by the U. S. Army Corps of Engineers for publication as Congressional documents on the subject of beach erosion control.

SELECTED AREAS

Magee Marsh, Eastern Lucas County, Ohio (Fig. 2)

A westward littoral drift along the barrier beach fronting Magee Marsh (State property 18 miles east of Toledo) is reported by Savoy (1953, p. 26). The evidence upon which this statement is based is the westward migration of the mouths of two creeks flanking the study area, accretion on the eastern side of structures, and a pattern of bay filling.

Some accretion patterns have indicated movement from the west, but these have been only short period reversals of the dominant trend.

The source of beach materials is apparently the line of till bluffs to the southeast. Littoral drift may actually be depleting the Magee area, and depositing material to the northwest against structures on private property.

The barrier beach is migrating slowly landward, exposing peaty and mucky deposits in various places offshore.

The sand stream moving northwest is very lean, possibly because of damming by several structures to the southeast.

Savoy's determinations of drift are in general agreement with those reported in House Document No. 177, 79th Congress, 1st Session (1945). This document, which also presents additional details on drift between the Ohio-Michigan line and Marblehead, Ohio, utilizes patterns of accretion as the principal evidence for detecting littoral drift. Somewhat east of Magee Marsh, slight eastward drifts are indicated, but the movement here is possibly better classified as "variable". Movement of dunes is reported to be insignificant in this area.

Lee's (1953, Fig. 1) map shows a southeastward drift in the area just northwest of Magee Marsh; this apparently conflicts with the information given in the preceding paragraphs.

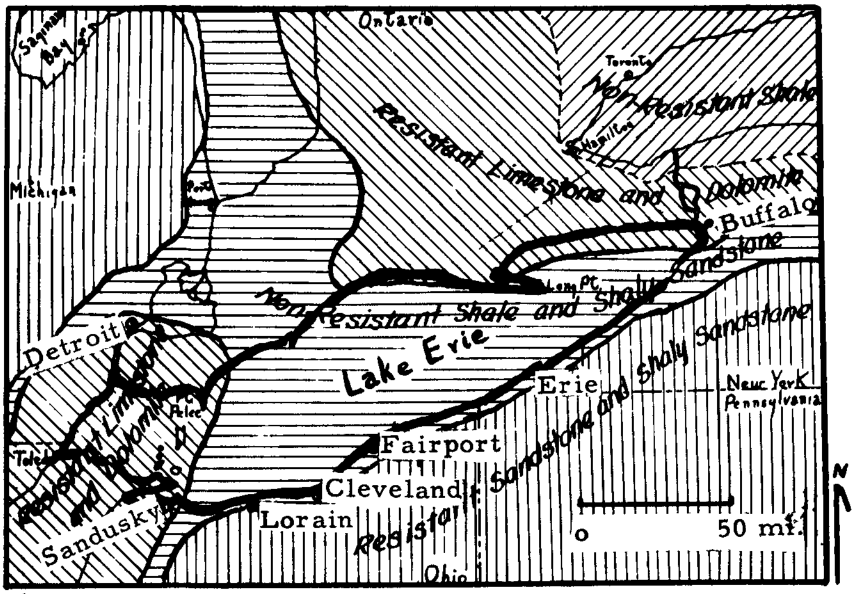

Fig. 1. Map of Lake Erie region, showing the distribution of resistant and non-resistant types of bedrock. From Carman (1946).

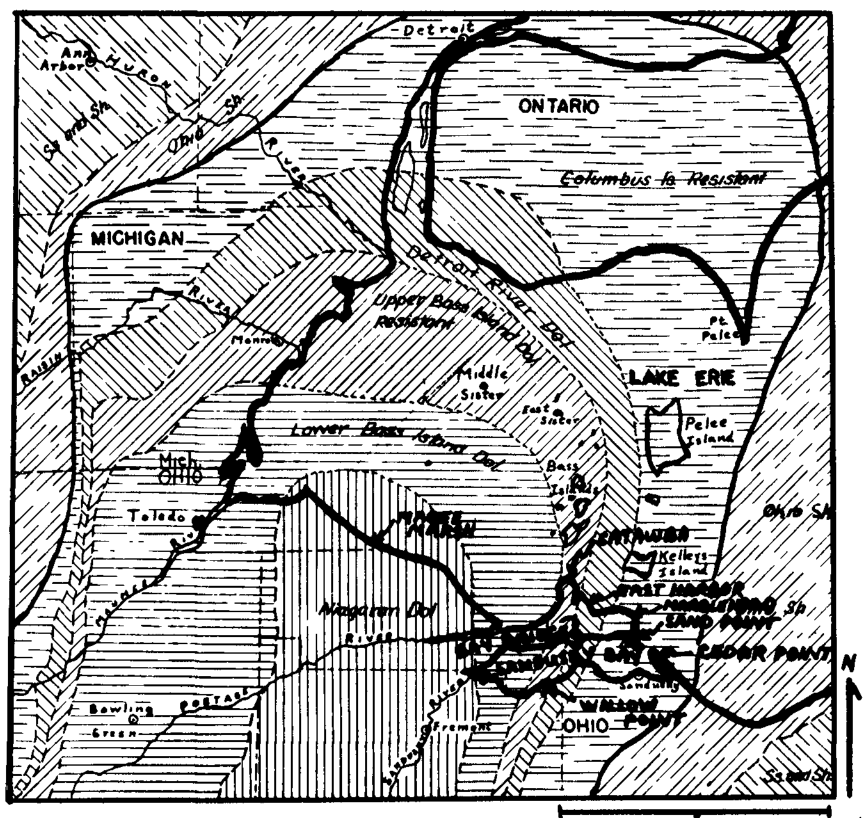

Fig. 2. Geologic map of the western end of Lake Erie, showing the arcuate pattern of the rocks. Study areas are shown in heavily inked letters. Geology from Carman (1946).

East Harbor Beach, Ottawa County, Ohio (Fig. 2)

Mechanical, mineralogical, and carbonate analyses of samples collected on a 1950 reconnaissance of the East Harbor Beach fail to show significant systematic variations which might yield some inferences about motion of sediment along this strip (Pincus, Roseboom and Humphris, 1951).

The Congressional document (1945) previously cited notes that just northwest of the East Harbor Beach, motion toward the southeast is indicated by the drifting of sand southeast across the mouth of West Harbor; east of West Harbor, indications of movement are nil. This report's historical work shows that progression of the shoreline in this area has been accompanied by a general deepening in offshore areas.

Although some of the dunes in this area are over 10' high, abundant plant cover has apparently reduced dune drift to zero.

Thus, the available data on longshore drift in this area, as derived from two types of evidence, i.e., accretion patterns and sedimentary analyses, yield equally inconclusive results. This is not equivalent to saying that the two types of evidence support each other.

Marblehead to Sand Point to Bay Bridge, Northern Sandusky Bay, Ottawa County, Ohio (Fig. 2,3)

Sand Point is a compound spit, growing southeastward (Humphris, 1952). Beach ridges along the eastern shore, near the southern tip of the spit, attest to the persistence of this growth pattern for some time. From Marblehead Lighthouse to the base of the spit, the shore is divided into three parts: 1. the northern third consists of bedrock (Columbus limestone) and limestone cobble beaches; 2. the central third has been covered with protective structures; 3. the southern third consists of till, with some limestone cobble and pebble beaches. Most of the north shore of Sandusky Bay, lying west of the spit, consists of lake clay lying on top of boulder clay. The tills in Ottawa County may contain as much as 20% sand size particles.

Humphris (1952) reports that longshore currents move south along the east shore of Sand Point, north along the west shore, and east along the north shore of Sandusky Bay, from Bay Bridge to the spit. These statements are based upon observations of accretion patterns and of the development of minor beach features, and upon consideration of wind-fetch relationships.

