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INTRODUCTION

Purpose and Scope of the Investigation

The Lake Erie Geological Research Program has been conducting a long-term inquiry into the nature of the Lake Erie geological environment in general, and particularly into how this environment applies to the Ohio shore area in terms of erosion and deposition. This research is spearheaded primarily by the Ohio Division of Shore Erosion, Mr. F. O. Kugel, Chief, and under the immediate leadership of Dr. Howard J. Pincus, Chief Scientist of the Division and Associate Professor of Geology at The Ohio State University.

Under this program the author investigated the 50 mile shore length between Fairport, Ohio, and the Ohio-Pennsylvania border during the summers of 1954, 1955 and 1956. The objectives sought were –

1) A detailed description of the stratigraphy of the bluffs;
2) The isolation of factors contributing to failure of the bluffs; and
3) An inquiry into the formation of the beaches and their sources of sediments.

The author believes that the greater part of these objectives were attained.

The field work was supplemented by laboratory and library work. Selected samples from bluff and beach were analyzed in terms
of size distribution and heavy mineral species. Bluff samples and auger samples taken by the Ohio Division of Shore Erosion from the Lake Plain were also examined in terms of the Atterberg coefficients bearing on the classification of clays by their moisture content. Experimental beach conditions of growth and decline under the impact of steep and low waves were viewed in a wave generating tank. Finally, the stratigraphy of the Lake Plain and the configuration of the bedrock surface underneath the Lake Plain were investigated by use of well logs filed in the offices of state and private agencies.

**Acknowledgments**

The Diamond Alkali Company presented the author with a copy of a bedrock surface contour map of the Mentor Quadrangle, the somewhat modified version of which is included in this paper. The Company also supplied the author with subsurface data on the area east of Fairport between the Grand River and the lake. This information enabled the author to isolate one of the factors actuating slumping in that area. The Morton Salt Company provided the subsurface data that helped the author to reconstruct the history of the Lower Grand River valley. The author appreciates their help and thanks Mr. D. R. Richner and Mr. D. D. McCormick, respectively, of the two companies.

The author obtained from the files of the Ohio Division of Water and the Ohio Division of Shore Erosion the numerous well logs on which he has based the bedrock surface contour map of the
Perry, Ashtabula and Conneaut quadrangles; and from which he has attempted to describe the stratigraphy of the Lake Plain and the Lake Escarpment moraines. The patience and generosity of the staffs of the two Divisions were unbounded, and the author hopes, justified. He remembers them with gratitude.

The author thanks Professors A. Brandenberger and F. J. Doyle of the Institute of Geodesy and Photogrammetry, The Ohio State University, who performed the photogrammetric and cartographic work on the beach models described in this text.

In the area of soil mechanics the author had to acquire new skills. Thus he stands deeply indebted to Professor R. F. Baker and Mr. K. S. Senanthirajaj, who opened the facilities of The Ohio State University Engineering Experiment Station to the author, and showed him how to make the Atterberg tests on his bluff samples. In this connection, auger samples from the Lake Plain included in this dissertation were classified by The Ohio State University Soils Testing Laboratory as a courtesy to the Ohio Division of Water. The author has benefited and thanks them also.

Closer to home, there is the Ohio Division of Shore Erosion without whom this dissertation could not have come into existence. The author wants to thank his competent and agreeable co-workers, Messrs. J. V. Verber, R. P. Hartley, W. Lemke and assistants on whom the author has leaned on many occasions for information on the offshore area, and who have helped to map and run offshore profiles.
The author extends his gratitude to Doctors R. P. Goldthwait and J. Forsyth, authorities on the Pleistocene; their constructive criticisms have pulled this dissertation out of many kettle-holes.

With deep appreciation the author, remembers Dr. H. J. Pincus, Senior Scientist of the Ohio Division of Shore Erosion, and the author's faculty adviser, who through the years has contributed the stimuli that now brings this work to fruition.

In conclusion, the author greets all contributors to this work and not mentioned herein, and thanks them.

Previous Work

Most of the very early workers, including M. C. Read (1873) and C. S. Prosser (1912), concerned themselves primarily with the stratigraphy of the bedrock. Read's work in particular was one of reconnaissance.

Leverett (1902) and Leverett and Taylor (1915) in their monumental monographs on the Great Lakes region described the topography developed on the Lake Escarpment moraines, and the prominent beach ridges of the former glacial lakes.

F. J. Carney (1908 - 1917, unpublished notes) specialized in a study of these former lake beach deposits, and made detailed maps of them.

C. W. Hutton (1940, unpublished M.S. thesis, The Ohio State University), produced a geomorphic and joint study of the area
covered by the U.S. Geological Survey topographic 15 minute Ashtabula and Conneaut quadrangles.

More lately, in 1947, the Beach Erosion Board, U.S. Army Corps of Engineers, in conjunction with the State of Ohio, conducted a cooperative survey of shore erosion along the Ohio Shoreline of Lake Erie. The synopses of these surveys are published in House Documents 351 and 596 (1952 and 1953 respectively). In conjunction with this study, P. R. Shaffer made a geological reconnaissance of the bluff stratigraphy. His unpublished reports are on file with the Ohio Division of Shore Erosion.

The shore was mapped by the U.S. Army Corps of Engineers in 1947, and airphotos were taken in 1954 and 1956. Maps and photos are filed with the Ohio Division of Shore Erosion. To the southwest of the study area, the shore areas between Fairport and the west boundary of Lake County were studied by Gordon (1956) and Christopher (1956).

In terms of current work, a series of seven maps treating the engineering geology of the Ohio Shoreline of Lake Erie by H. J. Pincus is in preparation. Both R. P. Hartley and J. L. Verber are drawing up maps of the bottom deposits of the lake, and W. J. Tinker III, is working on a genetic classification of Lake Erie beaches.

Concerning map coverage, the area lies across the U.S. Geological Survey 15 minute topographic sheets titled Conneaut,
Ashtabula, Perry and Mentor; the U.S. Lake Survey Charts, 1:80,000, numbers 33 and 34; and the U.S. Army Map Service topographic sheet, 1:250,000, V501.
Location and Size of the Area

The study area lies on the southern shore of Lake Erie in northeastern Ohio, between 41°43' and 41°59' north latitude and between 80°31' and 81°22' west longitude; i.e., roughly between Fairport, Ohio, and the Ohio-Pennsylvania border. About 50 miles long and an average 3 1/2 miles wide, the study area embraces all of the former glacial lake bed region in Ashtabula County and the northeastern half of Lake County. On the southeastern flank, a low belt of undulating Late Cary terminal moraines, called the Lake Escarpment moraines (F. Leverett, 1902, p. 65), demarcates the southern border, beyond which rises the Appalachian Escarpment of Mississippian rocks. To the northwest lies the bluff and shoreline of Lake Erie.

Geomorphology of the Topographic Surface

The Lake Plain of the study area forms part of Fenneman's (1917, p. 65) Eastern Lake Section physiographic subprovince.

It is newly emergent and represents the surface formed by a blanket of lacustrine sand, silt, and clay, and glacial till on bedrock of Chagrin shale.

*During the summers of field work, the level of the lake fluctuated between 572.5 and 573.8 feet. The United States Lake Survey uses 572.0 and 570.5 feet respectively as the Mean Stage and Low Water datum, measured above Mean Tide at New York, 1935 (U.S.L.S. Chart no. 34, 1949). In this report, the author has adopted the general summer level of 573 feet as a reference surface and shoreline for ease of usage.
Fig. 1. Location and Inset maps of study area, northern Ohio.
Along the northwestern edge of the Lake Plain stands the 8 to 75 foot high bluff of glacial till and lacustrine deposits overlooking Lake Erie. Against the southeastern margin rise the flanking Lake Escarpment moraines, a series of knoll-like forms under 100 feet in relief, that mark one of the southern limits of Late Cary ice readvances during the waning stage of the Wisconsin Ice sheet. Between these margins the Lake Plain falls unevenly toward the northeast with an overall slope of about 30 feet per mile, and terraced slopes of 10 to 15 feet per mile. The prominent breaks in slope represent former shores of glacial lakes that left behind beaches and bluffs 5 to 60 feet high.

Carved out of the northwestern flank of the Lake Escarpment moraines over the greater part of the area, the bluffs of Lake Whittlesey, the base of which lies at an elevation of 720 to 740 feet, attains its greatest development of 60 feet in Ashtabula County. However, it is everywhere well pronounced, and in certain spots presents a long view toward the north of the Lake Plain. The top of the bluff across the area is followed by State Route 84. As its height increases toward the northeast the relief developed on the bluff and moraines becomes stronger, especially in Geneva and Saybrook townships where Cowles and Indian Creeks and Red Brook transect them.

Between the bluff of Lake Whittlesey and that of Lake Erie lies the longitudinally continuous beach and bluff of Lake Warren (680 to 690 feet in elevation on the crest). This former shore
swings toward and away from Lake Erie as salient forms around relatively thick (35 to 50 feet), extensive sand and gravel deposits in Madison township in the southwest, and Kingsville and Conneaut townships in the northeast. These salients apparently represent depositional forms built out into and shaped by Lake Warren. Between these broad sand deposits the Warren shore sweeps inland to within 3/4 mile of the Lake Whittlesey bluff as it crosses Geneva, Saybrook and Ashtabula townships. In this area, from the Lake Warren shore toward Lake Erie in the north, a 5 to 20 foot thickness of glacial till forms a broad, shelving, sand deficient, loam covered surface. Apparently the shore of Lake Warren here is primarily an erosional feature.

Many smaller topographic features such as dunes, sand bars and spits dot the land surface. Hutton (1910) mapped many such features on the Ashtabula and Conneaut topographic quadrangles. The bars as mapped range between 0.3 and 0.6 miles in length, and maintain axes roughly parallel to the Warren beach. Additionally, traces of less distinct beaches occur. An example of such is presented by the beach of Lake Lundy in Madison township which apparently controls the westerly course of Chapel Creek (Carney, 1919).

The Lake Erie shore of the study area features throughout most of its length a wave-eroded bluff, broken by the gaps of major and minor streams. The bluff ranges in height from 45 feet in the southwestern one-third of the area, to 8 to 17 feet in the middle one-third, and up to 75 feet in northeastern one-third. Only the 3
major rivers, and a few smaller streams as Big Creek, Cowles Creek, Red Brook and Whitman Creek open gaps in the bluff exceeding 600 feet.

By virtue of its very existence the bluff constitutes an erosional form; the product of wave-erosion, surface wash, groundwater seepage and weathering in general. Since in general the bluff is carved out of uncemented material, it wastes rapidly. The homogeneous till bluffs, an exceedingly rare type, resist wasting best thanks to strong compaction by overriding glaciers, and low permeability. At the other end, bluffs of lacustrine clay and sand, like those that rise in Perry, Madison, Kingsville and Conneaut townships, retreat rapidly under the influence of groundwater seepage. Bluffs of glacial till overlying relatively thick, (6 feet or more) deposits of basal lacustrine material develop the spectacular block slump that afflicts the shore on both sides of Fairport Harbor and the shore across western Geneva and eastern Saybrook townships.

The major streams, such as the Grand, Ashtabula and Conneaut Rivers enter the study area from headwaters on the Appalachian Plateau. On the other hand, the larger minor streams spring from sources on the Lake Escarpment moraines; and most of the smaller minor streams extend headward no farther than the beach of Lake Warren.

The Grand River. The drainage basin of this stream encompasses 712 square miles, which places it a poor fourth in size for Ohio
streams entering the Lake when compared with the 6,586 square mile
drainage of the Maumee River, the largest of the stream systems
(Ohio Division of Water, 1950). The Grand River initiates its
58-mile course on the Appalachian Plateau in westcentral Trumbull
County to the south of Ashtabula County. It flows due north on
a glacial drift-filled valley for about 30 miles before turning
abruptly west to follow the Lake Escarpment moraines for 18 miles.
Along this westerly course below Harpersfield, the river flows at
the bottom of a canyonlike valley cut in shale, 140 to 180 feet
depth. Then it swings north through the moraine at northern Paines-
ville and continues its course on bedrock for 4 miles. Beyond
the Lake Warren beach the river leaves the shale and widens its
valley on glacial till by a factor of 3, continues north an addi-
tional 2 miles, and then meanders west for 1 1/2 miles to southern
Fairport. There it impinges on the Chagrin shale cropping out in
its southern valley wall at the B & O railroad bridge; from here
it swings north and enters the Lake at Fairport after another mile.

Sweeping southwesterly from Fairport in a great crescent,
opening toward the northwest, lies the Mentor Marsh, 3/4 of a mile
wide and 1 1/2 miles long. It is all that remains of a former
extension of the lower course of the Grand River after the river
valley had been intersected by bluff retreat at Fairport.

The Grand River is in process of recovering its own ancient
valley, and perhaps others, from the glacial debris filling it.
However this exhumation lacks system, for in its downcutting, the
river missed segments of the former valley. Accordingly, certain lengths of its valley which are comparatively narrow are interpreted as newly carved valley. Other lengths are broader, reflecting the presence of the ancestral valley. This relationship was observed by Carney (1908-1917) for the big meander between the cemetery and infirmary east of the City of Painesville (Perry topographic quadrangle). There, on a northbound course, the river emerges from a narrow "V" gorge in bedrock, and sweeps out the meander in a flat-floored valley twice as wide. Subsequent drilling just east of the cemetery shows that the bedrock surface lies at least 85 feet below the ground surface; i.e., at an elevation below 600 feet. Thus virtually the entire northeastern valley-wall at this site consists of un lithified material filling an old valley.

The Ashtabula River. Possessing only 136 square miles of drainage basin and 32 miles of length, the Ashtabula River is the smallest of the three major streams in the study area. It rises in western Pennsylvania and flows westward as the Ashtabula Creek to Kelloggsville in western Monroe township of Ashtabula County. There it is joined by the West Branch flowing from the south, whence it continues west, then north, and west again on a Zig-Zag course into the city of Ashtabula, through which the stream flows north to the lake.

For most of its course from Lake Erie to a point between Cageville and Kelloggsville, the river has flushed its ancestral valley
free of glacial fill. Farther upstream, however, the bedrock valley continues below the fill material.

The exposed bedrock valley carved out of the Chagrin shale is steep-walled and flat-floored. Its semi-angular areal pattern seems to be at least partially joint controlled.

Whereas the Grand River crosses the Lake Escarpment with a gradient of 5.5 feet per mile below a westerly gradient of 2.5 feet per mile, the Ashtabula River tumbles onto the Lake Plain at a rate of 20 feet per mile, after maintaining an upvalley westerly gradient to Cageville of 10 feet per mile. Upstream, beyond Cageville to Kelloggsville the gradient on the valley fill decreases to 5 feet per mile.

Three factors apparently exercise great influence on the magnitude of the stream gradient, especially in terms of its upstream flattening: (1) glacial valley fill, (2) bedrock attitude, and (3) net lowering of base level. Just downstream from Kelloggsville, the stream has developed a broad mature valley on the glacial fill because this material is readily eroded and reworked. Thus whatever base level is imposed downstream, this upstream portion finds no difficulty in keeping adjusted to it. The next valley segment downstream follows the strike of the bedrock from Cageville to the locality where the river turns north to cross the Lake Escarpment as a consequent stream. Its relatively low gradient probably reflects the regimen of a higher base level, or, since the stream is flowing along the strike of the beds, greater resistance to
downcutting is offered along this segment than in the consequent portion immediately downstream. The third segment, represented by the passage of the stream across the strike of the Chagrin shale all the way to the southern edge of the city of Ashtabula, includes the site of most active downcutting and steepest gradients. The stream falls lakeward on a profile of abruptly steepened and flattened slopes that lead to a low-water expression of an alternation of falls, a few feet high, and pools of water in the valley floor. From this, the author postulates that the river is not only adjusting its valley to the current base level at Lake Erie, but that the gently sloping flat segments ending at the different falls represent earlier attempts to attain grade when the base level was higher, i.e., when the river was emptying into the glacial forerunners of Lake Erie.

Thus the gentler upstream gradients are legacies of the past. On the other hand, the falls or knickpoints, products of static rejuvenation of the valley, are moving upvalley to impose the new gradient on the older valley profiles.

Above Bushnell, Ashtabula Creek is joined by three barbed tributaries, the most prominent of which occurs 1 mile northeast of Bushnell in central Monroe township. The other two lie just east of the Ohio-Pennsylvania border. Presumably, the Ashtabula valley channelled into Pennsylvania the meltwater from the Late Cary ice grounded on the Lake Escarpment.
Between the westerly courses of the Ashtabula and Grand rivers lie linking troughs or channels now occupied by Coffee and Center Creeks of Plymouth township. Apparently the streams once directed the flow of the glacier-blocked Ashtabula River southwesterly into the Grand River, which then either transferred the outflow southwest into the Chagrin-Cuyahoga drainage system flowing south, or due south into the drainage system of the Ohio River (Leverett, 1902, Pl. II).

Conneaut River. This river drains an area of 192 square miles, three-fourths of which lies in Pennsylvania. It enters Ohio on a west by southwest bearing, and just east of Kingsville turns toward the northeast, and empties into the lake at Conneaut after meandering across the Lake Plain in an entrenched valley for 13 miles. The Conneaut River lacks the deep spectacular gorge of either the Grand or Ashtabula rivers, but like them has its lower course carved into the Chagrin shale. East of Farnham and into Pennsylvania the river flows on glacial till. The bedrock valley still contains a great deal of alluvium which was probably introduced at the time of the higher glacial lakes.

Minor streams. Cowles Creek, the largest of the minor streams, drains an area of 23 square miles (House Doc. 351, p. 15). The stream rises on the Lake Escarpment moraines, and flows in a valley of glacial till to Geneva, where it enters upon the shale. Thence northward to the lake it flows in a 20 foot deep bedrock gorge which opens out into a broad drowned valley about 1 mile from the lake.
At Lake Erie, the stream once meandered parallel to the shore for 1,800 feet before emptying into the lake. However, intercision by the retreating shore has left this lower portion stranded as a swamp, 650 feet wide (Fig. 3). Beneath the swamp lies the bottom of the bedrock valley, at least 18 feet below the lake level, 573 feet in elevation.

Both Wheeler and Big (Arcola) creeks, the two neighbors of Cowles Creek to the southwest in Geneva and Madison townships respectively, are also carved into bedrock and exhibit drowned mouths. The submerged valley bottom of Big Creek lies at an elevation of 561 feet or about 12 feet below lake level of 573 feet. The elevation of the drowned valley of Wheeler Creek was not determined.

Indian Creek and Red Brook to the west in Geneva and Saybrook townships respectively, have eroded out broad mature valleys in the glacial till. The Indian Creek valley opens into the Lake about 3 feet below lake level of 573 feet. Red Brook likewise has a drowned mouth, since its valley floor at the lake lies 12 feet below the lake level. Also similar in development and topographic age, Whitman and Turkey Creeks of Ashtabula and Conneaut townships respectively, empty into the lake at approximately lake level.

Thus the lower valleys of these seven streams are typically mature, and reveal flat floors, valley widths that exceed the
meander belt widths by several times, meander scars and terraces. Likewise all of these streams originate on the Lake Escarpment moraines.

Most of the small minor streams spring from the Lake Warren beach ridge. Their valleys within one-half mile of the Erie bluff exhibit a "V" shaped basal valley incised into a broader, flat-floored valley, of which only remnants may persist as terraces. These flat-floored valleys where fully preserved display, in miniature, the signs of full maturity, including meander cut-offs, oxbow lakes, scrolls and scalloped walls.

Blackmore Creek, located in northwestern Perry township, typifies this category of streams at their full development. It has carved its higher mature valley from the readily eroded lacustrine clay, silt and sand, a unit 17 feet thick, overlying the more resistant till. The inner "V" valley is eroded into the subjacent glacial till, and has a well developed system of entrenched sigmoid meanders inherited from the higher valley. The higher or mature valley ends abruptly at the bluff, about 23 feet above the lake (573 feet), and is 300 to 450 feet wide. The inner "V" valley falls to lake-level across a narrow zone of increased gradient or upvalley migrating knickpoint.

Apparently when the Lake-Plain was first exposed and the stream established thereon, a broad, mature valley was swept out rather early. This would have been possible because the lacustrine material is readily removed, and the resistant till member of the bluff,
some 25 to 30 feet high, might have acted as a temporary base level over which the stream fell. With the passage of time, the till member of the bluff was notched to the level of the lake. However, the effect of the falling base level was communicated upstream more slowly by means of the knickpoints. Thus today, the last 800 feet of the inner valley length, i.e., the profile below the knickpoint, has a gradient about 10 times greater than that farther upstream.

The constant retreat of the bluff under pressure of wave attack also serves to expedite development of the inner valley, since the gradient of the stream from source to lake is effectively steepened (assuming that lake levels have remained within a certain constant range).

In the study area these valley-in-valley forms are found wherever the arrangement of lithologic types in the bluff at Blackmore Creek, i.e., 10 to 20 feet of lacustrine material on a similar thickness of till, is duplicated. All streams dissecting the bluff in Perry township maintain this type of valley, as does Red Brook of Saybrook township (Fig. 5).

Chapel Creek of Madison township is the only member of the larger minor streams that flows west into the lake. In fact, its course runs directly at right angles to Big (Arcola) Creek, its neighbor to the east in eastern Madison township. Flowing through a plush carpet of sand, 30 to 40 feet thick, Chapel Creek has developed a relatively broad valley in its middle course, and is
now eroding the underlying lacustrine clay member. Its tributaries follow the normal northerly direction of drainage from the Lake Warren beach ridge. At Lake Erie over 1,600 feet of valley-length has been lost by the encroachment of the lake into the longitudinal axis of the valley.

Carney (unpublished notes, 1908-1917) has hypothesized that the stream flows west because of the barrier effect exercised by the beach of Lake Lundy. The author concurs.

**Geomorphology of the Bedrock Surface**

The surface of the bedrock rises from the bottom of the lake, at an elevation of at least 500 feet (U.S.L.S. Chart 34) on a long, uneven, concave slope under the Lake Plain to the Appalachian Escarpment at 870 feet. Offshore, between the Conneaut River and Whitman Creek in eastern Ashtabula County, the portion of the slope under Lake Erie rises shoreward at the rate of 28 feet per mile. Beneath the Lake Plain this rate increases to an overall 44 feet per mile, then steepens on the Lake Escarpment between the Ashtabula and Conneaut Rivers to 140 feet per mile. At Geneva township in the middle of the study area, the offshore slope remains at 28 feet per mile; but the slope under the Lake Plain and on the Escarpment falls off to 18 and 40 feet per mile respectively. Farther southwestward into Perry, Painesville and Mentor townships, the patterns

*See Plates VII to X for bedrock surface contour map.*
Fig. 2. Cowles Creek. View toward the northeast, and up abandoned drowned channel. Stream now flows to the lake on a northerly course along the bluff with the white cottages in the far background. The lake lies at the end of the wooded line at left center. Width across valley - 650 feet. Date- Aug. 1956.
Fig. 3. View up the valley of Big (Arcola) Creek toward the south. Beach lies in foreground. Waterway shown is about 100 feet wide. Width of swamp filled valley = 400 to 500 feet.
Fig. 4. View down the valley of Blackmore Creek toward the north. Lake Erie lies in the central background. Observe broad flat-floored valley of the creek as developed on the till. Stream is now incised below. Meander-scars are visible in the middle foreground. Aug. 1956.
Fig. 5. Looking southwest along Lake Erie toward Red Brook, Saybrook township. Stream enters the lake at the long jetty. Long low bluff leading to the jetty in the far foreground represents bench developed by the stream on the till surface. Lake-level - about 573 feet. Aug. 1956.
of numerous buried channels and erosional highs associated with ancestral streams of the Grand-Chagrin River system and outwash courses of many glaciers, describe a complicated surface, the effective resolution and interpretation of which lie somewhat beyond the author's data.

Several drift-filled valleys, not now occupied by major streams, are buried beneath the unconsolidated deposits. The Austinburg valley of the ancestral Grand River, and the Kirtland valley between the East Branch of the Chagrin River and the Mentor Lagoon, comprise the largest two.

The Austinburg valley opens on the bedrock surface of the Lake Plain beneath the Lake Whittlesey bluff in southwestern Saybrook township. It represents the northern extension of the north-south buried valley of the Grand River, over which the present river flows before turning west at Mechanicsville. A transverse cross-sectional view, looking towards the north, reveals that the slope of the west wall of the valley rises at a rate of only 60 feet per mile, or less than one degree. On the other hand, the east wall has a slope of 280 feet per mile, or roughly 3 degrees, which makes it four times steeper than the west slope, although still relatively gentle. On the whole, the portion of the valley mapped is about 6 miles wide across the top, and about 260 feet deep, with a bottom elevation of around 600 feet (Plate II).

The Kirtland valley extends due south from the southwest end of the Mentor Marsh to the Lake-Geauga county line, where it runs
under the valley of the East Branch of the Chagrin River. There the buried valley lies on the northeast side of the river and heads southeastward. The elevation of the bottom of the valley ranges from 510 feet at the lake to 1400 feet in the south of the study area. Apparently, drainage through the valley was at one time mostly toward the north into the lower course of an ancestral Grand River. However, when the glaciers halted on the Lake Escarpment, or farther to the north on the Lake Plain, the valley's gradient was apparently reversed by southerly draining meltwater that flowed into the Chagrin-Cuyahoga River system. The older northerly profile of the valley under the Lake Plain is relatively flat; whereas the incised younger profile in southern Mentor township increases southward to a gradient 50 feet per mile.

Buried valleys of the three major streams extend into the offshore area, but these were not investigated by the author. However, R. Hartley (personal communication, 1959) reports the presence of a buried valley of the Ashtabula River at an elevation of 505 feet, or 68 feet below the level of the lake at 573 feet, and about one mile offshore at the East Breakwater navigational light of the harbor.

Very little of the subaqueous bedrock slope, linking the shore with the nearly flat bed of the lake, is covered by sediments, with the exception of the area off Mentor and Painesville townships where extensive sand and gravel deposits are spread outward from the shore and over the bottom of the lake. An even larger area
of similar deposits covers the lake-bottom off the Conneaut River, but apparently ends at the foot of the subaqueous bedrock slope about one mile offshore as shown in Fig. 6 (Hartley and Verber, unpublished map. 1959).

The control on drainage patterns exercised by bedrock structures has not been specifically studied; however, information obtained from reconnaissance up the Ashtabula River strongly suggests that the tributaries and part of the major stream itself are structurally controlled (Figs. 7, 8 and 9). These observations confirm the conclusions of Hutton (1940) who made a systematic study of joints found in the valleys of the Conneaut and Ashtabula rivers. The author also saw many minor faults and folds, especially in the north-south stretch of the Ashtabula River in Plymouth township, where he counted nine faults and two anticlines in the two-mile segment of valley between Dewey Road and State Route 83. All faults die out in the valley wall at a height of 6 to 7 feet, and most of them occur in the floor of the valley, or in the bench, 4 to 10 feet above the floor of the valley.

Folds as illustrated by Fig. 10 are present along the shore of the lake as well as in the valleys of the larger streams.
Fig. 6. Generalized map of bottom deposits of Lake Erie, between Fairport, Ohio, and the Ohio-Pennsylvania border.
Plate I, Fig. 7, Fig. 8. Hanging tributary of the Ashtabula River in the northeastern corner of Sheffield twp.

Fig. 7 - View toward the southwest parallel to the course of the Ashtabula. Stream makes sharp turn to the right below the falls, i.e., toward the northwest.

Fig. 8 - View at base of falls. Stream turns toward the observer.
Fig. 9. View downstream from the upper falls shown in Fig. 8. Stream plunges over a second falls before entering the valley of the Ashtabula in the sunlit area of the background.
Fig. 10. Small anticline on bench in the valley of the Ashtabula River, 500 feet south of the Dewey Road covered bridge, Plymouth twp. Axis surface of fault extends into a joint on the valley floor with bearing N 40° W. 1957.
GENERAL STRATIGRAPHY OF THE AREA

Stratigraphy of the Bedrock

Virtually the entire shoreline of northern Ohio, with the exception of the southwestern end, has been carved out of Upper Devonian rock dipping south-southeasterly into the Appalachian Basin. At its southwestern end, the lake impinges on the Findlay arch or platform of uplifted Middle and Lower Devonian and Upper and Middle Silurian rocks (Fig. 11).

In the study area only the Upper Devonian Chagrin shale crops out. An exposure of it, several hundred feet long, is found along the shore of Lake Erie in central Ashtabula township, where it rises a few feet above the level of the lake. Inland, it forms the steep walls of the major and some minor stream valleys as previously discussed. The formation consists of a blue-gray to dark gray silty shale, which locally includes large calcareous concretions. Also included in the formation are thin, resistant beds of sandy siltstones (Fig. 12). According to Pepper, DeWitt and Demarest (1954, p. 17), these siltstones increase in thickness and number toward the east, so that zones up to 50 feet thick of intercalated massive siltstones and thin gray shales, separated by thicker zones of relatively pure shales, develop.

The Chagrin shale is regarded as the eastern facies of the Huron and Cleveland shales, two black shale formations difficultly
distinguishable one from the other (Table I). All three formations are members of the Ohio shale. The Chagrin shale thickens eastward at the expense of the overlying tongue of Cleveland shale which thins out in Painesville township. However, the underlying Huron member thins less, and continues across northern Ohio below the level of Lake Erie. In Concord township, just south of Painesville township, lithologic logs show a thickness of 900 feet for the Chagrin shale and 600 feet for the Huron, but only 12 feet for the Cleveland. Farther east, near Pennsylvania, the Chagrin shale attains a maximum thickness of 1,200 feet.

Table I. Generalized table of formations in northeastern Ohio
(from Pepper, DeWitt, Jr., and Demarest, 1954, p. 10).

<table>
<thead>
<tr>
<th>Period and Epoch</th>
<th>Rock Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOWER MISSISSIPPIAN</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Guyahoga Group</td>
</tr>
<tr>
<td></td>
<td>Meadville shale</td>
</tr>
<tr>
<td></td>
<td>Sharpsville sandstone</td>
</tr>
<tr>
<td></td>
<td>Orangeville shale</td>
</tr>
<tr>
<td></td>
<td>Sunbury shale</td>
</tr>
<tr>
<td></td>
<td>Berea sandstone</td>
</tr>
<tr>
<td></td>
<td>Bedford shale</td>
</tr>
<tr>
<td>UPPER DEVONIAN</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ohio shale</td>
</tr>
<tr>
<td></td>
<td>Cleveland member</td>
</tr>
<tr>
<td></td>
<td>Chagrin shale</td>
</tr>
<tr>
<td></td>
<td>Huron member</td>
</tr>
</tbody>
</table>
Fig. 11 Geologic map of the Lake Erie region.
Fig. 12. Chagrin shale exposed in the valley of the Ashtabula River. Location: Eastern Plymouth township, about 1,500 feet north of the State Route 83 bridge. Aug. 1957.
Stratigraphy of the Surficial Deposits

Glacial Till. In broad topographic terms the glacial till assumes both the linear to curvilinear landforms typical of terminal moraines, and the extensive subdued surfaces associated with ground moraines. The Lake Escarpment moraines (Fig. 13) possibly represent the marginal deposits of the last major readvance or perhaps recessional pause of the Late Wisconsin ice-sheet in the study area.

On the other hand, the till sheets form the most widespread stratigraphic member of the deposits superjacent to the Chagrin shale; although this statement is qualified by the fact that basal gravels and sand up to 18 feet thick often underlie the till. Along the shore the till, usually made up of two layers herein called the Upper Till and Lower Till, presents an unbroken front that ranges from a maximum thickness of some 65 feet (exclusive of 6 to 10 feet of interstratified lacustrine deposits) in Painesville township, to a low of 10 feet in Madison township. Northeastward into Geneva township and beyond, this thickness again increases, fluctuating between 25 and 50 feet according to the presence and extent of the laterally discontinuous interstratified lacustrine beds.

Inland from the shore of Lake Erie in Lake County, the till thickens until it has passed beyond the Lake Warren beach and then

*Lithologic sections listed in the text are described under Appendix.*
Fig. 13. Geologic Map showing glacial deposits of Northeastern Ohio.
proceeds to thin as the Lake Whittlesey bluff is approached. Thus in Painesville township, whereas a thickness of 65 feet is recorded at the shore of the lake, only 8 feet of this thickness remains at a point one mile south of the Lake Whittlesey ridge against the Grand River valley. Again, this statement is qualified by the presence of drift-filled valleys in the vicinity of the Grand River. In Perry township, the thickness of the till, 35 feet at the lake, increases to 75 feet under the Lake Warren ridge, but thins to near zero at the town of Perry, about one-quarter mile north of the Lake Whittlesey ridge. Madison township reveals a similar relationship as shown by the cross-section of Figure 17.

On the other hand, the overall bedrock surface of Ashtabula County in the area west of Kingsville township and north of the Lake Warren ridge, is more thinly covered with till than similar areas in eastern Lake County. This mantle is thinnest in Geneva and Ashtabula townships, where only 3 to 4 feet and 10 feet respectively are registered, and thickest in Saybrook township, where 19 feet are recorded. However, immediately south of the ridges of Lakes Warren and Whittlesey, the till thickens to form modified benches facing the north. From the foregoing, the author postulates that the waves of Lakes Warren and Arkona-Whittlesey had cut away much of the till on the Lake Plain, and had left these benches as erosional forms (Figs. 14 and 15).

In general, the total thickness of the till on the Lake Escarp-ment exceeds that on the Lake Plain. These moraines were examined
at several localities by Read (1873, p. 516-17), who recorded the presence of two tills in the Lake Escarpment moraines as reproduced below. The section was measured in the locality where the Ashtabula River intersects the moraines.

<table>
<thead>
<tr>
<th>Top</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sandy loam</td>
<td>1 - 2</td>
</tr>
<tr>
<td>2. Yellow clay with fragments of shale</td>
<td>10</td>
</tr>
<tr>
<td>3. Blue clay with fragments of shale and boulders</td>
<td>1½</td>
</tr>
<tr>
<td>4. Fine sand, local</td>
<td>0 - 3</td>
</tr>
<tr>
<td>5. Coarse gravel, coarsest at bottom</td>
<td>10</td>
</tr>
<tr>
<td>6. Blue clay with boulders</td>
<td>50</td>
</tr>
<tr>
<td>7. Erie shale in place</td>
<td></td>
</tr>
</tbody>
</table>

On the Lake Escarpment across Painesville and Perry townships, the section maintains a thickness of 96 feet, and consists of capping and basal till units, 47 and 23 feet respectively, separated by 25 feet of lacustrine or fluvialite sand and clay (section 6). Towards the northeast into Madison township, the moraines thin to 70 feet on a rising bedrock contact (section 7). Across Harpersfield and Austinburg townships, the line of section passes through the old north-south Austinburg valley of the Grand River. Accordingly, the section undergoes gradual thickening to a maximum of 24½ feet at the base of the eastern wall of this valley (Plate II).

In conjunction with the thickening sedimentary section across the valley, additional beds appear below the thick till units traced from the southwest. The new units are described by the well drillers of the United States Army Corps of Engineers mostly as silty clay or pebbly clay, separated one from the other by beds of sand.
Plate II. East to west geologic cross-section through the Lake Escarpment moraines, Harpersfield and Saybrook townships, Ashtabula County.
They apparently occupy a position of onlap against the west wall of the valley. The author has separated from the logs (sections 10, 11, 12 and 13) three additional units of till, possibly Cary in age (Plate II). On the other hand, the two basal silty clay units and the included sand in the axis of the valley may be lacustrine in origin, if the fact that they lie below 700 feet in elevation, i.e., below the level of the higher glacial lakes, can be construed as an indication that the Austinburg valley was an arm of some pre-Late Cary glacial Great Lake. Unfortunately, the author lacks the means to test either postulate.

The stratigraphy becomes more simplified east of the Austinburg valley. At Munson Hill, Saybrook township, 90 feet of till rest on more than 22 feet of sand and gravel (section 14). Here the one-mile wide valley of Coffee Creek has been cut into the moraine. On the south side of the divide, Center Creek apparently occupies a moraine-filled bedrock valley (Fig. 14).

Passing into northern Jefferson township, the moraine forming the divide north of the westerly course of the Ashtabula River, thins to about 25 to 30 feet from the 90 foot value of Saybrook township, although thicker deposits are known to occur in the valley of the Ashtabula at Kellogsville. Nevertheless, the relatively thin mantle of till on the divide thickens northward to some 60 feet near the Lake Whittlesey bluff, as illustrated by the stratigraphic cross-section of Figure 15.
Eastward, between the courses of the Ashtabula and Conneaut rivers, only 5 to 20 feet of glacial till covers the Lake Escarpment. However, on the northern side of the Conneaut River, the moraines thicken to values between 60 and 90 feet (sections 16 and 17).

The spatial relationship between the till on the Lake Plain and the moraines on the Lake Escarpment is probably best delineated in Saybrook and Geneva townships of Ashtabula County (Fig. 14). The rather steep bluff of Lake Whittlesey marks the norther topographic front of the Lake Escarpment moraines, here 40 feet thick. From the base of the bluff the glacial till of the Lake Plain extends northward as a thin sheet. Nevertheless, the author traced the till sheet into the lower part of the Lake Escarpment moraines in the locality where Cowles Creek turns north through the Lake Whittlesey bluff.

A series of knolls resembling kames, 20 to 50 feet high, caps the Lake Whittlesey bluff in Saybrook township. The author measured the following section in a gravel pit cut into one of these hillocks.

Section 18

Location: State Route 81, between Indian Creek and Brown Road, Saybrook township.

<table>
<thead>
<tr>
<th>Top</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fine sand, red-brown, stratified and well sorted</td>
<td>8</td>
</tr>
</tbody>
</table>
Fig. 14. Geological cross-section B-B', Saybrook and Plymouth Townships, Ashtabula County, Ohio.
Fig. 15. Geological cross-section C-C', Sheffield and Kingsville Townships, Ashtabula County, Ohio.
2. Gravel and sand mixture; poorly sorted and irregularly bedded. Precise though undulatory basal contact .............................................. 8

3. Till; pebbly, poorly compacted silty to sandy clay (Road level elevation: ca. 750 feet) ........... 9

It seems to the author that perhaps a certain amount of the Lake Escarpment moraines postdate the typically compacted till of the Lake Plain, which in its turn would be correlative with lower portions of the Escarpment moraines. Units of the Lake Plain tills equivalent to the upper portion of the Escarpment moraines may have been removed by erosional activity associated with the glacial lakes.

Since the tills of the Lake Plain underlie lacustrine deposits laid down in lakes Arkona and Whittlesey, and since lacustrine beds of Lake Whittlesey age have been dated at Cleveland, Ohio, by techniques based on Carbon 14, as 13,600 ± 500 years before present (Goldthwait, 1958, p. 218), then the tills and moraines would not be any younger than this, i.e., Late Cary Age.