Systematic variations in mechanical and mineralogical characteristics and in carbonate content with respect to location along the spit have not been recognized (Pincus, Roseboom, and Humphris, 1951; Humphris, 1952), although carbonate content and certain mineral abundances appear to vary systematically with grain size. The sediments on Sand Point are finer grained and better sorted than those to the west, along the north shore of the bay. Humphris (1952) attributes this contrast to derivation of Sand Point materials from Sandusky Bay, and north shore materials from erosion of the local shore. He points out that the median size of material found along Sand Point is that size most easily moved by wave and current action, according to Inman (1949).

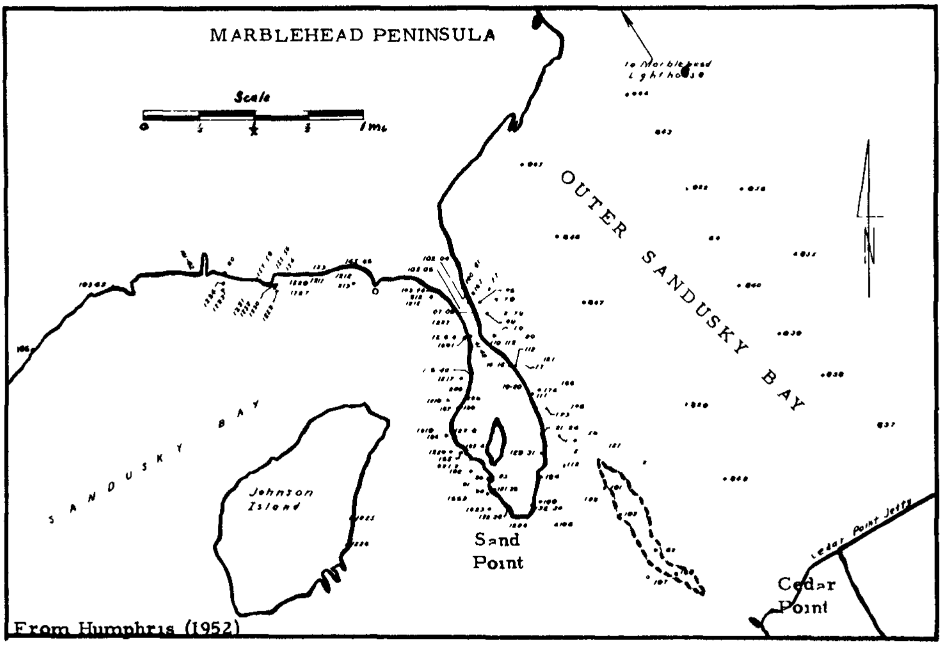

Fig. 3. Map of Marblehead Peninsula, Sand Point, and outer Sandusky Bay. Note location of Cedar Point jetty in lower right hand corner. Small numbers designate study localities,not discussed in this paper.

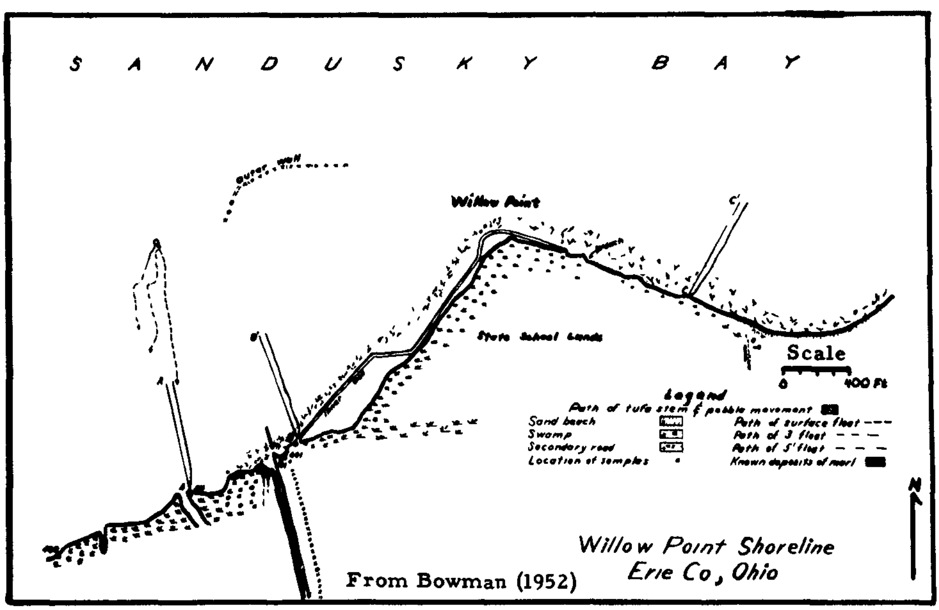

Fig. 4. Map of Willow Point area. Little Pickerel Creek runs just west of dirt road in lower left of map. Vertical exaggeration of profiles AA', BB' and CC' is 10X.

Shale fragments, $\frac{1}{4}$-1" in diameter, occur in great quantities along the southern and western shores of the spit. Shale fragments have not been observed in any nearby till exposures, and the bedrock is not shale (Fig. 2). The nearest known exposure of shale along the shore is about 9 miles east of Sand Point (Metter, 1952). Humphris (1952, p. 25) suggests that perhaps the shale fragments have been swept westward past Cedar Point, around the pierhead light, then to the southwest past the tip of the spit, and up its western side. House Document No. 32, 83d Congress, 1st Session (1953), p. 23, par. 59 reports a strong reversing current in the channel running northeast-southwest between the lake and the inner bay. The currents are attributed to changes in lake levels arising from wind action; velocities of over three miles per hour are attained, reducing channel maintenance considerably. Dominant longshore drift from the supposed source of the shale to Cedar Point is westward; the number of shale pebbles on the beach increases toward the east (Metter, 1952).

Outer Sandusky Bay, between Marblehead and Cedar Point (Fig. 3)

Sedimentary processes in outer Sandusky Bay appear to be directly related to those involving the eastern side of Sand Point. Grain size becomes smaller in an apparently continuous series from the spit out into deeper water (Pincus, Roseboom, and Humphris, 1951; Humphris, 1952). Trends of median grain size run parallel to the shore in the Marblehead area.

The sand on the bottom is more than 20' thick in some places, thinning toward the northwest. Beneath the sand lies a gray clay, lying, in turn, upon bedrock.

Data derived from mineralogical, mechanical, and carbonate analyses do not seem to throw any light upon the mechanisms of sediment transport.

An observation by the author in the autumn of 1950 may have some bearing upon this problem. The Program's research vessel was anchored west of the channel in the outer bay, near the pierhead light, with fairly high waves coming in from the northeast. Although the northeast winds blew the vessel southwest of the anchor, the vessel moved into the wind, drawn by the taut anchor line. The author interpreted this as the result of northeastward creeping of the bottom sediments, possibly in conjunction with a returning hydraulic current. However, coring operations during the following summer revealed that the bottom was covered with a crust which might inhibit or prevent such creeping; operators of sand-suckers have sadly confirmed the existence of this crust.

Some sand undoubtedly passes westward through or over the Cedar Point jetty; other materials probably are swept around the jetty and into the bay (Humphris, 1952). Metter (1952) reports an increase in grain size near the end of the jetty on the east side, apparently reflecting the effects of strong, observed currents entering or leaving Sandusky Bay (House Doc. No. 32, 1953). Contributions from the inner bay are probably minor.