Lacustrine and Fluviatile Deposits. Two extensive deposits of sand and gravel occupy broad areas of the Lake Plain in the study area. One such deposit, 20 to 50 feet thick, covers an 11 square mile area of Madison township of Lake County, between the bluffs of Lake Whittlesey in the south and Lake Erie in the north. The other deposit, about 12 square miles in area, is located in Ashtabula County, between North Kingsville in the southwest, and the city of Conneaut in the northeast. The 70 foot bluff of Lake
Fig. 16. Section through sand-capped moraine on State Route 81, between Indian Creek and Brown Road; Saybrook twp. looking south. Aug., 1956.
Erie terminates the deposit to the northwest, whereas the 60 foot bluff of Lake Whittlesey over­looks it from the southeast. Trend­ing diagonally across the area toward the northeast, the Conneaut River divides this deposit into two parts: a southeastern portion, consisting of a thin sheet of sand and gravel, 7 to 10 feet thick resting on bedrock, and a northern and western unit with sand more than 50 feet thick in the broad beach of Lake Warren, and 35 feet thick in the bluff of Lake Erie. Unhappily, the author has not gathered enough subsurface data to formulate a sound reconstruction of the history of this regional sand deposit. However, he believes that it has undergone a development similar to that given for the Madison township deposit below.

The Madison Township Sand Deposit. On the basis of its morphology, one may divide the Madison township sand deposit into a southern and northern area, and utilize the east-west, northerly arched sandy bluff of Lake Warren as the line of demarcation. At Haines and MacMackin Roads in the northwestern part of the township, the sand in the Lake Warren beach attains a thickness of 50 or more feet. Away from this area, toward the south, east and west, the southern sand deposit thins to less than 15 feet. Nevertheless, a thickness of 35 feet is maintained over most of its central area.

Isopachs drawn on the northern deposit (Fig. 17) reveal a westerly elongated body, the eastern end of which is anchored to the rising bedrock surface in the adjacent area of Geneva township. From the western end, where the sand body is truncated by the receding
bluff of Lake Erie, and the sand unit is 35 feet thick, the deposit thins progressively eastward to a thickness of 3 feet. The beach of Lake Lundy, just north of Chapel Creek, follows its axis as inferred from the isopachs.

Lacustrine clay under the northern sand deposits (Fig. 17) thickens toward the southwest to 20 feet. In its turn, the lacustrine clay rests on glacial till which thickens as the lacustrine clay thins toward the south and southeast, until it becomes about 40 feet thick under the Lake Warren beach. Thence southward the till pinches out against the rising bedrock surface (Fig. 18).

Concerning the source of the sand deposit, the author believes that glacial outwash and reworked till served as its parent material. Gravel and sand, up to 20 feet thick, and presumably glacial outwash, are found in many of the neighboring localities underneath the Lake Escarpment moraines. Since glacial Lakes Maumee (?), Arkona, and Whittlesey have benched these moraines, a great deal of the basal sand and gravel, as well as the coarse fraction of the till, must have been released for redeposition.

Also it is postulated that the source area lay to the southeast for the following reasons:

1) The bedrock surface slopes toward the northwest and west under the northern deposits; and lacustrine clay thickens in that direction at the expense of the sand deposit.

2) The southeastward and eastward increase of the bedrock elevation brings it to within a few feet of the topographic
surface in adjacent Geneva township. There the bedrock presents a broadly shelving, till-veneered surface, 20 to 40 feet higher than that in Madison township.

3) Additionally, in Geneva township, the bluff of Lake Whittlesey is 20 feet higher than that in Madison township, which implies strong erosion of the till and kame deposits found there.

Thus the author concludes that the predominant littoral drift of Lakes Arkona and Whittlesey was westward, and that it introduced the bulk of the sand deposits into the area. Each lower lake-stage continued the redistribution by benching the previously formed sand deposit, and spreading the derived and newly introduced sediments farther northward and northwestward over the deeper water facies of lacustrine clay. The last of these glacial lakes on the Lake Plain, i.e., Lake Lundy, reshaped and extended the northern deposit along the present site of Chapel Creek into a beach or spit beyond the present shore of Lake Erie.

It is worthy of note, if the foregoing be valid, that the littoral drift of these glacial lakes proceeded in a direction opposite to the predominant northeastward littoral drift existing in Lake Erie today.
Fig. 17. Isopach Map of surficial lacustrine sand deposits, Northern Madison Township, Lake County, Ohio.
Fig. 18. Geological cross-section A-A', Madison Township, Lake County, Ohio.
DETAILED STRATIGRAPHY OF THE LAKE ERIE BLUFF IN THE AREA

An erosional feature of shore and mass wasting processes, the bluff of Lake Erie presents a vertical stratigraphic cross-section of the Lake Plain. Two till formations herein called the Upper Till and Lower Till, locally separated from each other by lacustrine silt, sand and clay, red clay lenses, and boulder pavements, can be traced throughout most of the bluff area, from Mentor-on-the-Lake to the Ohio-Pennsylvania border. These units constitute the salient stratigraphic members of the bluff, except in the areas stretching across eastern Perry, Madison and western Geneva townships, and across Kingsville and Conneaut townships, where two units of lacustrine clay and sand, up to 50 feet thick, dominate the section.

The dark lacustrine clay and silt which overlie the Upper Till, may or may not grade downward into the till. Where they do, the transition zone is marked by an increase in toughness, an increase in the percentage of clay and pebbles, and a decrease in the percentage of silt and sand. Likewise, this pattern holds true for the basal contact of the lacustrine clay and silt interbedded between the tills.

Where the lacustrine unit between the tills is absent from the section, the intertill contact has been located by other criteria; such as, the presence of boulder pavements, zones of...
interfingering or incorporation of red, fatty, clay with pebbly, greenish gray till; by the presence of stringers and alignments of red lacustrine clay lenses in the till; and by the persistent tendency of the contact to follow an elevation ranging between 574 and 580 feet; i.e., 1 to 7 feet above lake-level (573 feet).

With respect to the appearance of the tills themselves, the author found no satisfactory method of distinguishing one from the other in the field or laboratory, save for a highly subjective interpretation of color differences. The Upper Till appears to be slightly more pinkish gray than the Lower. The existence of another older till is suggested by the lenses of greenish gray, very pebbly till occasionally incorporated into the lacustrine clay of the intertill contact zone.

In the following account, the bluff stratigraphy is described by townships, beginning with Painesville in the southwest, and proceeding northeastward. Plates XI to XIII provide a continuous section or fence diagram of the stratigraphic units.

**Painesville Township**

Throughout northwestern Painesville township, from the Grand River to Bacon Road, the bluff stratigraphic divisions consist, in general, of an upper till unit, 42 to 46 feet thick, overlying 6 to 12 feet of lacustrine material, which in turn rests on the basal member of Lower Till. The contact on the Lower Till is visible near beach level, especially in the area just east of Painesville
Township Park. Precipitous slopes and slump made difficult the accurate measurement of sections on the face of the bluff in this area.

On the property of the Diamond Alkali Company, the following two sections were drilled and described by the geological staff of that company, and are here presented through their courtesy.

**Section I**

**Location:** Diamond Alkali Company property, 150 feet south of the bluff, and about 3,000 feet west of Hardy Road on the east side of Painesville Township Park.

<table>
<thead>
<tr>
<th>Top (Elevation: 628 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Topsoil</td>
<td>0 - 3</td>
</tr>
<tr>
<td>2. Yellow clay, pebbly (weathered till)</td>
<td>3 - 11</td>
</tr>
<tr>
<td>3. Blue clay, pebbly (unweathered till)</td>
<td>11 - 14</td>
</tr>
<tr>
<td>4. Blue clay, soft, no pebbles (lacustrine)</td>
<td>14 - 32</td>
</tr>
<tr>
<td>5. Blue clay, firm, pebbly (till)</td>
<td>32 - 56</td>
</tr>
</tbody>
</table>

**Section II**

**Location:** Diamond Alkali Company property, 70 feet south of bluff, and 1,800 feet west of Hardy Road.

<table>
<thead>
<tr>
<th>Top (Elevation: 628 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Topsoil and yellow clay</td>
<td>0 - 10</td>
</tr>
<tr>
<td>2. Blue clay, pebbly (till)</td>
<td>10 - 14</td>
</tr>
<tr>
<td>3. Blue clay, soft (lacustrine)</td>
<td>14 - 52</td>
</tr>
<tr>
<td>4. Blue clay, firm (end of hole) (till)</td>
<td>52 - 62</td>
</tr>
</tbody>
</table>

In the length of bluff between sections I and II, lacustrine deposits appear at the top of the bluff. The material contains
locally well sorted sand, but is otherwise highly pebbly, as if
glacial lake water had but poorly reworked glacial deposits. This
unit is described under Section III, unit 1, and portrayed under
Fig. 19.

Section III

Location: At foot of Hardy Road, on the eastern side of Paines-
ville Township Park, Painesville Twp.

Top (Elevation: 628 feet).

1. Gravels of all sizes. The coarse sizes are rounded,
irregularly layered, and consist mostly of shingle,
1/4 to 1/2 inches in great diameter. Very coarse
sand, granules and pebbles lie in ill-defined lenses
at the lower contact. Material becomes soupy when
saturated, indicating high silt and clay content
(Fig. 19) .................................................. 3.5

2. Clay, pebble-free, reddish gray to brown, fatty.
Contain fatty red clay nodules and thin lenses of
fine gray sand and silt. Lower contact is gradual,
as indicated by an increase downward of
the pebble population, grayness and hardness, and
a decrease of the moisture content .................. 3.0

3. Till, gray, very hard. Mostly silty clay. Upper
3 feet contain small pockets and surfaces of sand.
Lower contact is obscured by slump. Thickness
unmeasured ............................................

4. Lacustrine clay, sand and silt. Observed primarily
in the slump forms. Basal contact is well developed,
and lies 2 to 7 feet above lake datum of 573 feet.
Contact zone includes lenses of gray-brown, fatty,
pebble-free clay and undulates, thickens, thins and
bifurcates to include lenses of till. Combined
thickness of units 3 and 4 = ..................... 46.0

5. Till, pebbly, gray, silty clay ........................
total 2

Apparently, the lower part of the Upper Till intertongues
with, and incorporates large quantities of lacustrine clay and
Fig. 19. Unit at top of Section III and 4 feet thick, 1,000 feet northeast of Painesville Twp. Park. The small rounded cobbles embedded in the clayey matrix are part of an eastward decrease in size of the constituents. About 1,000 feet to the southwest, the cobbles become boulders, and the sand percentage of the matrix increases. Farther to the NE, the unit grades into fine, well sorted sand. Aug. 1956.
sand. Thus the basal contact cannot be properly delimited. This heterogeneity of lithology is believed to facilitate displacement of the Upper Till member, because of the greater permeability and plasticity of the lacustrine member. Slumping occurs throughout the area as far northeast as Bacon Road, and is described under the Chapter dealing with "Mass Movement."

Units 1 and 2 of Section III continue northeastward for 3,600 feet. Unit 1 thickens to 6 feet, and the size fractions decrease into small pebbles in a matrix of silt and clay. Unit 2 thickens to 4 feet, and reveals slight laminations. Till remains the salient member of the bluff.

At Bacon Road, both units 1 and 2 have pinched out, leaving the bluff all till. The stretch of bluff across the property of Industrial Rayon was not investigated.

**Perry Township**

Northeastward across Perry township, the upper contact on the till undergoes a gentle but constant decrease in elevation (i.e., from 595 to 580 feet, over a distance of 25,000 feet) on which the lacustrine deposits correspondingly expand in thickness. Both Upper and Lower tills remain in evidence on a locally bold inter­till contact, that follows a level of 573 to 575 feet, and which becomes strikingly distinct in the southwestern part of the area by the presence of boulder pavements. Two lacustrine beds overlie the Upper Till; an upper sandy unit, and a lower clayey member. The
upper unit eventually dominates the lithology in the northeastern bluff area.

**Section IV (Fig. 20)**

Location: About 3,000 feet northeast of the Painesville-Perry township line, and 1,600 feet southwest of Blackmore Road.

Top (Elevation: 620 feet)  

<table>
<thead>
<tr>
<th>Feet</th>
</tr>
</thead>
</table>
| 1. Clay; buff, silty, pebble-free. Becomes laminated 3 feet from the top, and grades downward into gray laminated clay, silt and sand. Basal contact zone includes small (few inches long) surfaces of red clay | 18  
| 2. Till. Pebby, silty clay. Basal contact zone is 1 to 3 feet thick, and 1 to 5 feet above the beach | 22  
| 3. Till. Like unit 2 | 3  

Section III remains characteristic of the bluff toward Blackmore Road, with the exception that the upper 3 feet of unit 1, becomes distinguishable as a separate unit, which farther to the northeast develops as the sand member capping the bluff.

The contact zone between the tills was traced from a point 1,200 feet southwest of Blackmore Road to a point 300 feet southwest of the second creek northeast of Blackmore, for a bluff distance of 3,800 feet. This zone gently undulates between the elevation of 573 and 578 feet. Strongly contorted, red-mottled, pebbly, and pebble-free clay and sand characterize the material of this zone. This material strongly resembles the basal deposits of the lacustrine beds that cover the till in this area and elsewhere. The red spots in the clay consist of small hematitic pebble-size clay bodies.
Fig. 20. Bluff. Site of Section IV, 1,600 Northeast of Blackmore Road in the background (site of low bluff). Section consists of lacustrine sand, silt and clay on till. Dark seepage zone traces the upper contact on the till member. Height of bluff = 43 feet. Lake level = 573.5 feet. Aug. 1955.
About 700 feet southwest of Blackmore Road, gray-red, fatty, pebble-free clay forms the material in the contact zone (Fig. 21). Northeast of Blackmore Road, about 750 feet, the zone widens and thins, like boudinage, around 4 to 5 feet of contorted lacustrine sand, silt and clay (Fig. 22). Still farther to the northeast, about 1,100 feet from Blackmore Road, the zone thins, but is clearly demarcated by a boulder pavement (Fig. 23) made up of flat-lying sandstone slabs with a few rounded igneous stones. Beyond this last area, the contact zone thins to a few inches, but includes pockets of very gravelly, greenish gray till, before fading or becoming lost all together.

Along the length of this particular shore, the bluff fails by near vertical shearing-off of the massive till, caused by wave-undermining in general, and the scooping out of the lacustrine material of the contact zone in particular (Fig. 22).

Section V

Location: On property of the Roosevelt Camp for boys near the west boundary; and 1,150 feet SW of Perry Park Road, and 2,850 feet NE of Blackmore Road.

Top (Elevation: 617 feet)  


2. Mixture of silt, sand and clay; gray. Uppermost 4 feet include blue-gray, pebble-free clay, that inter-tongues laterally with brown interbedded sand and clay. Downward for 10 more feet distorted pockets and small lenses of sand, an inch to several inches long, appear throughout the fatty clay. Lateral gradations into laminated sand and clay are also present.
Fig. 21. Contact zone at base of Upper Till 800 feet southwest of Blackmore Road Perry township. Zone consists of pebbly, lean, reddish, dark-gray silty clay; pebble-free very fine sand, lenses of blue-gray till, and pebble-free red, fatty clay. Sept. 1956.
Fig. 22. Contact zone between Upper and Lower Till, 750 feet northeast of Blackmore Road, Perry twp. Zone thins and widens around contorted bodies of lacustrine sand, silt and clay, up to 5 feet thick. View towards the southwest. Wave action has scooped out some of the lacustrine material. Aug. 1956. Lake level = 573 feet.
Fig. 23. Boulder pavement on contact between Upper and Lower Tills. Location - 1,100 feet northeast of Blackmore Road, Aug. 1956. Water level: 573 feet. Looking northeast. Observe wave nipping at base of bluff.
Toward the base of the unit, the clay becomes more reddish, denser and harder, and includes small (0.1 to 0.3 inch), hematitic red clay bodies. The sand constituent disappears and rounded granules appear.

3. Till. Very hard, dense, pebbly to bouldery. Contains long bands of gravel and sand, 8 to 12 inches thick, and 1,500 feet long. Intertill contact unrecognized.

In this general locality, the beds of unit 2 of Section V are marked by the development of strongly contorted forms as described at the end of this subchapter, under the heading "Certain deformational features in the Lacustrine Deposits."

Northeastward to Section VI, the stratigraphy retains the three-fold grouping of Section V, and continues to exhibit the lenticular and intertonguing relations of unit 2 of that section.

Section VI

Location: Perry Township Park, on the eastern side of Perry Park Road, and 1,150 feet NE of section V.

Top (Elevation: 614 feet)

1. Buff silt and fine sand. Includes many horizontal surfaces of parting encrusted with limonite, to give a faintly bedded appearance. Lower 0.5 foot consists of buff, fine sand.

2. Clay; brown, fatty, pebble-free. Grades downward into laminated brown-gray clay and sand. Laminae are irregular and discontinuous. Sands are often bedded and lenticular.

3. Upper Till. Very pebbly, silty clay; few boulders. Grades downward from unit 2 through a tough clayey zone containing red clay pebbles and a downward increasing pebble population.

4. Lower Till. Like Upper Till. Contact between tills about 1 foot above the beach.
According to Chieruzzi and Baker (1958, p. 99), the till lies on 3 feet of basal gravel, which in turn rests on the shale at an elevation of 563 feet. Thus the Lower Till is actually 22 feet thick.

Unit 2 of section VI increases to a thickness of 9 feet, 600 feet northeast of that section, and its sand becomes cross-bedded and generally stratified.

Section VII

Location: 600 feet NE of Parmly Road extended, or 1,800 feet NE of Perry Park Road.

Top (Elevation: 616 feet)

<table>
<thead>
<tr>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Silt and fine sand, buff. Interbedded ........ 10</td>
</tr>
<tr>
<td>2. Sand; buff, and brown clay. Grade downward after 4.5 feet into gray sand and clay. The clay content increases downward, until after 13.5 feet, the unit becomes a gray-brown, stiff clay, nottled with red and black clay pebble-size bodies. The black clay bodies when freshly broken, give off a faint marshy odor. Near the basal contact, small pebbles appear, and the unit grades into the till ............. 19.5</td>
</tr>
<tr>
<td>3. Till. Very pebbly, silty clay ................. 14/43.5</td>
</tr>
</tbody>
</table>

Several hundred feet to the northeast of section VII, the gradational contact between the lacustrine clay and the till, yields to one that is clearly sharp, not only in the physical break, but also in the change of color from the reddish gray of the lacustrine clay to the blue-gray of the till.

Beyond this locality, the bluff becomes obscured by vegetation. However, the stratigraphic relations seem to maintain the order
of that of section VII to Center Road, a distance of 1,500 feet. This conclusion is supported by the occasional exposures of the bluff constituents along this isolated stretch.

Section VIII

Location: 2,200 feet NE of intersection of Center Road and Lockwood Road, or 600 feet SW of first creek east of Center Road.

Top (Elevation: 622 feet)

1a. Sand, poorly sorted, buff, pebbly. 3

1b. Sand, well sorted, bedded. Sharp basal contact. 9.5

2. Gray clay, silt and sand. Laminated. Becomes more clayey with depth. Basal zone contains discontinuous lenses of gray clay, red clay, silt and fine sand. Basal contact is sharp, but strongly undulatory, with a relief as great as 7 feet both southwest and northeast of the section ................... 23

3. Till (beach level) ................. 49.5

Section IX

Location: 3,000 feet east of center Road, or 800 feet northeast of section VIII.

Top (Elevation: 625 feet).

1a. Sand, buff, very fine ................. 3

1b. Sand, interbedded, bedded and cross-bedded. Subordinate silt and clay. All sands, fine to coarse, are encrusted with limonite. Clays and fine silts are generally gray. (See below for detailed description). .................... 7

2. Clay; gray, pebble-free, moist, and stiff. Contains lenses of sand. Lower one-third
becomes mottled with red clay and streaked with fine sand. Pebbles appear in the basal portion, which becomes very hard, and grades into the till.