Willow Point, South Shore of Sandusky Bay (Fig. 2,4)

Bowman (1952) has reported a net eastward drift along the shore in the vicinity of Willow Point on the south shore of Lake Erie. He cites the conspicuous eastward decrease in abundance of tufa pebbles washed into the bay from Little Pickerel Creek. Tufa stems are present in the west bank of the creek and in the shoreline property immediately to the west of the creek (Fig. 5). The band of tufa widens past Willow Point, possibly because the current continues eastward while waves spread the deposit southward toward the shore, which swings to the southeast east of the point (Fig. 4). Variations in grain size of the tufa material on either side of Little Pickerel Creek are very strikingly illustrated in Fig. 6. In this area it is possible to outline a path of sediment drift with considerable confidence, because of the apparently unique source of easily recognizable materials. In particular, the tufa pebbles, which seem to come from the creek alone, are especially reliable tracers.

In a survey of the shoreline to the east of the school lands, Pincus (1953) observed that both the amount of tufa and the particle size of beach materials diminished toward the east.

Beach materials in this area are continually being driven landward into the marshy areas so persistent along this part of the shoreline. Bowman (1951) has shown that variations in bay level, which depend upon wind direction, determine which layer of shore material is attacked by waves (Fig. 5). A layer of marl is particularly susceptible to such attack. Thus, water level affects the type of material introduced into the longshore currents. On the north shore of the bay, a glass wool plant had been dumping waste silicate beads and splinters for at least five years preceding Bowman's study. Bowman found these materials in every beach sample he collected along the south shore of the bay. Particle sizes of the artificial materials range from 4.0 to .064 mm; hardness and specific gravity are slightly less than that of quartz. The greatest inferred straight-line distance of cross-bay transportation is 5.9 miles. The actual paths of these materials are not known. Most of the bay in this area is less than 6' deep, and the bottom is largely composed of very fine materials.

Both the tufa and the artificial grains provide excellent means for tracing movement, in that distinctive materials are supplied at a "point source", or an approximation thereto. These observations have led to a program of developmental work in using "tracer grains"; the principal unsolved problem to date is that of obtaining sufficient quantities of innocuous, inexpensive materials, with adequate physical and chemical properties.

Cedar Point to Huron, Erie County, Ohio (Fig. 7)

House Document No. 32, 83d Congress, 1st Session (1953), treats the 20-mile strip of shoreline from Cedar Point to Vermilion Harbor; the Cedar Point to Huron strip, discussed in this section, and studied by Metter (1952), is the western half of the 20-mile strip.

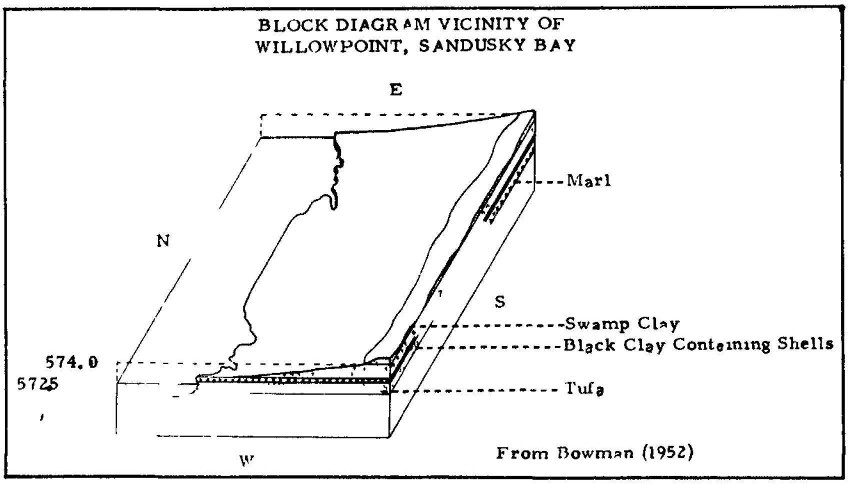

Fig. 5. Shore materials just west of Little Pickerel Creek . Note how small variations in water level bring different materials into zone of wave attack.

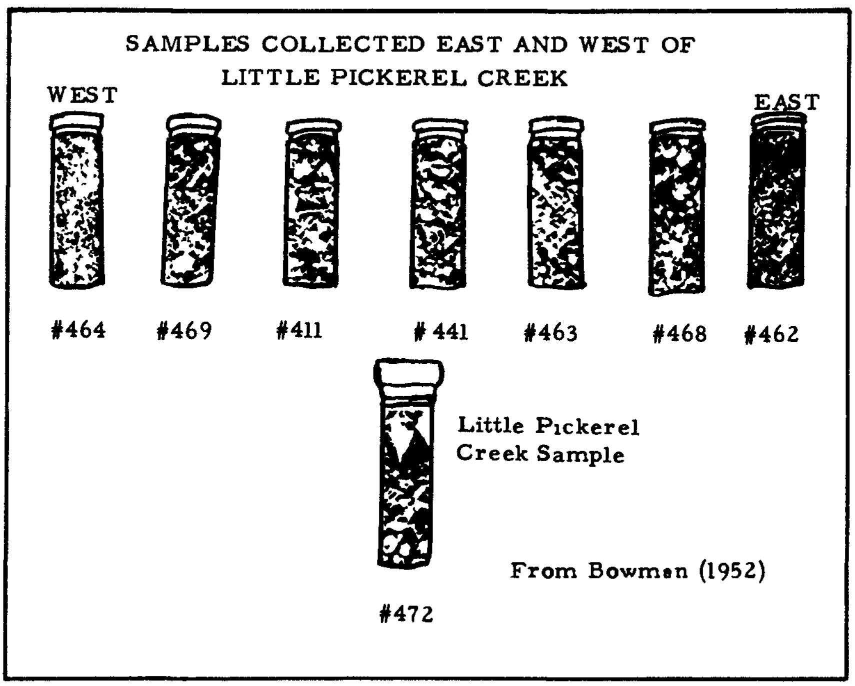

Fig. 6. Samples of tufa collected east and west of the mouth of Little Pickerel Creek. Note the decrease in size with increase in distance along the shore from the mouth.

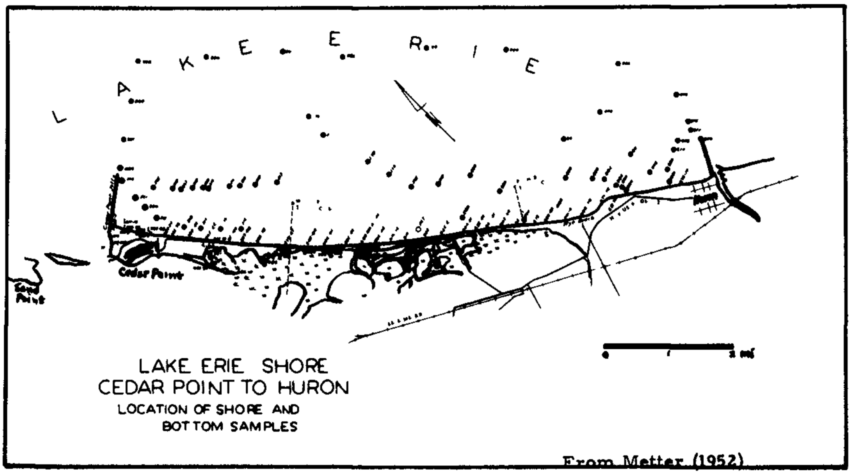

Fig. 7. Lake Erie shore from Cedar Point to Huron. Small numbers designate study localities, not discussed in this paper.

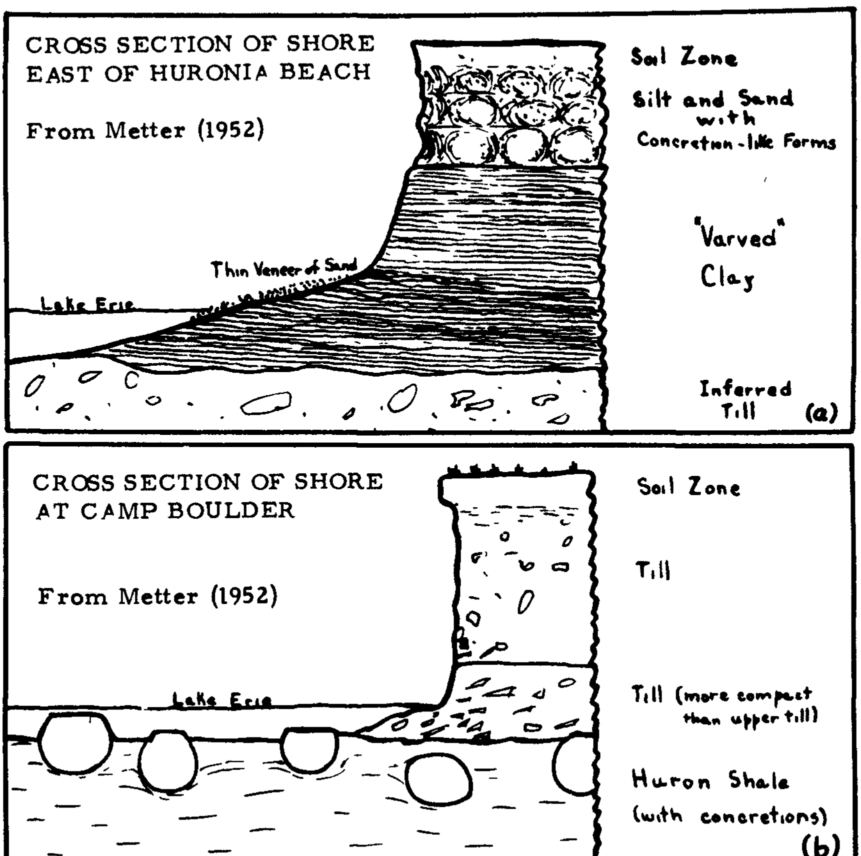

Fig. 8. Shore and bluff materials in the eastern part of the Cedar Point-Huron study area.

According to Document No. 32, longshore drift along this strip of coast is predominantly east to west. Accretion on the east side of the Cedar Point jetty and the east breakwater at Huron are cited as evidence for this statement. It is also pointed out that there is a westward movement of points east of these structures where wide beaches give way to beaches narrow enough to permit bluff erosion.

This document also carries information on littoral currents predicted from refraction diagrams for 4-second waves. While east and east-northeast storms generate east to west littoral currents throughout the area, and northwest storms generate west to east currents, northeast and north storms develop currents flowing away from each other at neutral points. The neutral point for northeast storms is about 3 miles east of the Cedar Point jetty; the neutral point for northern storms is Ceylon Junction, discussed earlier in this paper.

An earlier report, House Document No. 220, 79th Congress, 1st Session (1946), gives results of current observations with dyes and subsurface floats. These observations agree fairly well with the predictions of the more recent (1953) documents. Current velocities up to 60 ft/min. were observed during comparatively calm weather.

The 1946 document points out that approximately 5 miles east of Vermilion, there is a division between dominant east and west littoral drift, as evidenced by accretion patterns. West of this point, accretion is on the east side of structures; east of the point, accretion is on the west side of structures. Such a division point is not the same as the previously mentioned neutral point, for the latter is determined with respect to a specific wind direction. From the present compilation of data, and according to Lee's (1953) generalized map, the division point lies east of the point cited in the 1946 report. Possibly, the division point, or zone, lies at Lorain, or even eastward toward Avon Point.

According to the 1946 document, no littoral drift passes Huron Harbor. Thus, there are no natural outside sources of material in this area. To the west of Huron, erosion is indicated by changes in the shoreline and 6,12, and 18 foot depth contours, until 6000 feet east of the jetty; the shoreline and the 18 foot contours show accretion from this point to the jetty, while the 6 and 12 foot contours indicate erosion.

Metter's (1952) study shows a net westward drift at the western end of the spit, based on the accretion east of the Cedar Point jetty, and upon the fact that the Cedar Point spit was formed long before the construction of the jetty. His observations and inferences on sediment drift agree fairly well with those of the 1953 document.

Metter reports that a series of short groins about 6 miles east of the jetty have not collected much sediment. At the western end of this series, sand has accumulated on the western side; at the eastern end, sand has accumulated on the eastern side. Interestingly, this area lies between the neutral points for north and northeast storms, as described in the 1953 document. This groin series lies very near the neutral point for the northeast storms, which are far more severe than any other storms.

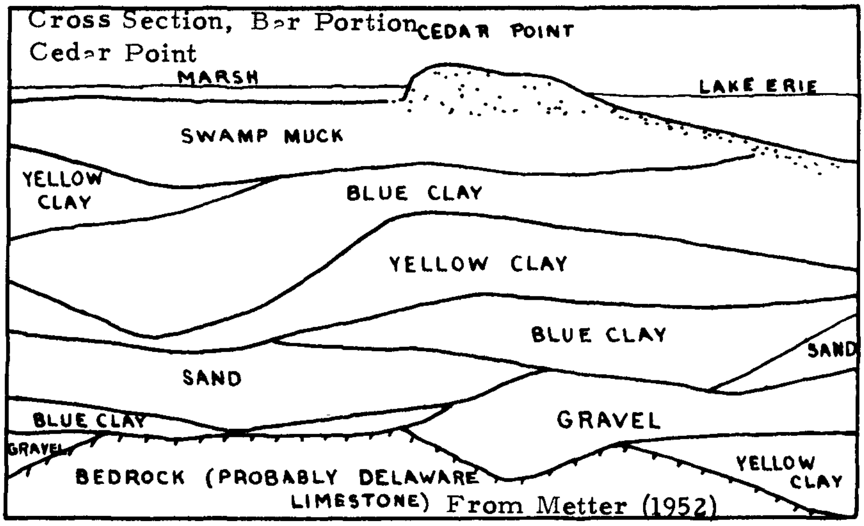

Fig. 9. Shore and subsurface materials in central part of Cedar Point-Huron study area. Subsurface structure inferred from borings by Sandusky City Engineer.

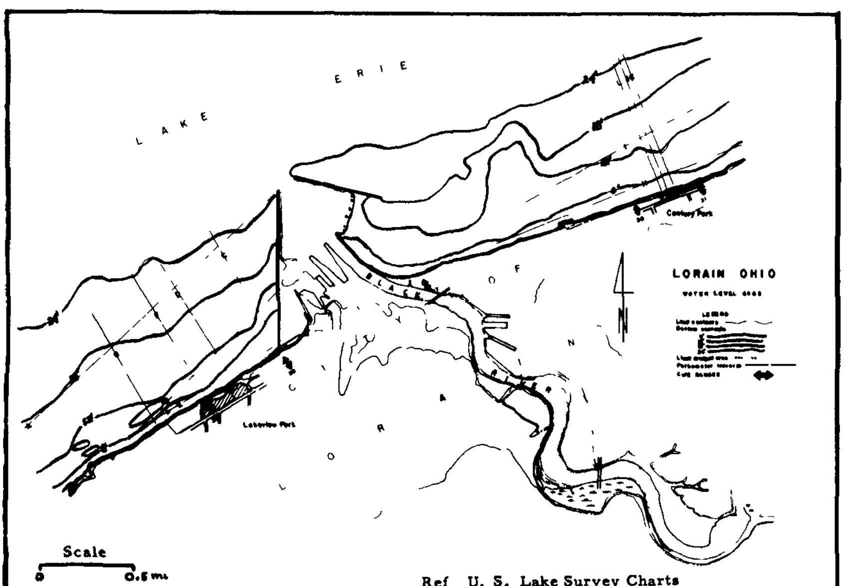

Fig. 10. Map of Lorain, Ohio, showing location of Lakeview and Century Parks. Note the apparent effect of the harbor breakwaters on bottom topography.