3. Till, Upper, pebbly to bouldery. Separated from Lower Till by contact zone 3 feet wide.

4. Till, Lower, gray pebbly.

Unit 1b of section IX bears the characteristics of a shallow water deposit as indicated by the abundance of cross-bedding.

Unit 1b (section IX)  

<table>
<thead>
<tr>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Sand; mixture of buff and gray, traces of cross-bedding, though generally nonbedded. 2</td>
</tr>
<tr>
<td>2) Sand, medium, gray and cross-bedded. Cross-beds span the entire thickness of the subunit, and dips NE about 30°. Individual laminae of the cross-beds attain lengths of 2.4 feet. Unit appears to be lenslike, and to have been deposited in a shallow hollow by currents (scour and fill). Size of sand grains become smaller toward the northeast in conjunction with thinning of the lens. 0.7</td>
</tr>
<tr>
<td>3) Five slightly cross-bedded layers of silt and sand 2.1</td>
</tr>
<tr>
<td>4) Sand; coarse to medium, gray and rusted. Strongly cross-bedded. Upper contact consists of wavy, limonite-encrusted silt, with bedding that follows the undulation of the contact. From this contact, cross-beds in the coarse sand dip easterly on curved surfaces, that suggest more of the scour and fill depositional patterns. A dark limonite encrusted layer that thickens westward to 1/4 inches, forms the basal contact 1.0</td>
</tr>
<tr>
<td>5) Bedded silts; gray to buff 1.5</td>
</tr>
</tbody>
</table>

Northeast of section IX, the contact on the Upper Till undergoes a steady decline in elevation, and falls to within a few feet of the beach, just west of North Perry Village Park.
Fig. 24. View of bluff 50 feet high between sections VIII and IX; about 2,000 feet SW of North Perry Village Park. Cavitated top unit with cavities. Unit consists of sand, in which martins have built their nests. The dark zone characterizes the denser and moister laminated lacustrine material. The line of vegetation delineates the contact on the till. View toward the west.
From a point about 1,000 feet southwest of the North Perry Park to Townline Road, at the eastern boundary of Perry township, no good bluff exposures are seen, except for an eroded remnant forming the north valley wall at the mouth of Chapel Creek.

In the long stretch of shore, vegetation, protected by a fringing beach, conceals the bluff stratigraphy. Isolated exposures reveal the presence of great thicknesses of sand, and lacustrine laminated sand, silt and clay, similar to that of section IX and section X of Madison township, and very little glacial till.

Certain Deformational Features in the Lacustrine Deposits

In the localities between sections IV and V, a distance of 4,000 feet along the bluff of western Perry, the lacustrine beds overlying the Upper Till reveal local, intense deformation on a small scale, of which the general site of section V, about 950 feet southwest of Perry Park Road, provided the best exposure. These features are diagrammed and portrayed in Figures 25 to 28, and discussed below.

The fold described in the diagram of Figure 25 rests on a bed of fine to medium, clean, well sorted sand, 8 inches thick, from which it rises sharply into an arch. Its northern flank dips more gently than the southern, and bends to form a gentle syncline, from which the clay beds work their way into the tattered ends of the interbedded sand and clay of unit 2 of section V. Contorted sandy lenses snake southerly from the broken beds and follow the
Fig. 25. Contorted forms in lacustrine beds of unit 2, section V; 950 feet southwest of Perry Park Road, Perry Twp. Fold apparently developed by plastic flowage and shear in response to differential loading.
Fig. 26. About 4 feet south of Fig. 25. Piercement fold (diapir) in lacustrine unit of interbedded sand and clay. Note small sand dike at the southern end of the fold protruding from the underlying beds.
Fig. 27. Contorted bedding laminated, lacustrine beds on the west side of "V" cut, 950 feet southwest of Perry Park Road; and immediately north of the site of Fig. 25. At the northern end where distortion is at maximum, the fold rests against a massive, dense block of silty clay. Beds of the middle section are mildly contorted. A similar anticline, but less deformed than the one in the north, lies to the south, and is marked the handle of the trenching tool at the left. This is the feature diagrammed in Fig. 25. Distance between trenching tools = 9 feet.
general curvature of the syncline. On the northern flank of the anticline, the array of closely imbricated and twisted miniature lenses of sand becomes legion, and assumes a bewildering complexity on the apex of the fold. Southward, the disorder diminishes and the crumpled forms straighten into flat beds dipping southerly at an angle of 3 to 9 degrees, for a distance of 15 to 20 feet.

Most of the distortion is reflected by the primary clay forms. The disruption of the interbeds at the northern end of the diagram and the associated curled and waved sand stringers suggest the former existence of a distorting force, which was probably largely compressional and exerted by a load. The body of the anticline probably represents the site of least stress into which the plastic clay members of the loaded interbeds were squeezed. Involution of the ends of the opposing pairs of sandy lenses in the lower body of the anticline indicates rotational as well as translatory movement from directions both north and south. The eight-inch sand unit below, possibly because of a greater competency in a confined environment, resisted deformation more effectively.

About 15 feet to the south of the anticline of Figure 24 occurs that of Figure 25. The flat but southerly dipping beds of Figure 24 repeat on a smaller scale the behavior of its northern counterpart. Again, primary distorted forms attain greatest development on the northern flank of the fold. Sheared beds are less in evidence than those of the more northerly neighbor; and the axial surface of the asymmetrical fold tilts toward the north.
The penetration of the brown clay by the upper part of the fold suggests diapirism, a behavior associated with piercement salt plugs. Sand dikes intruded into the southern flank of the fold from the underlying bed indicate that very little lateral slippage of the fold has taken place.

Both the fold of Figure 25 and another 9 feet north of it, are shown in Figure 26. The more northerly fold reveals even greater deformation than the fold of Figure 25, and apparently grew against the side of a massive block of dense, loamy clay. This block interrupts the normal horizontal distribution of the laminated beds of clay and silt, and apparently had lain on the floor of this particular lake during the period that the laminated beds were deposited.

As shown in Figure 27, another such block (on the opposite wall of the cut) had apparently also undergone some deformation. Overlying sand has been injected into the upper portion of the block, forming a pocket, from which tongues of sand splay into the body of the clay. Likewise, thin layers of sandy material rise along the southern margin as if in response to squeezing. Adjacent to the block diagrammed lies a similar block immediately to the south, which served as the opposing end of the vise between which the loam of unit 1 of section V was squeezed. The upper portions of both blocks reveal some invasion of the overlying horizontal material.

Beds resting on the blocks, as well as the upper part of the blocks themselves, are cut by numerous, lateral, limonite-encrusted fractures. These discontinuous fractures even intersect the
Fig. 28. Clay blocks opposite folds of Figs. 25 and 26, but on eastern wall of "Y" cut. Observe splaying of primary forms of the overlying loamy material injected into the upper part of the block. Near-vertical lines constitute primary forms in the material bordering the sides of the block. This material was compressed between this and adjacent block.
near-vertical primary structural forms, and thus apparently postdate them. The author believes that these fractures represent surfaces of pressure relief; i.e., the sediments involved were once loaded by a now absent agent.

Thus to summarize, all of the contorted forms discussed reveal evidence of having been forced into movement and deformed by a force, a component of which exercised a southerly thrusting effect on the sediments. Moreover, the presence of sand dikes penetrating the disturbed beds rules out the probability that mass sliding of the overlying beds was part of the disturbance. Finally, the laminated beds dip 4 to 9 degrees toward the south, or in a direction opposite that expected for depositional dips into the lake basin. Thus it seems that one may attribute the deformation described to differential loading by some agent, probably from the north, such as a heavy ice mass. Another probable agent may be the weight of the column of glacial lake water. In this situation, the loading would be equal, but disequilibrium may have been induced by unequal response of the sediments to the stress imposed.

**Madison Township**

The bluff falls across Madison township from an elevation of 630 feet in the southwest to 590 feet in the northeast. By far the greater proportion of its constituents consists of lacustrine sand with a subordinate amount of clay. The contact on the till remains near lake-level throughout.
Section X

Location: 600 feet northeast of Townline Road, at the western boundary of Madison township.

Top (Elevation: 629 feet)

1. Sand; medium, buff and limonitic; friable, washes and blows readily. Bedded, with some local cross-bedding. Beds dip 2 to 4° south. Lower 1.5 feet consist of gray bedded sand. Much of the sand is poorly sorted and ranges from medium to coarse. 31

2. Gray clay, and lenticular bodies of gray silt and sand. Lithologies are bedded, though often contorted. Clay is fatty and pebble-free. 10

3. Gray clay, fatty and pebbly. Mottled with hematite. Grossly contorted. Laterally, clay includes large masses of reddish, gray, hard, pebbly clay containing lenticular bodies of silt and sand. The matrix appears to be a very plastic till, which incorporates blocks of the more typically hard silty till. 13

On the western side of Townline Road, the contact on unit 3 of section X, falls sharply to beach level, and resembles an erosional contact forming part of the valley wall of an ancient Chapel Creek. Apparently, some mass movement on the contact by overlying lacustrine material has taken place, as is indicated by the curved surfaces of the contorted clay beds Fig. 29. Below the contact, a slab of pebbly till, 17 feet long and 3 feet thick in the middle, is visible in the figure. This slab of till apparently constitutes a remnant of the Upper Till, since it is underlain by red, plastic clay, a material that characteristically occupies the zone between Upper and Lower Tills across adjacent Perry township.
Section XI

Location: 1,000 feet southwest of Haines Road; about 51,000 feet northeast of section X.

Top (Elevation: 627 feet)  

<table>
<thead>
<tr>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sand, fine, buff. Horizontally bedded. Finer on the whole than that in section X. Upper 5 feet consist of poorly sorted, medium sand. 34</td>
</tr>
<tr>
<td>2. Clay, silty, gray. Horizontal layers alternate with contorted ones, and are varvelike, i.e., 1/4 to 1/2 inch thick. Toward the base, the clay becomes less bedded, more massive and redder. Within a few feet of the base, pebbles appear, as do stringers of fine, gray sand, red clay lenses and inclusions of till. 16</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>52</td>
</tr>
</tbody>
</table>

Toward the northeast the bluff loses elevation at the expense of units 1 and 2 of section XI. The rate of decline in elevation is greatest between Haines and Tuttle Park, as shown on Plate X. Hence northeastward, no more thick sand deposits are encountered in the bluff until one arrives in eastern Ashtabula township. Both groups of deposits, with respect to their distribution on the Lake Plain, have been discussed under the chapter titled "General Stratigraphy of the Area."

From Green Road toward the northeast, the bluff maintains a height of 17 to 10 feet above the beach, is mostly grassy and built over, and reveals only small exposures of the lithology.
Fig. 29. Contact of lacustrine clay and silt on the Upper Till. Observe erosional contact and the contorted forms of the lacustrine member on the till. Below the till, at beach level, lies the red clay bed associated with the contact between Upper and Lower Tills. Location: 150 feet SW of Townline Road, Perry. Sept. 1955.
Fig. 30. View of bluff; looking toward the SW; about 500 feet SW of Townline Road. Upper unit of bedded sand overlying lacustrine clay. Top of bluff slopes southward into the valley of Chapel Creek. Lake level: 573 feet. Height of bluff: 50 feet.
Fig. 31. Bluff, 400 feet west of Haines Road. View of bedded sand forming dominant member of the bluff lithology. Observe cavity in sandy unit, created by seepage of water on contact of the lacustrine clay. Sand unit is 34 feet thick. Aug. 1956.
Section XII
Location: 1,700 feet southwest of Hubbard Road, at the western side of Madison Township Park.

Top (Elevation: 593 feet) Feet
1. Sand, buff to limonite yellow, medium, and friable 3
2. Gray clay, poorly bedded with silt and fine sand; pebble-free .......... 2
3. Clay; gray-brown, fatty, contorted, laminated with fine silt and sand (Fig. 32). Lower one-third includes bodies of fatty red clay, and pebble-size, black, fatty, clay. Base obscured by talus .......... 10

15

Section XIII
Location: 1,600 feet southeast of Madison Township Park.

Top (Elevation: 590 feet) Feet
1. Sand; buff, medium to fine, nonbedded, pebble-free, sharp basal contact ................. 2
2. Sandy clay; thinly laminated, buff and brown respectively. Pebble-free and lenticular. Inter-bedded with a more massive, nonbedded variety of clay and silt. Grades downward into clay. Near base blocks of till and lenses of red clay occur 11-1/2
13-1/2

Toward the northeast, unit 1 of Section XIII thins out, leaving only unit 2, which becomes more clayey and till-like, but retains the red clay lenses and pockets of till. The section throughout maintains a height of 10 feet, all the way to Cowles Creek in Geneva township.
Fig. 32. View of contorted bedding in laminated clay and silt of unit 3 of section XII. Observe tightly contorted layers between flatter forms. Location: 1,700 feet SW of Hubbard Road, Madison. Aug. 1956.
Ashtabula County - Geneva Township

The low bluff of eastern Madison township continues across the boundary at Countyline Road into western Geneva township, where it rises rather abruptly at the east bank of the drowned valley of Cowles Creek.

Section XIV

Location: East bank of Cowles Creek, Geneva-on-the-Lake.

Top (Elevation: 591 feet)  

<table>
<thead>
<tr>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>la. Sandy silt (loam); few pebbles</td>
<td>2.5</td>
</tr>
<tr>
<td>b. Sand; buff, fine, poorly sorted</td>
<td>2.5</td>
</tr>
<tr>
<td>c. Gravel lens, poorly sorted</td>
<td>0.5</td>
</tr>
<tr>
<td>d. Thin bands of clay and silt</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Toward the northeast, the bluff rises rapidly to attain heights exceeding 140 feet. However, because of the combined effects of slump and artificial modifications of the bluff, no complete exposure of the bluff lithology was found in any given locality. However, it is known that a silty loam, about 8 feet thick, caps the Upper Till unit. The thickness of the Upper Till changes unpredictably from locality to locality. Beneath the competent till lies a plastic unit of lacustrine clay intermixed with sand. It appears that this unit grades upward into the till with an increase in hardness and percentage of pebbles. Locally, it is difficult to distinguish between the lacustrine unit and a clayey till.

Bedrock lies only a foot or two below lake level of 573 feet, and
thus it seems that the Lower Till is absent from this part of the shore. Sections XV and XVI, described below, were made with a 4-inch auger by the Division of Shore Erosion.

### Section XV

**Location:** North berm of State Route 531, 2,900 feet northeast of bridge over Indian Creek.

<table>
<thead>
<tr>
<th>Top (Elevation: 610 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Clay, silty (loam); includes some sand.</td>
<td>0 - 8</td>
</tr>
<tr>
<td>2. Upper Till. Silty clay, pebbly, gray. Some sand. Becomes more moist downward.</td>
<td>8 - 11</td>
</tr>
<tr>
<td>3. Clay and very fine sand, pebble-poor, gray, moist.</td>
<td>14 - 29</td>
</tr>
</tbody>
</table>

### Saybrook Township

The bluff across western Saybrook township retains the character of heavy slumping assumed in eastern Geneva township, to Saybrook Township Park, about 9,600 feet northeast of the Geneva township east boundary. Section XVI, augered on Route 531, about 1,150 feet northeast of the Geneva line, repeats the stratigraphic sequence described under Section XV.

### Section XVI

<table>
<thead>
<tr>
<th>Top (Elevation: 612 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Silty clay, hard, brown, pebble-free, or perhaps pebble-poor. Some sand.</td>
<td>0 - 9</td>
</tr>
<tr>
<td>2. Silty clay, brown, soft to mushy.</td>
<td>9 - 10</td>
</tr>
</tbody>
</table>
3. Upper Till. Silty clay, hard, gray, pebbly, calcareous. 10 - 14

4. Silty clay, gray, soft and moist. Pebble-poor to pebble-free, calcareous; apparently lacustrine. 14 - 39

Northeast of Nineveh Road, about 4,000 feet northeast of section XVI, the basal contact of the lacustrine clay (unit 4) has risen gradually to a height of 15 to 20 feet above beach level. However, the thickness of the unit remains unknown because of slumping. Just east of Saybrook Township Park, all traces of the lacustrine clay abruptly disappear. Thus the bluff immediately east of the Park presents an all-till front. For 2,400 feet beyond, vegetation conceals the section.

**Section XVII**

Location: 4,700 feet northeast of Saybrook Township Park, and 1,450 feet southwest of Red Brook.

**Top (Elevation: 615 feet)**

1. Silt and sand; buff, mottled with gray. Pebble-free, nonbedded, sharp basal contact. 12.5

2. Till, Upper; brown-gray, very pebbly with high silt content. Strong surficial creep of the surface of the bluff. Base obscured. 29 1/1.5

At the "V" cut in the bluff, 550 feet to the southwest, the lower part of unit 1, section XVII, includes lenses of brown-red clay, very fine sand and fatty, pebble-size red clay bodies.

The contact zone between the Lower and Upper Tills reappears just southwest of section XVII, and is traceable to a point 1,500 feet to the southwest. The zone lies near beach level, i.e., about
573 to 574 feet, is 3 feet thick, and consists of pebbly, red clay, which incorporates lenses of an exceedingly pebbly till. About 850 feet to the southwest of the section, the zone also includes a boulder pavement.

Toward the northeast, unit 1 increases in thickness until intercepted by the valley of Red Brook, where it has attained a thickness of 20 feet, and is floored by laminated clay and sand, on a layer of compact red-gray clay.

Northeast of Red Brook, the stream has carved a bench on the contact of the Upper Till, and most of the lacustrine deposits have been removed for a distance of 600 feet. Beyond, the bluff rises to include the entire sequence as described under section XVIII.

Section XVIII

Location: Ashtabula Country Club Allotment, 1,400 feet northeast of Red Brook.

Top (Elevation: 624 feet)

1. Aggregate of boulders, cobble, sand, silt and clay; buff. 2

2. Clayey silt, buff. Upper one-third contains some pebbles. Middle portion is relatively pebble-free, but includes an occasional boulder and pebble; also dense and locally distorted. Sand occurs as laminae in clay lenses. The basal 4 feet consists of reddish gray clay which terminates downward against a sharp contact. 18

3. Till, Upper. Silty clay, pebbly, blue-gray, with a well developed contact zone on the Lower Till. 26

4. Till, Lower. 3/49
A laterally extensive contact zone between the Upper and Lower Tills lies about 3 feet above beach-level in this locality. The zone undulates with a relief of 4 feet, and contains boulder pavement, erosional ledges where lacustrine silt and sand have been scooped out by waves, lenses of very pebbly, blue-gray till, and some red clay (Figs. 33 and 34). In general, section XVIII is nearly identical with section IV of Ferry township.

Further toward the northeast, within 200 to 300 feet, unit 1 of section XVIII grades into medium, well-sorted sand, and increases to a thickness of 6 feet. Also slumping, characteristic of the bluff in the western part of the township, returns to prominence, indicating the increase of the lacustrine clay between the Upper and Lower Tills to a substantial thickness.

Section XIX

Location: About 3,200 feet northeast of the mouth of Red Brook.

Top (Elevation: 623 feet)  

1. Sand; buff, medium to coarse. Sharp lower contact (Fig. 35).  

2. Till. Gray, pebbly, silty, massive clay. Very moist and soft. Pebbles range in size up to cobbles and constitute about 40 percent by volume of the till. Upper 6 to 8 feet are exposed; the rest is covered by slump debris.  

3. Lacustrine sand and clay. Revealed by their presence in slump blocks. Water saturated muds issue from near the contact on the Lower Till. This is unmeasured, but probably lies between 10 to 20 feet. Quite likely, the Upper Till and lacustrine deposit are intergraded.
Fig. 33. Saybrook twp., about 1,400 feet NW of Red Brook. Contact zone between Upper and Lower Tills. Note relief. Trenching tool is on the contact in the background. Sloping, curved indented ledge represents contact in foreground. View toward the southwest. Aug. 1956.
Fig. 34. Location as in Figure 33. Boulder pavement in contact zone between Upper and Lower Tills. See also Figure 23 Perry township. Aug. 1956.