The previously mentioned eastward increase in the number of black shale pebbles is to be expected, if their source were the shale outcrops 9 miles east of the jetty.

Near the center of Metter's study area, the sediment near shore is coarser than to the east or west; he attributes this to the erosion of coarse material from the lake bottom in this area. Sand and gravel 15-20 feet below the central part of the bar portion of the Cedar Point peninsula could provide coarse materials on the lake bottom, as the bar moves landward (Fig. 9).

Sorting of sediments along the water's edge increases with decreasing grain size. Dune materials become finer westward from the approximate center of the study area.

It is conceivable that the opposite offshore trends reported by Metter are caused, at least in part, by currents on opposite sides of a neutral point.

Abundance patterns of the heavy minerals simply and collectively suggest a central source someplace toward the center of Metter's study area; although these patterns are not too clear-cut in indicating an overall drift, there is the suggestion of more movement to the west than to the east.

In the postulated source area, the 1/8-1/4 mm. size grade contains as much as or more heavy minerals than the 1/8-1/16 mm. size grade; elsewhere the finer grade contains more heavy minerals. These relations are consistent with the hypothesis of transport away from the designated source area.

From the mineral assemblages observed in the beach materials, it appears likely that glacial till along the shores is probably an important source of sediments (Fig. 8). Although many of these minerals are considered to be easily weathered, fresh angular grains are usually observed in beach deposits. Metter proposes that continued abrasion in transport could account for this condition.

The possibility that some sources are on the lake bottom has been presented earlier.

The types of evidence used here seem to indicate multiple sources and fairly complex to-and-fro motion along the shore. Inferences drawn from the several types of evidence yield results which are fairly consistent with each other.

<u>Lakeview and Century Parks, Lorain, Ohio (Fig. 10)</u>

According to the U. S. Army Corps of Engineers report on the Vermilion to Sheffield Lake strip (1949), the predominant drift here is from east to west as indicated by accretion at Beaver Creek jetty (west of Lorain) and against small structures east of Lorain Harbor. Since the eastern fetch is much larger than the western fetch, this direction of drift is to be expected. This report notes an apparent local reversal of predominant drift immediately adjacent to and west of Lorain Harbor, inferred from accretion patterns. Also noted are these observations: 1. there has been little accretion adjacent to the many shore structures in the area; 2. the greatest loss has occurred immediately east of Lorain Harbor; and 3. east of Lorain there has been a net accretion offshore, possibly resulting from the eastward transportation of Black River silt.

Apparently beach material is derived through erosion of local materials, particularly the till bluffs (Fig. 11). Sea walls in this area cut down on the effectiveness of this source.

In a survey of Lakeview and Century Parks (Fig. 10), Pincus (1952-3) observed accretion on the eastern sides of Century Park structures (Fig.13), and, in 1952, accretion on the western sides of Lakeview Park (Fig. 12) structures. This agrees with patterns of bottom contours adjacent to the Lorain breakwater (Fig. 10). In 1953, however, accretion adjacent to the eastern structures at Lakeview had shifted to eastern sides. These eastern structures are longer than the structure to the west, and are closer to the Black River and its surrounding, large protective structures. The reason for this local shift in accretion is not clear, for during the same period there was an accumulation of material inside the permeable base of the west harbor breakwater.

Regarding mechanical, total heavy mineral, and carbonate analyses, Pincus (1952-3) finds no meaningful patterns. Abundance data for individual minerals are now being compiled. One interesting observation coming out of the analytical results is that in several of the areas bounded by two groins and the shoreline, the sedimentsin the center are finer than the materials around the inside of the area's edges. This might indicate an energy gradient toward the center of such systems, but what this means in terms of motion of sediment is not clear. Observations of currents with subsurface floats indicate complex water movements in the groin fields.

Thus, the only recognized patterns in the Pincus (1952-3) report i.e., accretion, agree generally with the observations of the Army report, but seem to indicate complications. Possibly the Lorain harbor structures are trapping sand moving alternately east and west, and are also reflecting significant amounts of wave energy.

Apparently, the Lorain-Vermilion sand and gravel deposit, 6 miles to the northwest, has no direct connection with the Lorain beach materials.

Avon Lake and Vicinity, Lorain and Cuyahoga Counties, Ohio (Fig. 14)

In a detailed study of the 9½ mile strip from Sheffield Lake (4 miles east of Lorain) to Huntington Park (west of Cleveland), Kleinhampl (1952) reports that most accretion,although not large, occurs on the west side of structures. This seems to indicate a reversal of the dominant direction of drift for Lorain as recorded by the 1948 report, and as recorded in this paper for areas west of Lorain. As mentioned earlier, it is possible that the division point, or zone, for littoral drift lies at Lorain or slightly eastward. Occasionally, there are accretions on the east and also equal accretions between two groins. Some of these apparently erratic patterns may be caused by reflecting surfaces. Newberry (1873) noted a

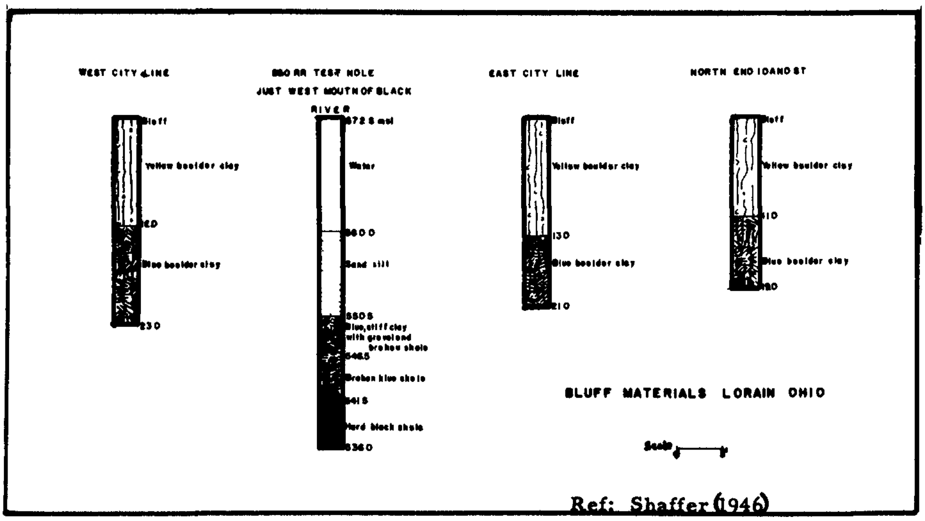

Fig. 11. Bluff materials along Lorain shore. Contrast with materials logged in test hole just west of the mouth of the Black River.

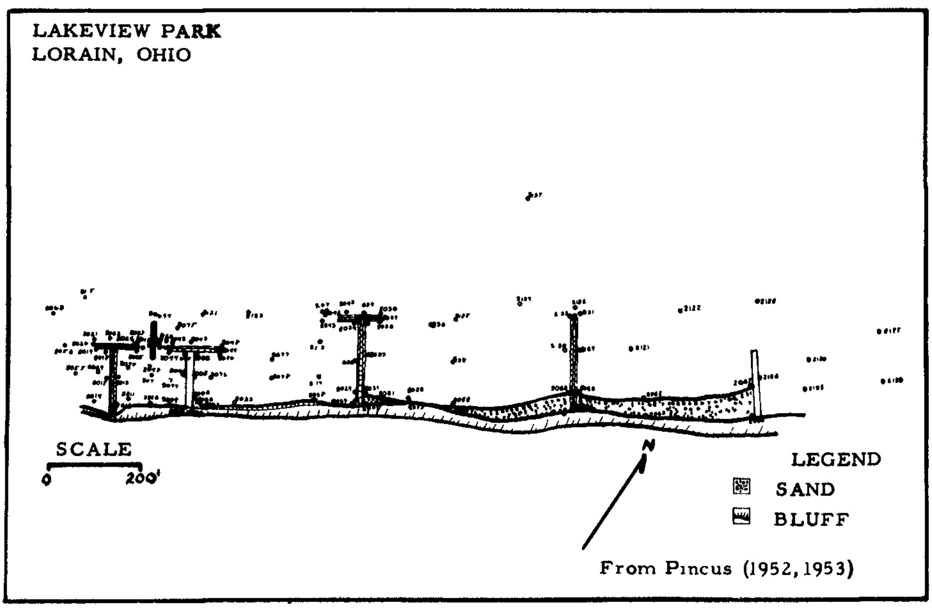

Fig. 12. Lakeview Park, Lorain, Ohio. Note areas of sand accretion. Small numbers apply to study localities, not discussed in this paper.

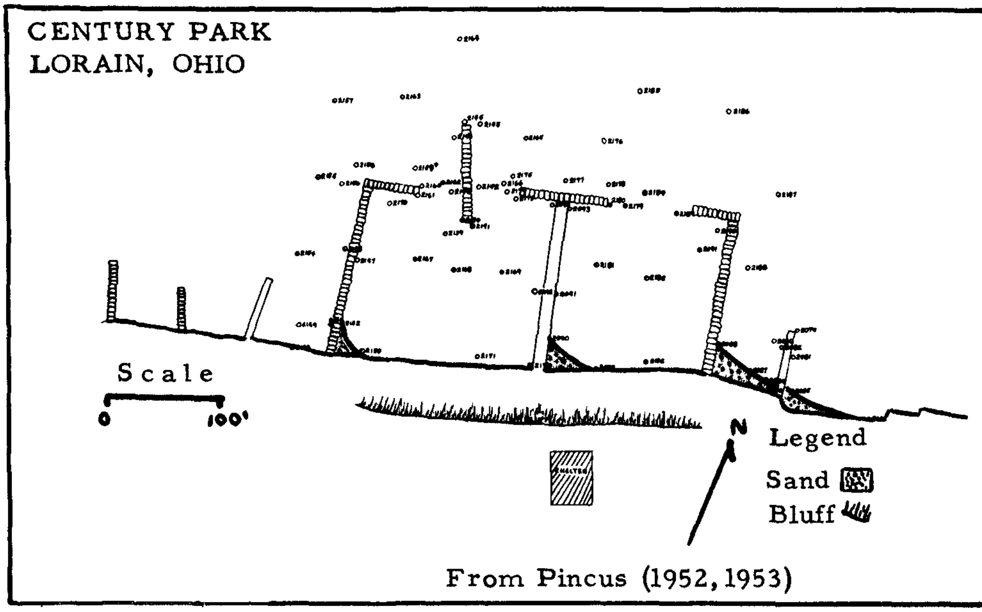

Fig. 13. Century Park, Lorain, Ohio. Note areas of sand accretion. Small numbers apply to study localities, not discussed in this paper.

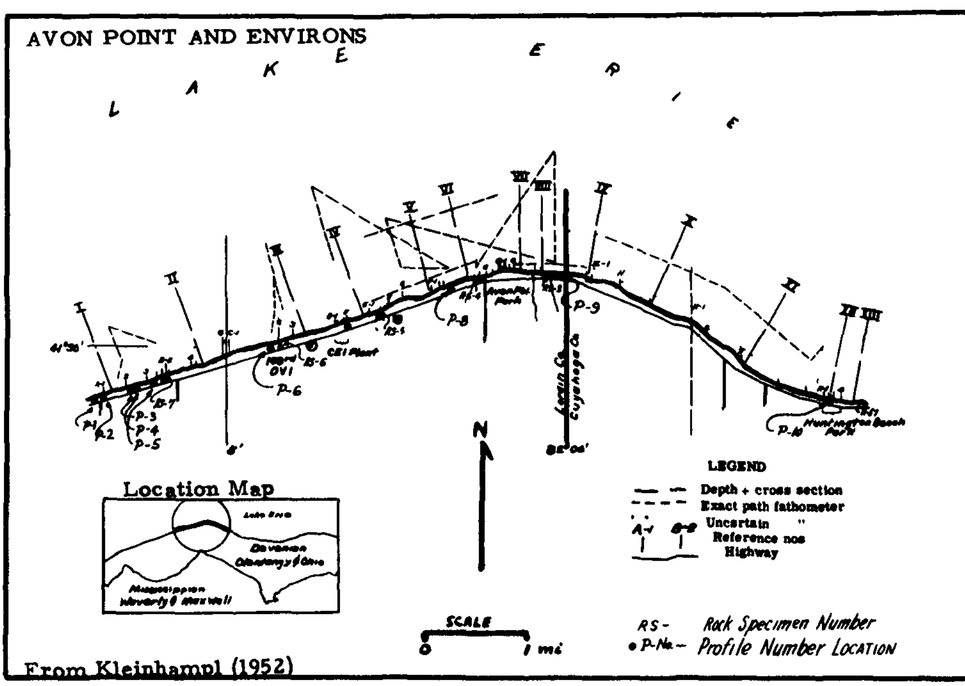

Fig. 14. Map of Avon Point and environs. Survey data in fine print are not discussed in this paper.

westward deflection of the turbid outflow of the Cuyahoga River; Kleinhampl (1952) reports that air photos show a westward deflection of Rocky River's outflow. However, such deflections could have been short-period events, of less long-time consequence as evidence of drift than the patterns of accretion cited above. Kleinhampl notes the association between the composition of the cliffs (Fig. 15) and the beach materials. The mineral composition and pebble counts of beach materials point particularly to a till source. The exposed shales and siltstones contribute shingle and fines. The largest single source of sand along the shore is believed to be the sandy bottom material of an older lake, just west of Huntington Park. Two creeks in the area cut through some old beach ridges; during heavy flow, they could carry gravel and sand into the lake.

Mineralogical and mechanical analyses reveal no systematic variations along the shore. Local supply appears to balance movement and thus to obscure evidence of movement in this area. Along the shore sorting is good, and median diameters approach that of Inman's "size most easily moved" (1949).

Some of the analytical values show conspicuous fluctuations slightly west of Avon Point. Possibly these fluctuations result from the action in this area of the many protective structures, some of which are very large, or from proximity to a point or zone of division of littoral drift.

House Document No. 502, 81st Congress, 2d Session (1950), reports on an 18-mile strip of shoreline from the west city line of Lakewood to the east city line of Cleveland. This area is almost adjacent to the eastern end of Kleinhampl's study area. This document reports a predominance of littoral current from west to east. Wind-fetch relations predict such currents, and patterns of accretion and changes in bottom contours attest to this type of movement.

Mouth of Chagrin River, Eastlake, Lake County, Ohio (Fig. 16)

In a reconnaissance report on shore processes in the immediate vicinity of the mouth of the Chagrin River, roughly midway between Cleveland and Fairport, Pincus and Hartley (1953) report littoral drift from the west. They cite as evidence the accretion on the west side of a large water intake structure to the west, and on the west side of the groin at the mouth of the river. Opposing weaker drift is indicated by the westward growth of small spits on the east side of the mouth of the Chagrin River.

Beach materials are apparently derived from the pebbly tills in the high bluffs; the lower-lying pebble-free clays and silty clays (which could be the remains of sediment laid down during an invasion of the river valley by an older, higher lake) are not effective sources of beach materials. Some patches of sandy materials on top of the high bluffs could contribute only very small total quantities to the longshore drift (Fig. 16,17).