About 600 feet northeast of Stowe Road, or about 1,800 feet northeast of section XIX, slumping ends. This change is reflected in the bluff stratigraphy by a rise in elevation of the lacustrine clay contact on the Lower Till, a thinning of the lacustrine unit, and an increase in competency of the Upper Till.

Section XX

Location: 1,000 feet northeast of Stowe Road.

Top (Elevation: 623 feet) Feet

1. Till; gray, pebbly, silty clay. Upper 6 feet weathered buff. 15

2. Very fine sand, silt and clay, gray-brown to red-brown. Poorly bedded, pebble-free. Clay content increases near lower contact, and becomes dark brown. Red fatty clay pebble-size bodies increase in percentage near lower contact; sand and clay become strongly contorted and compacted, and a few rounded granules appear downward. 9

3. Till, silty clay, pebbly, hard and massive. 25

This stratigraphic sequence remains constant to the township of Ashtabula.

Section XXI

Location: 3,000 feet northeast of section XX, and 1,500 feet southwest of the Ashtabula township line.

Top (Elevation: 626 feet) Feet

1. Till, Upper. Gray, pebbly, silty clay; also includes cobbles and boulders. 24
Fig. 35. Looking SW. Bluff of section XIX, 3,200 feet NE of Red Brook. Medium and fine lacustrine sand on the Upper Till. Sand unit is 4 feet thick, and is light colored in the photograph.
2. Gray bedded silt, fine sand and clay. Sharp upper contact. Unit is strongly contorted, and sand occurs as lenses, 1 inch long. Clay percentage increases downward. Pebbles appear in the massive clay forming the basal two feet, and the material becomes till-like. Red clay intertonguing with blue-gray pebbly clay marks the basal contact. 8.5

3. Till, gray, pebbly to bouldery, silty clay. 18

Northeastward into the township of Ashtabula, the basal contact of the intertill lacustrine unit undulates downward with a relief of 5 feet. The unit itself thickens and thins irregularly. Lacustrine sand at the top of the bluff becomes locally conspicuous, attaining thicknesses up to 6 feet.

Section XXII

Location: 700 feet northeast of the western boundary of Ashtabula township.

Top (Elevation: 631 feet) 18

1. Sand, buff, binded by silt. 6

2. Mostly a pebbly, clayey silt. Apparently a till, it contains lacustrine clay and sand in its lower portion, where lenses of brown-gray sand can be seen. It is possible that the entire unit consists of a mixture of lacustrine sand and clay, and till, since the whole mass when moistened creeps down the face of the bluff as a gigantic blanket, 2 feet thick. 35

3. Lower Till, pebbly, blue-gray. 13

The basal contact of the intertill lacustrine member, continuing its descent toward the northeast, becomes lost under the vegetative cover of the bluff behind the Ashtabula breakwater-impounded beach.
Fig. 36. Bluff 50 feet high, just SW of section XXI, near eastern boundary of Saybrook twp. Steep lower face is presented by the Lower Till. Middle lacustrine member slopes upward at an angle of 45°. Upper Till lies above the second break in slope. The "V" notches in the bluff represent areas where the lacustrine clay has been thickened; perhaps by the shoving action of glacial ice. The bluff at such sites of thickening, tends to slump more readily. View toward the south-west. July, 1956.
Fig. 37. Detail of bluff at site of section XXI. The section shown consists of Upper and Lower Tills, and intertill lacustrine unit. Trenching tool is embedded on the basal contact of the lacustrine member. Saybrook township. Sept. 1956.
Ashtabula Township, Northeast of the Ashtabula River

Across the breadth of Ashtabula township, five stratigraphic members, exclusive of bedrock, form the bluff. These include two till members and an intertill lacustrine unit, which are overlain by lacustrine laminated clays and sand, topped by a sandy lacustrine member resting disconformably on the laminated unit.

The two till members and the intertill lacustrine unit are correlatives of those to the southwest, and therefore Late Cary or older in Age. The laminated clay beds apparently rest on a broad bench swept out on the Upper Till by an ancestral Ashtabula River, and were probably deposited in Lake Warren or some older glacial lake. The sand deposit at the top of the section and its basal gravels, ranging in elevation between 626 and 635 feet, probably date back to Lake Grassmere-Lake Lundy time.

About 2 miles of shore length, between the Ashtabula River and Russell Road, 1,500 feet southwest of section XXIII is not described in the following description of the bluff. However, the void has been filled on the fence diagram of Plate XI by the insertion of 3 graphic sections (A, B and C), of Paul R. Shaffer (unpub. rept., 1947).

Section XXIII

Location: Wheatfield; 1,500 feet northeast of Russell Road (extended).
Fig. 38. Sharp basal contact of laminated silt and clay on the Upper Till. Marked by steel chain reel in left central area of photograph. Section XXIII, looking southwest. Ashtabula township. July, 1956.
Top (Elevation: 631 feet)  

1. Sand, fine, limonite-stained, nonbedded, and heavily mixed with silt. Floored by 1 foot of basal gravel and coarse sand. Basal contact disconformable.  

2. Sand, fine, interbedded with clay. Clay laminae are 1 inch thick, contorted, dense, and becomes bluer gray with depth. Toward the west, the sand interbeds increase to a thickness of 1 foot. Contact drawn at seepage zone.  

3. Laminated blue-gray, fine sand and fatty clay. Laminated pair is one to two inches thick. Locally contains small red clay lenses. Clay units become less defined upward. Sand grades out downward, and disappears near basal contact, marked by red clay pebble-size bodies, black carbonaceous surfaces, and granules. Sharp basal contact.  

4. Till, Upper. Gray, pebbly, and includes minute silty lenses. The basal contact undulates 2 to 3 feet above lake level of 573 feet. The contact zone is thin, poorly delineated, and reveals thin, (2 to 3 inches) sand lenses, and one foot thick pockets of gravel binded by blue and red clay.  

5. Till, Lower. Like the Upper Till.  

Farther to the northeast, the intertill lacustrine clay returns to the section as revealed by section XXVI.

Section XXIV

Location: 3,500 feet east of Russell, or 350 feet southwest of first stream east of the Cleveland Electric and Illuminating Company’s property.

Top (Elevation: 637 feet)  

1. Fine sand, buff, resting on 2 feet of gravel and coarse sand. Pebbles are flat, rounded on the edges and horizontally aligned.
2. Sandy silt with stringers of clay; brown or rust; compact with a faint bedding pattern. Clay is fatty and contorted. Sharp basal contact marked by springs.

3. Dense gray silt; grading below the upper two feet into thin laminated units of gray silt and fatty gray clay. Contorted bedding is present, and the unit yields plastically, and washes readily when saturated. It is largely obscured by slump, and creep material from the overlying unit and its upper portion per se. Clay dominates the basal one-third, near the bottom of which, thin, discontinuous, laminae of red clay appear. Basal contact is sharp.

4. Till, Upper. Pebbly, blue-gray. Sharp basal contact marked by thin laminae of fine limonite-stained sand.

5. Silt and clay, blue-gray, lacustrine. Highly compact and pebble-free in the upper one-third, it grades downward into an irregularly bedded portion of very fine sand, and pebble-free clay. The basal zone, (1 to 2 feet thick), consists of pebbly clay and includes small red-clay bodies. Basal contact remains sharp, and is delineated by a parting.


7. Shale, greenish-gray to black, fissile, jointed. Chagrin.

Thus from sections XXIII to XXIV, a distance of 2,200 feet, the upper contact of the Lower Till, as traced in the bluff, rises on an undulating line from an elevation of 575 feet to one of 587 feet. The intertill lacustrine material, unit 5 of section XXIV, makes its first appearance at a point a few hundred feet southwest of section XXIV, and has thickened out of the material in the contact zone between the tills of section XXIII. Hence, northeastward
they remain present in the bluff, a correlatable unit all the way to Conneaut Township Park.

This behavior is the eastern counterpart of that on the western side of the Ashtabula River, where the contact on the Lower Till slopes downward toward the Ashtabula River valley, and the intertill lacustrine material lenses out. The combined relationship thus presents a cross-section of what resembles a glacial interstadial valley of the Ashtabula.

Section XXV

Location: 3,400 feet west of Labounty Road, or 1,350 feet east of first creek east of Russell Road.

Top (Elevation: 637 feet).

<table>
<thead>
<tr>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>la. Buff, fine sand</td>
</tr>
<tr>
<td>b. Buff, fine sand binded with silt; compact</td>
</tr>
<tr>
<td>c. Basal gravel zone, mixed with sand and silt. Bedded gravel consists of crystalline and sedimentary types, are well rounded and polished; and range in size from granules to cobbles. Sharp basal contact with springs</td>
</tr>
<tr>
<td>2. Gray silt and clay; laminated and banded. Thinly laminated units, 1 to 2 feet thick, and generally contorted, alternate with beds of dense silt, 2 to 3 feet thick. These dense silt units contain whorls of laminated clay, 8 to 24 inches in diameter, which weather out to leave cavities in the matrix. This habit causes the unit to collapse (Fig. 38). Sharp basal contact</td>
</tr>
<tr>
<td>3. Upper Till</td>
</tr>
<tr>
<td>4. Lacustrine clay and silt; highly contorted. Like unit 5 of section XXIV</td>
</tr>
<tr>
<td>5. Lower Till</td>
</tr>
</tbody>
</table>

61
Fig. 39. Whorls of laminated silt and clay weathering out of dense, homogeneous silty-clay matrix. Section XXV. Ashtabula township.
Northeastward from section XXIV, the shale outcrop continues to rise, becoming, in the process, more effective as a bulwark against wave attack on the bluff. About 600 feet southwest of section XXV, it attains a maximum elevation of 579 feet, or 6 feet above lake level. The shale presents a serrated front to the lake as outlined by its joint pattern.

Section XXVI

Location: 2,150 feet east of first creek east of Russell Road, or 2,650 feet west of Labounty Road.

Top (Elevation: 635 feet)  

<table>
<thead>
<tr>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sand, limonite-stained, very fine, well sorted and nonbedded. Overlies basal gravel zone. Sharp basal contact</td>
</tr>
<tr>
<td>2. Laminated gray clay and silt, interbedded with two foot beds of very fine sand. Unit is less coherent than unit 2 of section XXV, and contains blocks (1x5 feet) of till, embedded in the unit, which may represent ice-rafted material. Sharp basal contact</td>
</tr>
<tr>
<td>3. Till. Lower contact is debris covered</td>
</tr>
<tr>
<td>4. Silt and clay, lacustrine. Apparently yielding plastically under the weight of the overlying material</td>
</tr>
<tr>
<td>5. Till, Lower</td>
</tr>
<tr>
<td>6. Chagrin shale</td>
</tr>
</tbody>
</table>

Northeast of section XXVI, unit 2 thins against a rising till contact after a continuous exposure of more than a mile. It does not return to the section as a significant member until Conneaut township is approached from eastern Kingsville township.
Section XXVII

Location: 2,100 feet west of Labounty Road, and 500 feet northeast of section XXVI.

Top (Elevation: 633 feet)  Feet

1. Fine sand, buff, grading downward into a loam mottled brown and gray .............. 2

2. Clay, gray to brown; becoming till-like downward. Pinches out 300 feet to the northeast. It is the equivalent of unit 2 of section XXVI ....... 4

3. Upper Till. Lower 6 feet has slumped heavily, and appear to move on shear planes parallel to the slope (30°), and on which are found thin layers of silt and sand, including limonite-stained sand, which suggests the downward percolation of ground water through the fractures. It is probable that this lower portion of the till, has incorporated within it, a part of the underlying lacustrine silt and clay. Lower contact unlocated .......... 32

4. Pebble-free clay and silt; lacustrine. Strongly contorted. Contacts not located .......... 6

5. Till, Lower .................................................. 15

Toward the northeast, about 600 feet, the intertill lacustrine material thickens to 15 feet; and the topography features creep and flowage in the intertill lacustrine material, and slump in the overlying till. The upper contact of the lower till lies 23 feet above the beach.

Section XXVIII

Location: 200 feet west of Labounty Road.
Top (Elevation: 633 feet)  

1a. Sand, buff, fine. Sharp contact ........................................ 3.5

1b. Clay and silt mixture; mottled gray and buff. Lower contact is highly irregular and includes blocks of till; although to northeast and southwest of the section, is sharp and relatively horizontal ........................................ 4

2. Till, Upper. Retreating as a scarp recessed on unit 4, the Lower Till ..................................................... 19.5

3. Intimate mixture of silt and clay. Sharp basal contact underlies zone of laminated clay and silt with red clay bodies. Strong seepage occurs near the basal contact ..................................................... 11

4. Till, Lower ................................................................. 19.5

About 1,000 feet east of Labounty Road, the Lower Till includes layers and bands of silt and laminated clay and silt, 1 to 12 inches thick, and all lying below the intertill lacustrine deposits, i.e., unit 3 of section XXVIII. The till also includes contorted bodies of very fine sand, and in general has a layered appearance, featuring units of pebbly clay and pebbly sandy clay. Bodies of a bluer, more pebbly clay also lie in the till. Thus it appears that along this stretch of bluff, the till contains a high percentage of lacustrine material mixed into the normal till. This mixture of lithologic types characterizes the Lower Till for the 1,800 feet distance to Whitman Creek.

Kingsville Township

The section from the southwest into Kingsville township becomes simplified to the three-fold arrangement of the Upper and Lower Tills,
separated by 20 to 30 feet of lacustrine material. However, on
the eastern side of the Whitman Creek valley the intertill lacus-
trine unit, there 33 feet thick, was dissected to a depth of 18
feet and a width of at least 2,000 feet, by an ancestral stream
of Whitman Creek, the valley of which was later filled with fine
sand and covered by the Upper Till.

About 2,500 feet northeast of Whitman Creek, three till units
are present in the section, each separated by a lacustrine unit.
The author believes that the uppermost of these till units lenses
into and out of the section within a distance of 5,000 to 6,000
feet and is apparently a later phase of the ice advance that de-
posited the characteristic Upper Till.

A lacustrine lens subjacent to the Uppermost Till, and resting
on the Upper Till, is regarded as a shallow valley filling of another
ancestral valley, subsequent to that described for Whitman Creek
above.

In the northeastern one-third of the township, a relatively
thick section of sand and subordinate laminated clay, returns to
the bluff, and thickens northeastward on the falling contact of
the Upper Till.

Section XXIX (Fig. 40)

Location: 700 feet northeast of Whitman Creek at the Kings-
vilie township west boundary.

Top (Elevation: 632 feet) Feet

1. Till, Upper. Buff, silty clay; slightly bedded
appearance, pebbly to cobbly. Sharp basal contact. 12
2. Gray sand, fine; some cross-beds, but mostly massive and friable. Thins 300 toward the northeast by a rising basal contact. 

3. Laminated clay and silt, gray. Clay layers increase in thickness from one-half inch near the top to mostly clay near the basal contact. There it includes layers of red and gray clay with fine pebbles.


Unit 2, as mentioned previously, represents a valley filling of an ancestral Whitman Creek valley that was cut into unit 3, of the section above.

Approximately, 1,000 feet east of Whitman Creek, or 300 feet northeast of section XXIX, unit 3 includes large, dense, lenses of silt, integrated into the laminated clay, silt and sand. Similar blocks appear in the sections of eastern Perry township within the laminated lacustrine material overlying the Upper Till. They probably developed as a result of a non-uniform distribution of sediments over the bottom of the lake, since laminated layers are observed to grade into the margins of these massive forms.

Toward the northeast, unit 2 of section XXX thins against the rising contact of unit 3, until about 900 feet from the section, it becomes only 5 feet thick (fig. 41). On the other hand, unit 3 expands to 33 feet. The Upper Till also thins to 5 feet, whereas the Lower Till remains at 17 feet.
Fig. 10. Looking south at section XXIX. Upper Till 7 feet thick overlies the pock marked sand unit. Portion of bluff covered by the clumps of grass, represents the laminated clay and silt unit. The Lower Till in the foreground is a bench former. Kingsville township. June, 1957.
Fig. 41. Looking southeast at bluff 1600 feet NE of Whitman Creek. Till overlying lacustrine bed. Chain reel rests on upper contact of dense, blue-gray silt, unit 3 of section XXIX. Kingsville township, June, 1957.
Section XXX

Location: 1,900 feet west of Route 90 (extended), and 1,400 feet northeast of section XXIX.

Top (Elevation: 635 feet)

1. Till, Upper. Buff, grading downward into gray. The unit has thickened from the 5 feet recorded 200 feet to the southwest. Toward the northeast some 100 feet, its middle one-third consists of pebbly, cobbly, wavy, laminated beds of till and sand. Cobbles in the laminated till are angular and lie in the bedding surface; although in the nonbedded till immediately above, no apparent alignment exists. Sharp basal contact. (Figs. 42 and 43).

2. Laminated clay and silt, gray. Gradational lower contact, through which massiveness of the clay, small red pebble-size clay bodies and larger lenses, and thin pebbly, clay beds increase.

3. Till, Lower. About 150 feet to the northeast, the upper contact slopes 12.5 degrees east-northeast, on a concave arc; an outline followed by the lower layers of unit 2.

Beyond section XXX, the so-called Upper Till of this paper, generally represented throughout the study area by a tough, compacted, pebbly till, is replaced in the section for the next 3,000 feet, by a sandy, pebbly poorly compacted material, but still regarded as till by the author. This new unit is underlain by lacustrine sand and clay; below which lies a member of tough till, underlain by more lacustrine clay, and then the Lower Till. Accordingly, the author correlates the typical Upper Till with the till unit in the middle of section XXXI. For the sake of convenience, the third till phase is called the "Uppermost" till. It is possible
Fig. 42. View of laminated till, 100 feet NE of section XXX. Note the bedding alignment of cobbles in the laminated layers; the randomly directed cobbles in the non-laminated portion; and the layers of sand between interbeds of till. View toward the NE. Kingsville township. June, 1957.
Fig. 43. Topographic form eroded from the laminated till of section XXX. The base of the form rests on the intertill lacustrine clay and silt (against which the board is leaning). View toward the southeast. Board is 5 feet long. June, 1957.
that this "Uppermost" till represents ice-rafted material, or material deposited from floating ice-sheets into a shallow arm of a glacial lake, because it lacks compaction, and grades both to the northeast and southwest into water sorted deposits.

Section XXXI

Location: Kingsville Park Association; 1,300 feet southwest of Route 90 (extended).

Top (Elevation: 636 feet) 

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Till. Sandy to loamy, pebbly, brown; soft and friable, and apparently highly permeable. Un- compacted. Stands out as ridges separating rill- eroded amphitheatres. The pebbles are angular, and range up to cobbles in size.</td>
</tr>
<tr>
<td>2.</td>
<td>Pebble-free silt and clay. Upper one-third is dense and hard. Fine sand becomes more common in the lower one-half, decreasing the compactness. Faint traces of laminations occur, and red clay bodies appear near the base.</td>
</tr>
<tr>
<td>3.</td>
<td>Till, Upper. Hard, gray-brown</td>
</tr>
<tr>
<td>4.</td>
<td>Fine sand and silt. Contacts are very irregular, and often the unit interfingers with the till, especially the overlying till. The unit has undergone strong distortion, thickening and thinning by as much as 6 feet vertically for 12 feet horizontally</td>
</tr>
<tr>
<td>5.</td>
<td>Till, Lower. Hard, gray</td>
</tr>
</tbody>
</table>

Toward the northeast a lens of sand emerges from the contact between the Uppermost Till and its subjacent lacustrine member, and thickens at the expense of the till.
Section XXXII

Location: Kingsville-on-the-Lake, 400 feet west of Route 90 (extended).