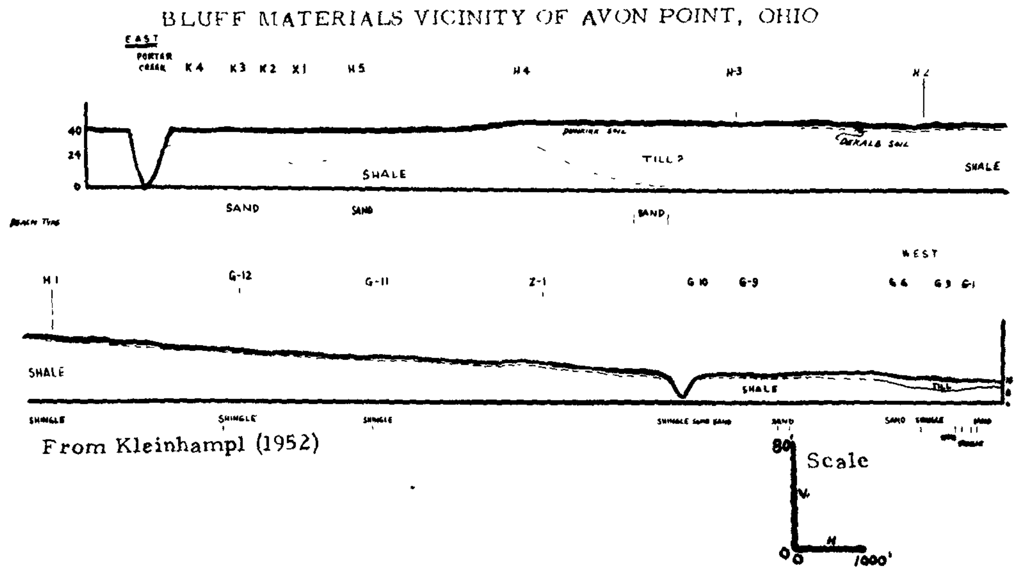

Fig. 15. Shore and bluff materials in the vicinity of Avon Point, as viewed from offshore. Vertical exaggeration 20X. Note relief on the bedrock surface.

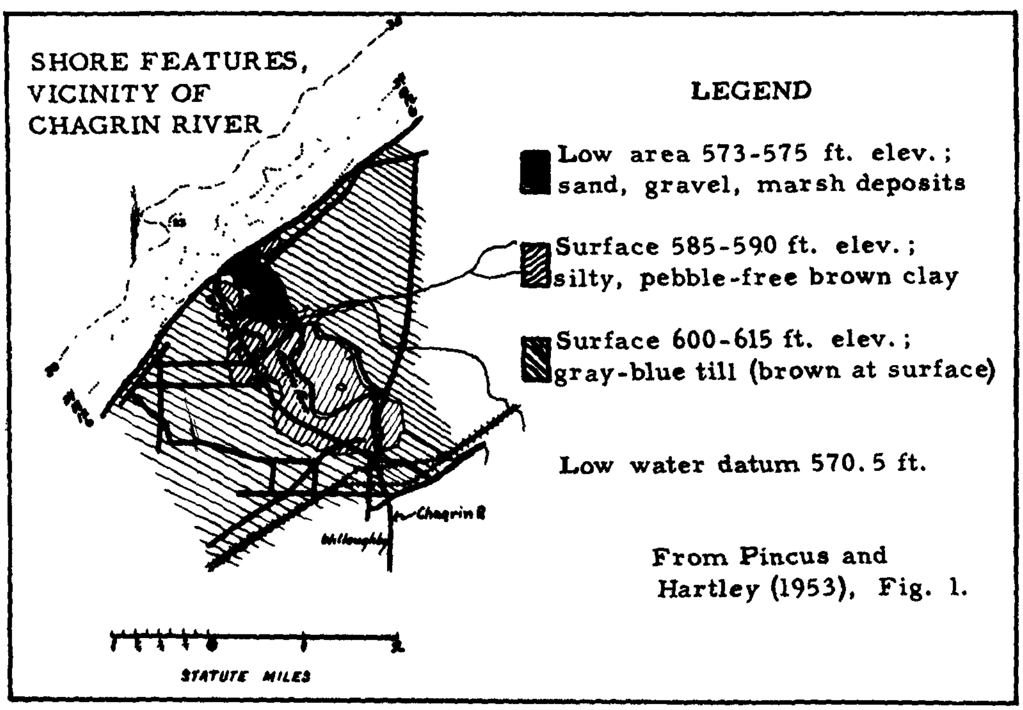

Fig. 16. Shore materials and offshore topography, mouth of Chagrin River.

The Chagrin River is not believed to be a significant source of beach materials, principally because it reaches lake level some distance south of the lake shore, depositing much of its load upstream. Observations of materials in the bed of the stream support this contention.

Some beach materials are migrating inland, over marsh deposits in old channels of the river, and into the base of the low bluffs of pebble-free clay and silty clay.

House Document No. 596, 81st Congress, 2d Session (1950), which treats the Lake County shoreline, reports littoral drift from the west. This drift is attributed to wind-fetch factors; accretion patterns confirm the analysis.

This document reports the occurrence of offshore bars off the mouth of the Chagrin River, and immediately west of the west breakwater off Fairport Harbor.

The Fairport commercial sand deposit, northwest of the harbor, is possibly connected with longshore sedimentation west of Fairport. These sands are fairly fine and fairly well sorted.

Madison Township Sewage Disposal Plant, Eastern End of Lake County, Ohio (Fig. 18)

Just offshore from the Madison Township Sewage Disposal Plant (15 miles east of Fairport) a thin veneer of sand (Fig. 19) trends roughly northeast from the small point of land protected by sheet steel piling (Pincus and Blackburn, 1953). In recent months, erosion has occurred on the west side of the point, and accretion has occurred on the east side. A small spit at the mouth of Arcola Creek was observed growing westward (Fig. 18, 19).

According to House Document No. 351, 82d Congress, 2d Session (1952), treating the shoreline between Fairport and Ashtabula, littoral currents are dominantly from the west, with temporary reversals, depending on the wind. The evidence for the statement is, once again, accretion patterns. The observations of Pincus and Blackburn (1953) appear to be in agreement with those reported by this document.

According to the same document, little material comes from outside the area (i.e., Fairport to Ashtabula) due to damming effects of harbor structures at each end. This implies that much of the beach materials have been confined to and reworked in this area, and therefore that processes of selection might have operated with considerable effect. This appears to be consistent with the observation (Pincus and Blackburn, 1953) that unusually large accumulations of heavy minerals occur here; there is no reason to suppose that the source areas are unusually rich in these minerals, although this is certainly possible.

House Document 350, 82d Congress, 2d Session (1952), treating the strip of shore from Ashtabula to the Pennsylvania state line, reports predominant currents from the west, with temporary reversals. This statement is based on consideration of wind and fetch, and upon observed

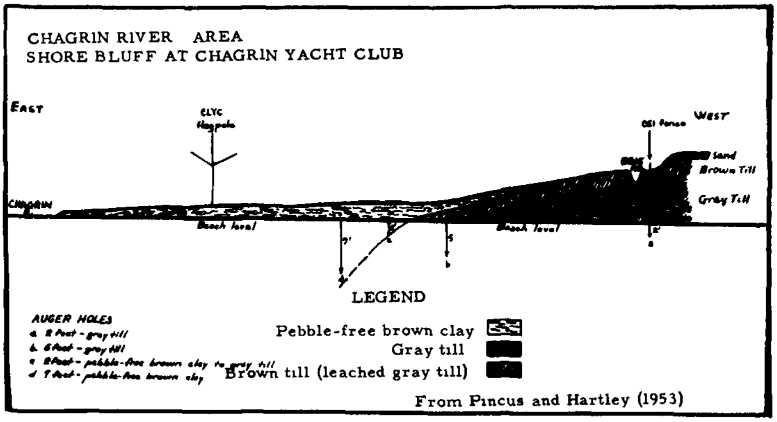

Fig. 17. View from offshore of shore and bluff materials just west of the mouth of the Chagrin River.