Top (Elevation: 635 feet)

1. Till; silty clay, pebbly to cobbly, crumbly, brown. 3.5

2a. Fine sand, brown. Lenticular. Tongues out into unit 1, 500 feet to the northeast, for a total length of 1,200 feet. .......................... 6

2b. Laminated silt and clay, gray-brown. Topped by large blocks of dense, pebble-free silty clay. ............................................. 13.5

3. Till, The intertill lacustrine clay and silt of the sections to the southwest are not in evidence. The author believes that the lacustrine material overlying this unit is equivalent to unit 2 of section XXXI. ................................. 35

The author has traced unit 2b, the laminated clay and silt member of section XXXII, 1,800 feet to the northeast, where it thins out into the contact between the Uppermost Till and the typical Upper Till.

On the other hand, the intertill lacustrine member which occupies the section between the Upper and Lower Tills, though absent at section XXXII, returns to the bluff at a point about 1,200 feet to the northeast of the section, and at an elevation of 25 feet above the beach. However, it is intermixed with till, erratic in distribution, and undulates with a relief of 5 to 10 feet on the lower contact. Because of the capricious distribution of the lacustrine beds, i.e., abrupt thickening and thinning, erosion and mass wasting have developed a sawtooth outline on the bluff,
like that on the faulted front of a stream dissected block mountain. The lacustrine material, where thickened, readily washes, flows and slumps; where thinned, the bluff stands as triangular facets. This bluff, stratigraphically and topographically, resembles that found 1 1/2 miles southwest of the Ashtabula Harbor west breakwater (Fig. 36).

Section XXXIII

Location: 300 feet southwest of the second creek east of Route 90, or 2,600 feet east of Route 90.

<table>
<thead>
<tr>
<th>Top</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sandy loam; buff, mixed with angular rock fragments. Grades laterally into brown laminated sand and clay. Sharp contact.</td>
<td>8.5</td>
</tr>
<tr>
<td>2. Till, Upper. Basal contact approximate</td>
<td>13</td>
</tr>
<tr>
<td>3. Silt and clay; some lamination. Variable thickness</td>
<td>5</td>
</tr>
<tr>
<td>4. Till, Lower</td>
<td>30 35.5</td>
</tr>
</tbody>
</table>

Section XXXIII remains typical of the bluff section for a distance of 3,000 feet, whereupon unit 1 grades into sand, after passing through a zone containing large pockets of gravels, 8 x 4 feet in cross-sectional area.

Section XXXIV

Location: 3,750 feet west of Harmon Road, or 1,700 feet southwest of groin at first creek west of Harmon Road.

Top (Elevation: ca. 636 feet) | Feet |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Buff sand and silt, grading downward into clay. Lower contact is apparently gradational, although toward the northeast a sharp contact is present</td>
<td>5.5</td>
</tr>
</tbody>
</table>
2. Till, Upper. Buff, grading downward into blue-gray. Lower contact is marked by zone of red clay particles ................. 6.5

3. Blue-gray silt and clay. Pebble-free. Sharp lower contact ......................... 6

4. Till, Lower ................................................................. 11

At the site of section XXXV below, the intergradational zone between the Upper Till and the superjacent lacustrine clay is marked by an alternating sequence of till and lacustrine material through an 8 foot zone. Thus it appears that the upper portion of the till was probably deposited from a fluctuating ice margin into a pro-glacial lake.

Section XXXV

Location: 350 feet west of Harmon Road.

Top (Elevation: 640 feet)  Feet

1a. Sand, silt and clay mixture. At the base lies a horizontal layer of rounded pebbles, 3 inches thick . 1.5

1b. Clay and silt with minor pebble population; mottled buff and gray. Pebbles are sub-angular. The material resembles the alluvium found in the terraces of the local streams. Downward, it becomes a solid buff and more clayey, featuring strong spheroidal contortions. The basal zone contains blocks of hard, gray, pebbly clay, mixed with red clay, and some sand; and grades downward into the Upper Till ..................... 8

2. Till, Upper. Pebbly laminated clay and silt, and pockets of sand occur about 5 feet from the top, and extend for 300 feet to the east, where slump covers the feature. The lower part of the till grades into the subjacent lacustrine clay  ........ 23
3. Laminated, pebble-free clay and silt. Contorted. Includes lenses of fine sand in the upper part. Red clay lenses occur near the sharply defined base. ............................... 10

4. Till, Lower ............................................ 24

About 750 feet to the northeast of section XXXV, the lower contact of unit 3 on the Lower Till falls to a height of 15 feet above the beach (575 feet).

Another 500 feet northeastward, sand becomes the dominant constituent of the topmost unit in the bluff.

Section XXXVI

Location: 500 feet southwest of second creek east of Harmon Road, and 2,050 feet east of Harmon Road.

Top (Elevation: 627 feet)  

1. Sand, buff, fine to coarse, binded with silty clay, roughly bedded. Sharp basal contact . . . 13

2. Till, Upper. Blue-gray, relatively high silt content ........................................... 26

3. Laminated clay and sand, brown-gray with red clay near the base . . . 4.5

4. Till, Lower. Very pebbly . . . . . . . . . . . . . . . . . . 10

Between sections XXXV and XXXVI, alternating beds of pebbly clay and lenses of silt and fine sand become the principal lithologic types in the Upper Till.

Toward the northeast from section XXXVI, unit 1 thickens. Thus 1,250 feet northeast of the section it consists of --
a. Fine sand, irregularly bedded .... 5.5 feet
b. Gravel layer mixed with fines .... 0.5 foot
c. Beach sand, coarse, medium to fine. Bedded to cross-bedded .... 12.0 feet

Another 450 feet northeastward, and the above unit has increased to 27 feet.

Section XXXVII

Location: 1,100 feet west of Poor Road.

Top (Elevation: 641 feet)

<table>
<thead>
<tr>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a. Sand with some silt, buff</td>
<td>28</td>
</tr>
<tr>
<td>1b. Fine sand and silt, blue-gray</td>
<td>7</td>
</tr>
<tr>
<td>2. Till</td>
<td>31/66</td>
</tr>
</tbody>
</table>

Beyond section XXXVII, vegetation and slump obscure the exposures of bluff lithology. Nevertheless, the incomplete exposures indicate that the general stratigraphic picture remains essentially unchanged for the 7,500 feet distance to the eastern boundary of Kingsville township.

Conneaut Township

The broad depositional basin outlined in the upper half of the bluff of eastern Kingsville township continues into Conneaut township, where half of the bluff section is dominated by lacustrine sand and subordinate clay. The remaining half consists of till. The heavy wash and slippage of lacustrine material over the till make it difficult to trace continuously the contact between the Upper and Lower Tills.
As the city of Conneaut is approached, the Upper contact on the Upper Till rises until the lacustrine unit thins to 11 feet at Conneaut Township Park, and 3 feet at the Ohio-Pennsylvania border.

At the western township line of Conneaut, the upper levels of the sand unit, with elevations ranging between 635 and 650 feet, consist of typical beach sand; and the author postulates that these deposits were laid down in Lake Grassmere (640 feet). Underlying laminated clays are probably of Lake Warren Age. Tills are probably Late Cary as discussed under General Stratigraphy of the Surficial Deposits.

Section XXXVIII

Location: 500 feet east of the Kingsville-Lakeville boundary, (west Conneaut twpline).

<table>
<thead>
<tr>
<th>Feet</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>Elevation: 646 feet</td>
</tr>
<tr>
<td>1a. Buff silt and clay, pebble-free</td>
<td>3.5</td>
</tr>
<tr>
<td>1b. Fine sand, cross sets one foot thick, dipping 31° east. (dune sand?)</td>
<td>2</td>
</tr>
<tr>
<td>1c. Medium sand and cobbles. The very coarse layers alternate with well sorted, medium, quartz sand beds which include a zone of black iron rust coating granules and sand grains. The author believes that the limonite-rich zone is the end product of the weathering of magnetite rich layers in beach sand. Believed to be Lake Grassmere in age</td>
<td>12</td>
</tr>
<tr>
<td>1d. Laminated sand, silt and clay. Sand beds disappear with depth, and the unit becomes all clay near the base</td>
<td>17</td>
</tr>
<tr>
<td>2. Till, Upper</td>
<td>11</td>
</tr>
</tbody>
</table>
3. Lacustrine silt and clay. Irregular and indistinct contacts ........................................ 6
4. Till, Lower .......................................................... 18

About 1 mile separates section XXXVIII from section XXXIX.

The collapse of bluff materials and the overgrowth of vegetation prevented the measurement of good sections. However, enough of the lithology is visible to indicate that the overall stratigraphic relations remain constant.

**Section XXXIX**

<table>
<thead>
<tr>
<th>Top (Elevation: ca. 643 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>la. Compact sand and silt, buff .........................................................</td>
<td>1</td>
</tr>
<tr>
<td>lb. Gravel, fine sand, silt ...............................................................</td>
<td>3</td>
</tr>
<tr>
<td>ld. Gravel, shingles, granules, medium sand; certain layers poorly sorted. Erosional basal contact (Fig. 44) ..........................................................</td>
<td>3</td>
</tr>
<tr>
<td>le. Silty clay, brown .............................................................................</td>
<td>1</td>
</tr>
<tr>
<td>lf. Fine sand, high quartz content, interbeds one foot thick, alternate with brown silt, one-half foot thick ..................................................</td>
<td>3</td>
</tr>
<tr>
<td>lh. Thinly laminated very fine sand and silty clay ....................................</td>
<td>12</td>
</tr>
</tbody>
</table>

2. Till. Contains typical intertill lacustrine material about 12 feet below the upper contact of the till. However, talus and slump obscure the exact relationships ........................................ 37

Northeastward, both laminated and sandy lacustrine units begin to thin on a rising till contact, as shown by sections XL to XLII.
The Origin of Loam at the Top of the Stratigraphic Section

A type of loam resembling the local alluvium, here sandy, there clayey and often pebbly, occurs ubiquitously over the Lake Plain and at the top of the bluff section. It grades laterally from a till-like lithology to one that is purely lacustrine, and includes
Fig. lll. Section XXXIX. Gravel beds of unit 1d, on fine, bedded sand of 1e. Observe disconformable contact of 1d on 1e. Thickness of section shown is about 5 feet. July, 1957.
basal pockets of gravel. The author regards this unit as the product of sheet wash acting on till and lacustrine deposits of the Lake Plain. The process could have taken place either as a terminal lacustrine effect and/or as a subaerial development.

Under the first condition, the author postulates that there was a point in the falling stage of the glacial lake level when the water became too shallow to permit extensive transport of material from a readily erodible bottom and shore. Thus it was probable that local material on the topographic highs, as it became disaggregated by the saturating effect of lake water, was merely spread over the lower area without extensive sorting where the gradient was low, and with better sorting where the slopes and the permeability of the surface permitted it.

Under the second condition, meteoric sheet wash acting on low gradients or highly permeable slopes could accomplish the same end. Loam deposits of Kingsville and Conneaut townships and elsewhere rest directly on coarse and medium sands postulated as having been deposited in Lakes Grassmere and Lundy, the last glacial lakes reported for the Lake Plain in the study area. Thus it is probable that most of the loam deposits postdate the period of glacial lakes. Also the high permeability of the sand beds over which some surface runoff must travel would inhibit gully ing, since so much water is lost by seepage into the ground. On the other hand, deposition or spreading of material downslope by sheet wash would be favored.
Summary of the Bluff Stratigraphy between Fairport and the Ohio-Pennsylvania Border

Apparently, the characteristic stratigraphic sequence of an Upper Till overlying thick lacustrine clay, silt and sand, which in turn rest on the Lower Till, found in western Painesville, represents the northeastern extension of a similar sequence that makes up the bluff of northeastern Mentor township on the western side of the Grand River Valley. The intertill lacustrine unit remains a member of the lithology for about 3 miles east of the Grand River mouth, and like its counterpart on the west side of the River, seems incapable of maintaining the heavy overburden of the Upper Till. Thus heavy slumping affects the shore of Painesville township, as it does that of the Mentor Headlands area.

The intertill lacustrine deposits disappear from the section as a significant unit across Perry and Madison townships, and only a contact zone, which one may trace at intervals across Perry township remains. This zone reveals itself by a physical, undulatory break in the monolithic face of the till, by the presence of fatty, pebble-free clay, silt and sand, boulder pavements, and by dense, fatty, red clay lenses, and it maintains a general elevation ranging between 573 and 577 feet.

Lacustrine laminated clay, silt and sand, superjacent to the till, gain prominence in the section from western Perry township toward the northeast, and attain a maximum thickness of around 30 feet in central Perry township. Thence they undergo thinning,
as another sandy lacustrine member, overlying the laminated beds increases to its maximum thickness of 35 feet in the bluff of western Madison township. This sand unit consists of deposits laid down in Lakes Grassmere and Lundy. On its part, the Upper Till undergoes progressive thinning northeastward across eastern Perry township, and falls below beach level.

Across Madison township, the bluff, having undergone a rapid decline in elevation just east of Haines Road, in the western part of the township, at the expense of the sand unit, maintains a height of 10 to 15 feet, all the way to Cowles Creek in western Geneva township, where it abruptly rises. Across this area, the contact on the till remains near lake level, i.e., 573 to 574 feet. With the return of the bluff to topographic prominence, the Upper Till reoccupies the section at the top of the bluff. Slumping across Geneva and western Saybrook townships, like that in Painesville township, also returns. Auger borings by the Division of Shore Erosion, reveal that the typical Upper Till of compacted, silty clay is about 14 feet thick, and that it overlies a 25 foot thick, somewhat permeable, pebble-poor to pebble-free unit of silty till, and lacustrine sandy to clayey material.

Beyond Saybrook Township Park, the lacustrine intertill unit thins out, and the basal contact of the Upper Till returns to beach level. On approaching Red Brook, sand appears in the top section of the bluff, thickening toward the brook.
East of Red Brook, the lacustrine clay between the Upper Till and the overlying sand bed attains local importance, but thins rapidly against a rising till contact, after an exposure of 600 feet. The sand bed at the top of the bluff lenses out within 2,500 feet of Red Brook. On the other hand, the intertill contact, near beach level, becomes well delineated by a boulder pavement, and about 2,500 feet northeast of Red Brook expands to include rather thick deposits of lacustrine material.

On both sides of Red Brook, the stratigraphy throws some light on the history of the stream. The basal contacts of both lacustrine units - that on top of the Upper Till, and that between the tills - dip inward toward the present valley of Red Brook, and probably represent the cross-sections of ancestral valleys of the present stream, one of which was obliterated by drowning and glaciation, and the other by drowning in one of the late glacial lakes.

Toward Ashtabula township, the intertill lacustrine material rises in the section, and thins to the benefit of the Lower Till, which throughout eastern Saybrook attains an exposed thickness of 15 to 20 feet. However, in Ashtabula township, the contact on the Lower Till falls again below beach level as the river is approached, and all lacustrine material disappears from the section, save for a thin capping of loamy material.

On the eastern side of the Ashtabula River, the Lower Till returns to its position of prominence about 2 miles from the river,
and retains this position into Conneaut township. In like manner, the intertill lacustrine beds return to the section, and attain a maximum thickness of 35 feet at Whitman Creek in the border area of Ashtabula and Kingsville townships. The Upper Till, exclusive of the area east of the city of Conneaut, nowhere attains the 40 foot thickness of eastern Painesville township, it fluctuates within short distances, and ranges between 6 and 30 feet.

Fairly thick (17 feet) deposits of laminated lacustrine clay, superjacent to the Upper Till, crop out between Russell and Labounty Roads of Ashtabula township, where the unit occupies an apparent bench, cut by an ancestral Ashtabula River on the till. The lacustrine material also grades downward into a tough clay, with small, rounded pebbles or granules, and some red clay, although the contact on the till remains marked by a physical break.

Above these laminated beds lie sand deposits, 7 to 20 feet thick. Both lacustrine units terminate, in essence, against the rising till contact at Labounty Road. The sand unit, like that of Perry and Madison townships, forms a low topographic hump, and is regarded by the author as a depositional form laid down in Lake Grassmere, and now truncated by the Lake Erie bluff.

Across eastern Kingsville and all of Conneaut township west of the city of Conneaut, sand deposits, 5 to 6 miles in bluff length, and mostly 30 to 35 feet thick, occupy the bluff section. The upper portion of the deposits was probably laid down in Glacial Lake Glassmere, 640 feet in elevation.
Northeast of Whitman Creek of Kingsville township, two ancestral valleys were cut and filled in the bluff section. The older valley was eroded into the intertill lacustrine clay, and then filled with sand, and sealed by the Upper Till. The younger valley was excavated farther eastward into the Upper Till. This valley was then drowned by one of the glacial lakes, filled with lacustrine clay, and covered by a later phase of the Upper Till or reworked glacial material.

Other intraglacial valleys antedating the Upper Till are portrayed in the bluffs adjacent to the Grand River, Ashtabula River, and the aforementioned Red Brook.
The ancestral bedrock valleys of the Grand and Ashtabula rivers predate the glacial till of the study area by virtue of the fact that the tills of the Lake Plain and the Lake Escarpment moraines occupy segments of these valleys. On the other hand, the evidence seems to indicate that the Conneaut River arrived into the area as a post-till event, since an ancestral valley of this stream was not located in the area. Moreover, along the westerly course of the Conneaut River, a northern bedrock wall to the bedrock floored valley is virtually absent. Thus the falling surface of the Lake Escarpment forms the southern wall, from which the bedrock surface descends northward to the Lake, independently of the course of the above stream. Thus it appears that the Conneaut River is controlled topographically, either by the presence of the bedrock controlled moraines or by the former existence of an ice-front in the area.

One of the ancestral bedrock valleys of the Lower Grand River runs southwest between the Mentor Marsh and the Lake Erie bluff to enter the present basin of the lake under Mentor Harbor, where it joins the buried Kirtland valley (Plate IX) at an elevation of 509 feet. Likewise, the ancestral valley of the Ashtabula River enters the lake slightly west of its present site, and about 1 mile offshore lies at an elevation of 506 feet. Thus it appears that a period of very low lake levels preceded by some unknown
interval of time the deposition of the Lower Till. It is of interest to note that such low lake-levels, i.e., a difference of 69 feet from the present level, would virtually empty most of the western and central parts of the lake if one assumes that the same basin morphology existed then as exists today.

Both of these valleys were buried under the Lower Till and inundated by the glacial lakes that succeeded the period of ice invasion. The author has found no clear evidence, such as a valley cut into the Lower Till, to indicate that the Grand River used any of its outlets in the study area or in the immediate vicinity to the southwest at that time. Accordingly, the author assumes that the river was diverted by the ice, presumably into the Chagrin-Cuyahoga system via one of the buried channels between the Lakes Warren and Whittlesey beaches. On the other hand, the Ashtabula River and Red Brook of Saybrook township did carve channels into the Lower Tills in the vicinity of their present courses (Plate XIII).

The intertill glacial lake stretched at least from one end of the study area to the other, and continued for an unknown distance into Pennsylvania on the northeast, and at least as far southwest as Mentor Harbor. The thickness of the laminated clay, preserved in this basin, locally equals that deposited in the post-Upper Till glacial lakes of the area. This is especially true in the Kingsville-Conneaut townships border area, where 33 feet of lacustrine clay have survived glacial erosion. In this area, a 2,000 foot wide ancestral valley of Whitman Creek was cut into
the laminated clay, and then filled with 17 feet of fine to medium sand. From this one may conclude that more than one intertill glacial-lake episode had transpired, since after deposition of the lacustrine clay had taken place, there must have been a period of lake retreat and readvance to permit cutting and filling of the valley.

Subsequently, the ice-sheet readvanced to the Lake Escarpment, eroding, incorporating and redistributing most of the lacustrine clay under it. Those beds left behind were, with local exceptions, badly distorted.

Concomitant with the withdrawal of the ice-sheet the period of the glacial lakes began, and the record of their presence is largely preserved as beaches and bluffs on the Lake Plain. These lakes rose and fell from one level of shore to another; and the elevation of each strandline was governed by the fluctuating margin of the waning ice sheets, which covered and uncovered outlets of the several Great Lakes of that time, and by uplift of the Canadian Shield. The lithologic pattern of the lacustrine clay in the Lake Erie bluff, wherein the lacustrine clay grades downward into till in many of the localities, suggests that the initial lakes were proglacial and that the lacustrine environment of deposition merged with that of the till. This is emphasized by the presence of blocks of till in the lacustrine clay of section XXVIII, unit 1b, of Kingsville township (p. 104).
About 15 levels of glacial and postglacial lake levels have been catalogued for the Lake Erie basin by Leverett and Taylor (1915, p. 397). Since the resolution of all these shorelines in the study area was beyond the scope of this work, the author contented himself with the recognition of only those which were of stratigraphic importance to the study; i.e., Lakes Whittlesey, Warren, Grassmere, Lundy and the lower stages of Lake Erie. The following glacial lakes, their sequence (beginning with the oldest), elevations and outlets are summarized from the work of Hough (1958, p. 283), and presented in Table II.

Lake Whittlesey, which has developed strong bluffs across the southern part of the study area, has been dated as 12,800 _ 250 years before present. Lake Lundy, the beach of which briefly crosses northern Madison township, was given a possible radiocarbon date of 8,513 _ 500 years before present (Goldthwait, 1958, p. 218).

The evolution of Lake Erie from the 343 foot stage to the 573 foot level is probably best reconstructed from the deposits buried in the lower course of the Grand River, as revealed by borings. East of Fairport, the old abandoned course of the Grand River trends southwesterly to Mentor-on-the-Lake via the southerly bowed Mentor Marsh. The valley is incised into till to an elevation of 551 feet at Fairport, and 544 feet at Mentor-on-the-Lake, for a gradient of roughly 1.5 feet per mile over the 4.5 mile course.
<table>
<thead>
<tr>
<th>Name of Lake</th>
<th>Elevation in Feet</th>
<th>Glacial Event</th>
<th>Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maumee I</td>
<td>800</td>
<td>Cary Ice Retreat to the Tinley - Defiance Moraine</td>
<td>Fort Wayne to Wabash River</td>
</tr>
<tr>
<td>Maumee II</td>
<td>760</td>
<td>Farther Retreat of Ice</td>
<td>Saginaw Bay</td>
</tr>
<tr>
<td>Maumee III</td>
<td>780</td>
<td>Cary Ice Advance to the Lake Escarpment Moraine</td>
<td>Fort Wayne to Wabash River</td>
</tr>
<tr>
<td>Arkona I, II, III</td>
<td>710 (700, 695)</td>
<td>Ice Retreat</td>
<td>Grand River</td>
</tr>
<tr>
<td>Low Stage (?)</td>
<td>?</td>
<td>Cary-Port Huron Interstadial</td>
<td>?</td>
</tr>
<tr>
<td>Arkona IV</td>
<td>695</td>
<td>Port Huron Ice Advance</td>
<td>Grand River</td>
</tr>
<tr>
<td>Whittlesey</td>
<td>738</td>
<td>Ice Retreat</td>
<td>Ubly Channel</td>
</tr>
<tr>
<td>Warren I, II</td>
<td>690 (682)</td>
<td>Ice Retreat</td>
<td>Grand River</td>
</tr>
<tr>
<td>Two Creek Low Water Stage</td>
<td>?</td>
<td>Port Huron - Valders interstadial</td>
<td>St. David Filmed gorge (?)</td>
</tr>
<tr>
<td>Wayne</td>
<td>655</td>
<td>Advance &amp; Retreat of Valders Ice</td>
<td>Mohawk River</td>
</tr>
<tr>
<td>Warren III</td>
<td>675</td>
<td>Ice Retreat</td>
<td>Grand River</td>
</tr>
<tr>
<td>Grassmere</td>
<td>640</td>
<td></td>
<td>Lake Glenwood</td>
</tr>
<tr>
<td>Lundy</td>
<td>620</td>
<td></td>
<td>Lake Calumet</td>
</tr>
<tr>
<td>Early Erie</td>
<td>540</td>
<td></td>
<td>Niagara River</td>
</tr>
</tbody>
</table>
The section at the lower outlet consists of 14 feet of medium sand on 17 feet of silty muds, which in turn rests on the till. Somewhere between the depths of 9 and 14 feet, i.e., the elevations of 566 and 561 feet, marsh deposits are found in the section. At the other end of this valley segment, on the west side of the Grand River off Fairport, the following represents a typical section recovered:

<table>
<thead>
<tr>
<th>Top (Elevation: 576.66 feet)</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Soft, gray silt</td>
<td>573</td>
</tr>
<tr>
<td>2. Soft black peat</td>
<td>570.6</td>
</tr>
<tr>
<td>3. Sandy gray silt with seams of peat</td>
<td>564.6</td>
</tr>
<tr>
<td>4. Loose medium to coarse gray sand and gravel</td>
<td>553.0</td>
</tr>
<tr>
<td>5. Brown sandy silt, some vegetation</td>
<td>551.4</td>
</tr>
<tr>
<td>6. Sandy till.</td>
<td></td>
</tr>
</tbody>
</table>

Silty muds in the lacustrine environment are generally associated with deeper water sedimentary facies. Thus the presence of the basal silty muds in the section at Mentor-on-the-Lake indicates that the mouth of the river was already drowned to a great depth at the time of deposition or, at least, that the rate of drowning exceeded the rate of fluviatile tractional sedimentation. From the equivalent sand and gravel section upstream at Fairport, it appears that the site of sedimentation had already shifted upstream from some point downstream, beyond the present locale of Mentor-on-the-Lake.

Apparently the level of the lake had temporarily halted in its climb or had slowed at some value between 561 and 564 feet, because sedimentation in the lower valley was able to catch up
with the lake waters, and marsh deposits came into existence.
Upstream, the steady inflow of coarser detritus tapered off into
silts; and also alternated with marsh-forming conditions, as indi-
cated by the beds of peat interbedded with the silt. Whereas it
is possible that the source of the sand and gravels had dried up,
the greater probability exists that the stream meandered at Fairport
at this time might have undergone incision by the receding Lake
Erie bluff, and thus diverted the river into the lake north of the
present harbor at Fairport. This part of the valley must then have
become a backwater settling basin and swamp.

Subsequent increase in the level of the lake must have continued
slowly, drowning the valley more, and intensifying marsh conditions
over most of the valley segment, at elevations between 568 and
573 feet. Moreover, at Mentor-on-the-Lake, beach sand encroached
on the valley and began to seal it off from the lake by damming.

With the opening of the valley to the lake at Fairport, beach
material was apparently driven into the valley by wind and water,
with the result that a portion of the marsh deposits there was
covered with sandy material up to an elevation of 580 feet, or to
a depth of 7 feet.
THE RELATIONSHIPS BETWEEN BLUFF LITHOLOGIES
AND DEGRADATIONAL PROCESSES

Three major lithologic types characterize the bluff constituents of the area:

1. Poorly cemented lacustrine sand
2. Massive laminated and nonlaminated clay, silt and sand
3. Glacial till

Sand deposits more than 5 feet thick, as a rule, occupy the topmost section of the bluff, and are developed, 10 to 35 feet thick, across the townships of Perry and Madison in the southwest, and all of Ashtabula County between Ashtabula and Conneaut Harbors. The lone exception to the stratigraphic position of these deposits is found in the border area of Ashtabula and Kingsville townships, where 17 feet of sand underlies 5 to 17 feet of Upper Till.

Invariably, the massive lacustrine clays underlie the sand deposits. Nevertheless, in terms of thickness, the clays outrank the superjacent deposits in western and central Perry township, and in Ashtabula township, northeast of Ashtabula Harbor, where they range in thickness from 15 to 32 feet. The upper two-thirds of these clays are generally interbedded with sand and silt; but downward in the section these subordinate layers become scarcer as the clay increases in homogeneity and density.
Regionally, glacial till forms the dominant lithologic type, and exhibits a virtually complete bluff-front across Painesville, western Perry, Geneva, Saybrook and eastern Conneaut townships. Only in eastern Perry and all of Madison township does the till disappear as a strong lithologic constituent of the bluff.

The degradational processes include —
1. Chemical and physical weathering;

2. Mass wasting, i.e., the transfer downslope en masse of bluff debris under the primary influence of gravity; and

3. Erosion, primarily by water and wind.

Weathering in terms of freezing and thawing, oxidation, hydrolysis, hydration and solution attacks the tills most, since a great deal of the till contains particles derived from igneous and metamorphic rocks. Freezing and thawing disrupt silt-rich material by the growth of ice crystals. Hematite and pyrite in the tills are hydrated to limonite; carbonates are leached into solution, and it is assumed that hydrolysis reduces igneous minerals such as feldspar and mica to clay minerals. The net effect of this process is one that increases the bulk of the weathered till, loosens it and renders it more susceptible to movement, especially where this process has acted in the deep vertical joints of the till. On the other hand, hydration of magnetite layers in the sand deposits has produced the limonitic cementing material that helps to bind the sand bluff.

Mass wasting expresses itself in a wide spread of types that range from the fall of sand grains down-bluff to the vertical collapse
of tons of undermined massive blocks of till; from small mud flows to extensive slumping and creep. This process operates most effectively in the bluffs of till and lacustrine clay, and is strongly aided by the weathering and erosional processes.

Erosion occurs primarily by meteoric and subsurface waters, runoff and seepage, and by the motion of lake waters that erode and remove material by wave and current action. Wind activity makes itself felt by its deflational effects on the sandy bluff.

No one lithologic type occupies a given stretch of bluff to the exclusion of the other; nor does one type of degradational process operate on the bluff to exclusion of the other. Nevertheless, a certain amount of association does exist between some of the degradational processes and a major lithology of a given area.

Degradation of Sandy Bluff Deposits

The bluff of the Perry-Madison township area exhibits, from the top downward, a 25 to 35 foot layer of medium to very fine sand resting on 15 feet of lacustrine clay, on 2 feet of exposed till. The sand unit maintains a steep slope ranging from 45 to 90 degrees (fig. 31). It is also perennially damp to wet downward from the uppermost 2 or 3 feet, and contact springs issue from the base over the lacustrine beds.

One may attribute the prevalence of steep slopes on the sandy bluff to (1) a slight increase of adhesion obtained by a thin, cementing coat of limonite on the individual grains; (2) strong
angularity of the grains, and (3) the presence of vadose water seeping downward through the sands. These factors tend to increase the intergranular friction, so that the angle of internal friction, or angle of repose (30 to 35°), for loosely piled sand is greatly exceeded. As suggested by Kaye (1950, p. 95-96), one may demonstrate the importance of intergranular friction on sand strength by filling a soft rubber bladder with loose dry sand under atmos­pheric pressure, and watching the rigidity of the sand increase as the air in bladder is evacuated. The increase in rigidity is attributed to the condition whereby the intergranular pressures are raised by the sand bearing the weight of the atmosphere pressing on the bladder. This weight is roughly equivalent to an overburden of 20 feet of sand. Downward percolating water also adds to the intergranular pressures, because the drag effect exercised by the water on the sand grains acts to pull them together and downward.

During periods of rain, the high permeability of the sand preserves the upper portion of the bluff from strong sheet wash, except under extreme conditions. However, the relatively impermeable floor on the lacustrine clay serves as the substratum for contact springs that seep from the sand unit. The basal sand is plucked away and transported onto the beach as trickles forming miniature alluvial fans (Fig. 45). If the springs become particularly strong, then large cavities develop in the bluff by collapse of the flanking layers and masses into the spring (Fig. 31).
This effect of underground stream erosion acts to undermine the face of the bluff in general, so that thin layers, chunks and discrete particles fall off the face as the general mass wasting process. On the other hand, wave erosion by lake waters seldom obtains the opportunity to attack the sand deposits directly since these deposits maintain a position recessed 10 to 30 feet above the lake, and 20 to 40 feet behind the salient subjacent till and lacustrine clay members. Wind deflation probably acts most effectively during the dry summer months when the wind is blowing gustily. Most of such material knocked from the parent material falls as talus, and is transported over the till by the contact springs and sheet wash.

The situation described for the Madison-Perry township sand deposits remains essentially the same for the Kingsville-Conneaut deposits.

Degradation of the Lacustrine Clay-Silt Member

In terms of its physical properties, the lacustrine clay occupies a transitional zone between the members dominated by sand and those dominated by glacial till. Since in most areas these deposits are capped by sand, contact springs from the upper contact pour over the face of the clay beds to exercise a certain amount of sheet wash and rill erosion thereon. The effectiveness of this type of erosion on a given unit depends in great measure on the character of the laminations. In the presence of numerous permeable
sand layers, a great deal of the moisture is stored until full saturation of the sand beds is accomplished. In such an eventuality, the clay layers become plastic and, weighted down by the excess moisture, may yield plastically. This is especially true of the lower massive portion of the unit, which consists mostly of clay. The entire mass may then move over the till contact as part flow and part slump. However, actual sliding may depend on the dip of the contact on the till, since the dip does change from one locality to another. East of Perry Township Park, sliding was observed during the field season (Fig. 146), and there the dip of the contact was lakeward. Southwest of the Park, the contact dips away from the lake, and failure was observed to occur largely as flow and small scale slumping and sapping of the lacustrine unit onto the till contact.

Where the clay layers tend to dominate the sand laminae, sheet wash of surface waters becomes effective in removing a great deal of the material. Chieruzzi and Baker (1958, p. 81) place great emphasis on this process in their detailed study of the bluff at Perry Township Park. The author concurs, but in regional terms, believes that this process as it acts on the lacustrine clays is somewhat overshadowed by the processes of mass wasting.

Degradation of Bluffs Composed of Competent Glacial Till

Characteristically, the till consists of a heterogeneous assemblage of preconsolidated particles ranging from clay to boulders.
Fig. 45. Alluvial fan of fine sand formed on beach by spring issuing from contact the sand member and the subjacent lacustrine clay, Madison township, 400 feet southwest of Haines Road. Aug. 1956.
Fig. 46. Lacustrine massive clay sliding over contact on the Upper Till which forms the salient bluff member. Shear surface and contact marked by long horizontal fracture. Height to shear surface = 13 feet. Observe vertical flutings on the face of the bluff, the product of rill erosion by surface wash and contact springs. Western Perry twp. Perry Township Park lies on the distant promontory. View toward the southwest. July, 1955.
Fig. 147. Scarred surface of till over which saturated lacustrine material have slid in a sudden descent after a period of heavy rains. Ashtabula Twp., 3,500 feet E of Russell Road. June, 1957. View toward the south.
Mechanical analyses of 12 samples, selected from sites in Perry, Geneva, Saybrook, Ashtabula and Kingsville townships, reveal a composition rich in silt, clay and very fine sand, but dominated by the silt and clay fractions (Fig. 48). Lateral consistency or trend in the ratio of these constituents, one to the other, appears to be lacking. This observation is partially reflected by changes in the behavior of the mass wasting properties of the bluff from one locality to another.

With respect to the classification based on the Atterberg Limits (Fig. 49), the data from 16 till samples are plotted on the Plasticity Chart of figure 50. There the tills are shown to consist primarily of an inorganic silty clay with low to medium plasticity.

Where virtually the entire bluff is composed of impermeable, well-consolidated till, and the bluff is under wave attack, a near vertical to vertical face is maintained.

Failure is induced by direct wave undermining, usually on the easily eroded lacustrine contact zone if it lies within reach of high waves, but above the general level of the lake. Slides occur as sudden events, moving on near vertical fissures and dumping tons of material on the beach.

Such a bluff typifies the one-mile length of shore centering on Blackmore Road in western Perry township. Here the bluff maintains a height of 45 feet, and rises nearly vertically from the water's edge (Fig. 51). The contact zone between the tills ranges
Fig. 48. Grain size distribution of till samples from the bluff of Lake Erie, Perry to Kingsville townships. Numbers refer to the last two digits of the sample numbers. In terms of Pleistocene geological age classification, the sand-silt-clay ratios do not fit the distribution of either Shepp's Cary I or Cary II groupings. See Appendix B for numerical data.
Fig. 49. Plasticity Chart showing soil classification (after A. Casagrande, in Terzaghi and Peck, 1948, p. 35). The dry strength of inorganic soils plotted above the "A" line increases from medium for those with liquid limit below 50, to very high for those near 100. Samples plotted below the "A" line with a liquid limit below 50 possesses very low dry strength, while those with a liquid limit of 100 have only a medium dry strength (Terzaghi and Peck, 1948, p. 35).
Fig. 50. Relationship between liquid limit and plasticity index for typical soils as compared with those from the till of the Lake Plain of the study area. (After A. Casagrande, 1947, p. 803).
- Lake Erie bluff samples
- Northern Lake Plain
in elevation between 574 and 576 feet, i.e., 1 to 3 feet above lake level, and consists of lenses and pockets of lacustrine sand, silt and clay. Waves readily undermine this bluff by the removal of nonresistant material from the contact zone. Vertical fissures parallel to the face of the bluff develop near the base, possibly as a result of hydration which may promote an expansion lakeward of the bluff, or possibly as a product of freezing and thawing of capillary moisture drawn up from the base of the bluff. Howbeit, with sufficient undermining, down come tons of material from above (Fig. 51).

In general, the above described process of mass wasting, i.e., Soil Fall (Varnes, 1955, p. 22), operates wherever in the study area massive basal units of competent till are exposed to wave undermining. However, the spectacular effect exhibited at the above site becomes subdued in other localities by the fact that the till is seldom as thick, and by the presence of thick superjacent lacustrine beds, on which related processes of degradation operate more effectively. Thus debris is supplied by these overlying beds in sufficient amount to reduce the intensity of wave attack against the bluff. To this one must add the factor of sheet and rill erosion of the bluff by contact springs issuing from the lacustrine unit onto the bluff, which helps to reduce the upper slope of the basal till (Fig. 46).
Fig. 51. Bluff NE of Blackmore Road, western Perry twp. Observe steep face, and collapsed material in the background resulting from waveing undermining. Aug. 1955. Water-level = 573.5 feet (approx). View toward the northeast. Height of bench in middle foreground about 20 feet.
Failure by Creep in Certain Bluffs of Glacial Till

Creeping of bluff constituents occurs everywhere in the study area; but only in Saybrook township, between Saybrook township and Red Brook, and in Ashtabula township at the western border area, and a locality about 2.5 miles northeast of Ashtabula Harbor, does this process assume a wholly integrated form. The entire face of the bluff, 1 to 2 feet thick and several hundred feet wide, inches its way down and out over the beach. The author has seen beaches up to 25 feet wide at the above sites covered by such a mantle (Figs. 52 to 55).