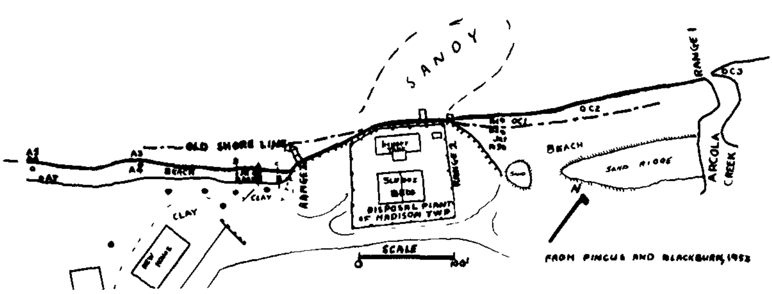

Fig. 18. Madison Township Sewage Disposal Plant at eastern end of Lake County. Note "old shoreline" and split at mouth of Arcola Creek.

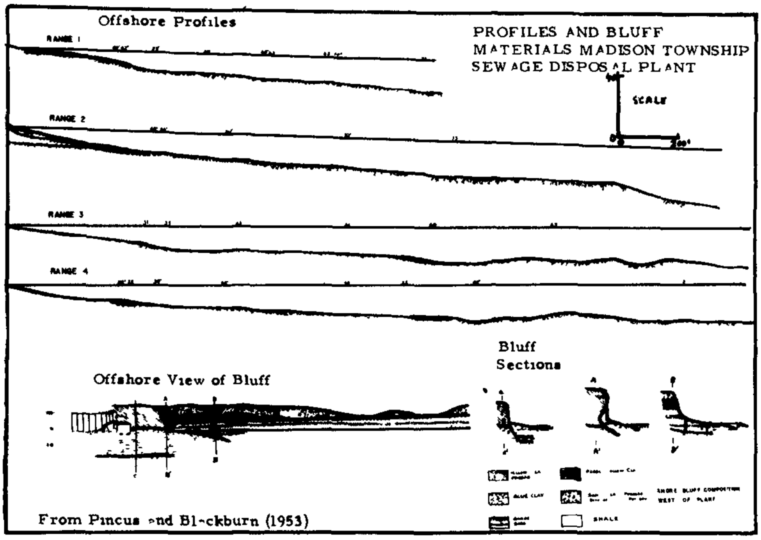

Fig. 19. Bluff materials and inferred offshore profiles, Madison Township Sewage Disposal Plant. Note that unconsolidated materials are apparently veneers covering bedrock (shale).

accretion at Conneaut, near the state line. The Harbor structures at Ashtabula and Conneaut appear to confine much of the shore material between the two cities.

Lee's (1953) detailed study of Presque Isle reports a predominant drift from the west; this direction is evident from accretion on the west side of structures and from the shape of Presque Isle. The source material apparently comes from the bluffs between Conneaut and Presque Isle. Wind-fetch factors favor an eastward drift.

SUMMARY AND CRITICISM OF THE EVIDENCE USED FOR DETECTING SEDIMENT DRIFT

The types of evidence useful for detecting sediment drift are:

1. Topographic changes: This category really deals with changes such as:

   a) Bluff retreat
   b) Shoreline changes, adjusted for comparable water levels, where possible.
   c) Accretion patterns, generally adjacent to structures of known age. (Age of structure allows estimation of rate of accretion.) These are tied to erosion patterns, where possible. Both erosion and accretion patterns can be mapped out (as in the House documents cited) from changes in bottom contours.

Regarding all topographic changes, the specification of the time during which the change has taken place is extremely important in estimating rates. Topographic changes usually reflect long-range changes, some of which are irreversible (viz., bluff retreat).

None of these changes defines the path of sediment transport. They indicate only effects which apparently show a predominance of drift in one direction. Combinations of sources of evidence will sometimes point to a to-and-fro or reversing motion, such as that inferred for Lorain Harbor.

c) may be tied to b) or a), or to some other possible source of sediment, such as streams, to work out an inferred path of transport. But here, there is always the possibility that there may be another "source", or there may be groups of sources as yet unidentified as such, the knowledge of which could yield a totally indifferent interpretation of sediment drift.

These changes also tell only the "algebraic" sum of all changes at a point---they do not indicate how much material has been moved in a period of time. Again, this is another way of saying that the path of transport has not been uniquely determined.

2. Changes in attributes of the sediments (mineralogical, chemical, and carbonate analyses):

a) Changes in mechanical properties, such as median grain size, sorting, skewness, and kurtosis, apparently indicate transportation only when some aspect of the transportation process or processes serves to modify the sediment with respect to one or more of these properties along the path of transport, and only when there are no contributions to the material along this path. Since much of the Lake Erie shore is actively eroding, there are relatively few longshore paths which would not be subject to such "pollution". And, of course, the use (in a problem) of a "variation series" for indicating path implies that something is known about the mechanism of transport.

Changes in mechanical properties which can be attributed to contributions from a distinctive source area may be used for indicating an overall direction of transport; this method, however, is subject to the limitations stated in the previous section, viz., the uniqueness of the source is assumption, not fact.

Combinations of mechanical properties may allow deductions which will yield clearer insight into possible modes of transportation by limiting the number of possible mechanisms of transport.

b) Mineralogical or compositional variations present similar problems of interpretation. Of course, such factors as mineral densities and shapes may provide insight into transport mechanisms, and in turn, into directions of movement. Into the problem of mineral assemblages come such factors as weathering. Are easily weathered minerals removed while in the till bluffs, in transport, or on the beach? Are weathered coatings removed by abrasion in transport? Also, there are sampling problems, such as those involving heavy mineral laminae, variations within single layers depending on distance from water's edge, etc.

3. Indirect Indicators: Wind direction, fetch, orientation of shoreline and wave patterns deal with the way in which energies are to be applied to systems of this kind. By themselves, they tell little about the motion itself: they merely restrict the possible directions and intensitiee which one can apply to descriptions of sediment movement. Of course, carefully thought through refraction and diffraction diagrams give considerable help in apportioning wave energy to various stretches of shoreline, and in combination with other types of evidence may prove to be fairly powerful toole for inquiry. The Lake Erie Geological Program has just inetituted a project involving construction of refraction and diffraction diagrams for some of the crucial areas studied during recent years.

4. Scale models: Models which might prove very helpful, have not yet been used in the work of the Lake Erie Geological Research Program.

5. Observations of single grains, either in the field or in models: This technique, if successful, would yield behaviors of individual grains, which might be of about the same use here as the description of the supposed behavior of single gas molecules is useful in understanding some aspects of the behavior of a gas.

Combinations of these and other types of evidence provide important checks on interpretations, and the discrepancies arising from such comparisons may lead to a more complete understanding of the nature of the evidence.

ACKNOWLEDGMENTS

The investigations of the Lake Erie Geological Research Program have been conducted under the principal sponsorship of the Ohio Division of Shore Erosion, of which Mr. F. O. Kugel is Chief. Aid to the Program has come also from the Ohio State University through its Graduate School and Department of Geology and from the Ohio Departments of Geological Survey, Water, and Wildlife.

Valuable information has come from the Buffalo District of the U. S. Army Corps of Engineers, and from the United States Lake Survey. The cooperation of the U. S. Coast Guard and the loan of equipment from the U. S. Navy have contributed considerably to the efficiency of the Program.

The personnel of the Program are very grateful for this help, and for the friendly spirit of cooperation in which it has been offered.

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