A mechanical analysis made of a till sample (9632) from the Saybrook township creep material revealed that the till contains 17% sand, 40.2% silt, and 42.8% clay. The western Ashtabula township site was not sampled. However, the Upper Till unit in eastern Ashtabula township, at the locality of section XXIV, also creeps in a similar manner; and the mechanical analysis of a sample there (9635) revealed 16% sand, 67% silt and 17.3% clay. The silt percentages of the two samples are higher than those of any till samples taken from other sites in the study area, except for the weathered Upper Till sample taken from the bluff east of Whitman Creek, Kingsville township, which revealed a silt content of 40%. Again, the sand percentages of the two samples are substantially lower than any of the other samples, save one, an exceedingly clay-rich variety.
Fig. 52. Blanket of till, 2.5 feet thick, creeping from off face of bluff in the background and advancing over the beach in the foreground. Site: Saybrook twp., 3,000 feet NE of Saybrook Township Park. Aug. 1956.
Fig. 53. Like Fig. 52. Same area. Observe polygonal fractures, the product of repeated saturation and drying of the till. Freezing and thawing in the spring probably laid the groundwork for the movement displayed. Aug. 1953.
Fig. 54. City of Ashtabula near western limit. Blanket of till creeping down the 60 foot bluff and advancing over beach. Wave erosion has nipped the frontal margins. View toward the SW. July, 1956.
Fig. 55. As Fig. 54, but one year later and from top of bluff. Wave erosion has removed most of the basal material. Only a small amount of movement has occurred over the year. Aug. 1957. View toward the SW. Lake level: 573 feet.
With respect to the creep phenomenon of these sites, the high silt content of the bluff constituent bears great significance. Observations during the summers of 1955, 1956 and 1957 indicate that the typical summer showers scarcely affect the quasi-stability of these creeping masses. The rain barely wet the face of the bluff, because of the steep slopes and the resultant rapid runoff.

On both hypothetical and empirical grounds, as discussed by Krynine (1941, p. 81) and Terzaghi and Peck (1950, p. 131), sediments dominated by the silt sized fraction are strongly susceptible to disruption by freezing and thawing, because such sediments combine a considerable height of "capillary rise" with fair permeability. Moreover, the force of crystallization that induces a flow of water toward the zone of freezing is identical in effect with the capillary force that causes water to rise from a ground-water source through the voids of a soil toward the surface of evaporation. The ice formed tends to force the silt grains apart, thereby reducing the internal resistance of the material. In contradistinction, clay lithologies possess a "high capillary rise," but little permeability. Sands, though highly permeable, include within their structure sufficiently large voids to accommodate the increase volume gained by the freezing of interstitial water.

Eventually, thawing ensues, and the silts become saturated with melt water from the ice developed within them. Thus with the fabric of the affected unit already disrupted by freezing, and the intergranular pressure further reduced by the excess moisture, the
surface layer of the bluff is set into motion by gravitational stress. The depth of frost penetration ranges from 21 to 23 inches for the area (Chieruzzi and Baker, 1958, p. 76). This depth is of the same order of the thickness of the creeping masses which ranges from 1 to 2.5 feet.

Maximum rate of movement apparently occurs in the early spring, but as the bluff dries out during the summer months, movement comes to a halt. Not only the increased rigidity gained by the bluff constituents, but also the braking effect of material moving onto the beach serve to end the motion. However, the agents acting to disintegrate the creeping masses continue to function. Dessication and wetting, especially of the lower portion of these deposits, follow in rapid sequence, as implemented by rainfall and spray from rough water on the lake. Additionally, water from above is channelled through the fissures in the blocks. Eventually the mass that had crept over the beach is dissipated, leaving the winter-spring process of freezing and thawing to resume the operation. The end effect is that of bluff retreat by parallel retreat of the slope. The retreat as measured at the top of the bluff in western Ashtabula township has been of the order of 2 feet per year for the period 1954-1956.
Slumping in Composite Bluffs of Glacial Tills and Interbedded Lacustrine Clay

Bluff slumping, by far the most effective of the mass wasting processes in the study area, affects the following two groups of stratigraphic sequences:

A. that consisting from top to bottom of lacustrine beds, Upper Till, intertill lacustrine beds, and Lower Till; and

B. that which includes a virtually all-till bluff section resting on lacustrine material, discrete or poorly integrated into the till near lake level. The Lower Till or bedrock may lie below.

Slump in the area is facilitated by wave erosion of the bluff and by the presence of water-saturated units lying at depth in the section of bluff affected.

Group "A" Slumps Only the bluff of Ashtabula County presents the well-developed sequence of thick alternating beds of glacial tills and lacustrine sediments prerequisite to this category of slump forms. A steplike profile is presented by this stratigraphic succession, wherein the Lower Till forms the salient, basal front, 20 to 30 feet high, behind and above which lacustrine sediments, 6 or more feet thick, rise on a subdued slope. Superjacent and recessed more than 20 feet inland, the front of the Upper Till rises sharply for a height of 16 to 25 feet. At the top of the section, sloping inland for a horizontal distance of 40 feet from the shore, lies another lacustrine unit, 3 to 35 feet thick (Fig. 56).

The Lower Till is characterized by low permeability, lithologic consistency, toughness and good competency. Thus it contributes
a stable base for the overlying beds. On the other hand, the lacustrine unit, interbedded between the Lower and Upper Tills, contains miniature lenses of sand in silty clay, and bears moisture perennially. In some localities it is saturated with water even in the relatively dry months of summer. When the unit exceeds 6 feet in thickness, it tends to fail under the stresses generated by the overburden of Upper Till and lacustrine sediments. Failure apparently occurs by plastic yielding of the clay, aided by the removal of sand by ground water issuing at the base of the unit.

Where this lacustrine unit is thick enough to generate relatively large displacements, flowage of its constituents causes slumping to develop in the more competent Upper Till member overlying it. On the other hand, a thin unit of such interbedded lacustrine deposits apparently produces little adverse effect on the resistance to failure. However, one must condition this observation by the fact that thin interbeds of lacustrine material are generally discontinuous and dry, thus indicating that they do not intercept sources of ground water.

The lacustrine material at the top of the bluff may wash, flow or slump, depending on the response of the particular lithology to the degradational forces acting thereon. However, good permeability generally characterizes these beds, which therefore act as a good water bearer. Seepage from the contact on the Upper Till finds its way below, to facilitate movement there. An example of
Fig. 56. Looking south at 60 foot bluff section made up of sand (in the distance), resting on the Upper Till which rises sheerly as a bench above the underlying lacustrine member as a bench in the middle foreground. The immediate foreground shows the Lower Till partially covered by debris from above. Site: section XXVI, 2,650 feet west of Labounty Road, Ashtabula Twp. June, 1957.
the erosional effects of such seepage is revealed by the vertical
flutings developed on the face of the Upper Till in Fig. 56.

**Group "B" Slumps** Slumps of this category involve the entire
bluff as a unit. Thus they are by far the most spectacular. By
the very nature of this type of slumping, stratigraphic relations
of the affected bluff become obscured, and information in this re-
gard must necessarily be sought by drilling into the roof of the
bluff. Additionally, one may obtain clues from the lithology of
the slump blocks themselves. In general, the contact on the Lower
Till lies near lake level, and the constituents of the bluff consist
of a relatively thin to thick (10 to 16 feet) crust of compacted
till which grades downward into a more plastic or clayey till layer
and/or lacustrine sand and clay.

This substratum of permeable and plastic material constitutes
the critical factor. Apparently its subsurface extension and thick-
ness are irregularly distributed over small areas, and this irregu-
larity is perhaps attributable to the distortional stresses imposed
on the lacustrine material by the glaciers that deposited the super-
jacent till. Auger sections made by the Ohio Division of Shore
Erosion into such deposits during the summer of 1956 revealed plastic
clays that one could knead between the fingers without the addition
of more moisture. Likewise, R. Chieruzzi (1956, personal communi-
cation), on making borings into such clay at the foot of the Mentor
Headlands bluff in Mentor township, found the clay to have a natural
moisture content of 13.9 to 24.7 percent. Thus in this category
of slump, like that in group "A," the beds were moist even during the relatively dry months of summer, and therefore must transmit even more water in the early spring when slump becomes accelerated.

The sites of these slumps in the study area extend across Painesville township, but the author specifically studied the slump just east of Hardy Road in Painesville township. Additionally, all of the bluff from Geneva-on-the-Lake to Saybrook Township Park in central Saybrook Township, a distance of 4 miles, is likewise affected and was studied over most of its length.

**The Slumps of Painesville Township** Most of the bluff of Painesville township, from the vicinity east of Fairport to Bacon Road, undergoes slumping where it is exposed to wave attack. The writer selected for study the 9,000-foot stretch of shore centering on Hardy Road just east of Painesville Township Park, because the slump process here typifies that of the aforementioned shore length, and access to the shore was easily made. This site and hinterland is shown on the map of Figure 57.

The bluff of this area ranges in elevation from 625 to 628 feet, i.e., 52 to 55 feet above lake level of 573 feet. On the other hand, bedrock lies 20 to 25 feet below the lake level and rises southward at a rate of about 60 feet per mile. Glacial till dominates the stratigraphy, which possesses the tripartite arrangement of an Upper and Lower Till unit separated by 6 to 10 feet of lacustrine clay. The relatively competent Upper Till, 40 to 46 feet thick, forms the dominant member of the bluff. However, the
relatively incompetent lacustrine unit occupies the critical basal section. On its part, the Lower Till lies mostly at or below water-level.

This in essence is the stratigraphy presented by the bluff all the way into western Perry township. However, in Perry township, the lacustrine unit has thinned to between 1 and 3 feet. One suspects that this thinning of the lacustrine unit exercises a profound control on the type of bluff failure that prevails. In Perry township, as discussed earlier, waves removing the lacustrine material undermine the competent Upper Till which then fails by vertical shear. Contrariwise, slumping occurs throughout Painesville township, where the Upper Till is virtually floating on a relatively thick substratum of plastic clay interbedded with sand.

This lacustrine unit has been traced inland by means of well logs for a distance exceeding 3,000 feet, and the author assumes that it probably extends all the way to westerly Grand River valley (Figure 57). About 3,000 feet south of the bluff, the top of the lacustrine unit, as determined west of Hardy Road, lies at a general elevation of 595 to 600 feet, or roughly 15 feet above its elevation in the bluff. Thus there apparently exists a gentle slope on the upper contact of 1:200 or roughly 26 feet per mile toward the north. Should one project the contact southward 2,000 feet to the wall of the Grand River, it would intercept it at least 15 feet and more likely 20 feet above the surface of the river. This fact if
valid is of significance in a negative sense, when compared with the other fact bearing on the relatively high moisture content of the lacustrine clay wherever sampled. Apparently one cannot attribute influent seepage from the river as the source of the moisture. Finally, the clay thins toward the lake, from a maximum of 16 feet, and a general order of 10 feet in the south, to 6 feet in the bluff, thus providing for a larger moisture storage volume in the south.

To account for the presence of moisture in the lacustrine unit, the author hypothesizes that the lacustrine bed intercepts the topographic surface in the area to the south, most likely the northerm wall of the Grand River valley. There, the unit receives moisture by surface infiltration and transfers it northward down its gradient. Since the clays have but low permeability, the recharge and discharge proceed slowly. This hypothesis can be extended to another major area of slumping, that of the Mentor Headlands area on the western side of the Grand River at Fairport. There the abandoned valley of the Grand River, now the Mentor Marsh, and the presence of even thicker intertill lacustrine clay in the bluff have set up what resembles similar physical conditions (Christopher, 1955).

Returning to the Painesville slumps, the presence of moisture in the intertill lacustrine clay and sand serves to soften the very foundation of the bluff. The weight of the till above is transmitted to the semiplastic and plastic clay below, through which the compressional stress is partially distributed hydrostatically.
However, the confining pressure within the lacustrine clay diminishes in the direction of the bluff, because of the presence of the boundary between bluff and atmosphere, because of the lakeward directed hydraulic gradient and contact slope on the lacustrine clay, and lastly, because of wetting by high waves. Consequently, the lacustrine clay yields plastically, by the development of what the author interprets as shear joints (Figure 63), and by shearing on the lower and upper contacts (Figure 62). Since the overlying till in an undisturbed state neither bends nor flows easily, it eventually breaks as its support is removed, and develops a series of rather nondescript, linear slump blocks mixed with debris.

The author observed that the surface of shear near the base of the bluff (Figure 62) slopes upward into the bluff at an angle of less than 5 degrees with respect to the horizontals and that the angle on the back scarp of the slump lies near the vertical at the top of the bluff. Thus one can fit the classical model of a downward, rotational movement of slumping material on a concave surface of shear, as described by Sharpe, 1938, p. 65. However, the till is brittle and the lacustrine unit is well defined; thus one should not expect to find a continuous discrete surface of shear over any area in excess of 100 feet. Thus the diagrams of Figures 58 and 59 represent the author's idealization of the Painesville township slump at Hardy Road, wherein steep surfaces of shear, developed in the till, flatten on encountering the lacustrine unit. This situation is regarded as similar to that portrayed in Figure 13
of Varnes' (1938, p. 27) work, where a photograph of a slump cross-section in lacustrine clays revealed a similar flattening of the shear surface along a bedding plane.

Over the years of 1954 to 1957, the slump area at Hardy Road has undergone a cycle, wherein the slope on the bluff has increased from a 1:2 ratio to that of 1:1, then returned to the 1:2 ratio. This behavior is partially illustrated by Figs. 60 and 61. Movement during the summers, falls and winters was relatively slow, which is understandable in view of the summers' dryness and the winters' freeze. Greatest movement coincided with the spring period of thawing and freezing, and prolonged rainfall, in which a great deal of water was released for entry into the numerous tensional cracks on the slump blocks, not to mention the recharging of the moisture carrying lacustrine clay and sand.

Thus with all of the foregoing as background material, the author summarizes his impressions on the topic in the following reconstruction of the 4 stages of events.

1. The slope of the bluff lies at its maximum value of roughly 45 degrees, or a ratio of 1:1. One may regard this slope ratio as critical, since further steepening leads to failure (Figure 58).

2. Lacustrine clay near the base of the bluff, softened by ground and surface water, begins to yield, expanding lake-ward and subsiding vertically. Tensional fractures in the till on the lower slope of the bluff reflect this flowage
Plate II, Figs. 58 & 59. Schematic cross-section of slump at Hardy Road, Painesville twp.

Fig. 58. Critical position; surface slope at 1:1. Slump lies at point of renewal. Stage 1.

Fig. 59. Stable development. End of slump cycle, with surface slope at 1:2. Stage 3.

SCALE: 1 inch = 30 feet.
beneath the till. Lakeward transport of the lower constituents of the bluff as creeping blocks leave the upper bluff material unsupported, and failure by slumping moves upslope, with little change in the angle of slope.

3. Surface waters enter the slump fractures and lower the internal resistance of the till by hydration, a process that tends to reduce the apparent cohesion of clay size material by destroying the surface tension of water films adhering to the particles (Terzaghi and Peck, 1948, p. 114–128). Thus slumping, abetted by flow, continues until the relatively low slope of 30 degrees, or ratio of 1:2, is developed. This slope becomes explainable by the assumption that the curvature on the surface of shear is flattened through the lacustrine clay unit (Figure 59). Thus the movement of slump blocks over the lower slip surface becomes impeded by increased frictional forces. Slope stability can now be achieved but for wave erosion.

4. Eroding of the toe of the slumped area and the removal of debris by wave action increases the angle of slope by shortening the horizontal spread of the bluff. Additionally, by removal of the toe material, conditions of disequilibrium are reinforced. However, the force of static friction is not overcome until the slope ration of 1:1 is approached.

The length of a complete cycle ranges between 4 to 5 years under the high lake level conditions of 1954 to 1957. In estimating
amounts of shoreline retreat in the area, one should select either the top or bottom of the bluff and measure the retreat over a given cycle, since the rates of retreat of the top of the bluff and that of the bottom are pulsational and alternating.

The photographs of Figures 60 to 62 portray the process of slumping as it developed over the years 1955, 1956 and 1957, at the site just east of Hardy Road. In spite of the spectacular nature of the slumping here, the bluff line itself has retreated only some 45 feet in 5 years, or about 9 feet per year.

The Slumps of Geneva and Saybrook Townships In the 4.5 miles of shore between Cowles Creek of Geneva township and Saybrook Township Park, slumping affects all unprotected bluffs. Should one compare this area with that of the above described Painesville township bluffs, one would find that the bluffs lie 10 to 15 feet lower, i.e., they range from 25 to 40 feet high, the stratigraphy is similar in the respect that glacial till overlies lacustrine clay, but the slumps of the Geneva-Saybrook township area exhibit greater complexity.

Stratigraphically, the Upper Till member caps the bluff along this stretch of shore. However, it lacks lithologic isotropism, and grades downward into a rather unpredictable heterogeneity of lacustrine clay, silt and sand, a rather clayey till or a mixture of all. The consolidated Upper Till unit apparently fluctuates in thickness from point to point within a few hundred feet. In like
Fig. 60. Bluff at Hardy Road, Painesville twp. Slump site. Above the wave nipped bench, bluff maintains a 1:1 slope. Observe two trees marked by arrows. The one in foreground has already moved one-third of the way down the bluff. The poplar in the background has not yet moved. Material is in process of moving away from under the pavement of route 535. View toward the NE. Lake-level = 573.5 feet. August, 1955.
Fig. 61. Same locality as in figure 60, but one year later. The pavement is broken and has moved one-third of the way down-bluff. The poplar tree in the background has also moved a similar distance. The tree in the foreground is now on the bench or nearly two-thirds of the slope down-bluff. Wave erosion has heightened the basal bench to about 15 feet, from the 8 to 10 feet of figure 60. August, 1936. Lake-level = 573.5 feet.
Fig. 62. Continuation of figure 61. August, 1957. Base of slump area. Wave erosion has removed the slump talus and has exposed the shear surface developed in the contact zone between the Upper Till and lacustrine clay. Movement of the sliding block occurs in the direction of the trenching tool handle. At top of photo lies the lower edge of the pavement which has shifted its position downslope 14 feet below that shown in figure 61. Lake-level = 573 feet.
Fig. 63. Contact zone at the base of the Upper Till. Below the trenching tool, the lithology consists of a red, slightly pebbly clay, with a plastic index of 14, and a liquid limit of 37. Author interprets the fractures that trend into the contact as shear joints. Actual movement toward the observer occurs immediately to the east in figure 62. August, 1957.
manner, the moisture content of the subsurface material varies according to the local permeability.

The author's study suffers from the lack of core holes made behind slumping stretches of the bluff. However the author has gathered much collateral information on the bluff lithology from the slumped fragments themselves, and has supervised the augering of two sections in the very critical area east of Indian Creek in Geneva township (section XV), and a point in Saybrook township (section XVI), about 1150 feet east of the Geneva township line.

The first of the auger sites was located 2,500 feet west of the west Saybrook township boundary and 1140 feet inland of the waterline. This section revealed that the Upper Till retained its characteristically tough, compacted lithology for only the upper 10 feet. From 114 to 39 feet below the surface, sand integrated into the somewhat pebbly clay and silt was encountered, and the moisture content increased downward until in the last 10 feet, i.e., 29 to 39 feet below the surface, the material became mushy; i.e., the liquid limit of 32 for a sample 17 feet below the surface was well exceeded. The zone of highest moisture content lies at an elevation of 571 feet, or roughly 2.5 feet below the lake level of that time. Unfortunately, the auger did not touch bedrock, but the author is fairly certain that bedrock probably does not lie more than a foot below the elevation reached, since at the shore it lies at an elevation of 571 feet as part of a flat shelf sloping
gently lakeward. Thus it seems to the author that water is seeping along the contact or contact zone into the bluff through a permeable layer, and perhaps through joints in the bedrock acting as pipes.

The other auger hole was bored at a point 130 feet from the shore. Uppermost in the section lay 9 feet of hard, dry, weathered till, below which was found a soft to mushy zone of silty clay, one foot thick. Then was encountered an additional ¾ feet of hard till, underlain by more than 25 feet of plastic, sandy to clayey till. The hole ended at the elevation of 573 feet, or roughly that of the lake at that time. The moisture content in section was less than that of the counterpart section in Geneva township.

Thus it is clear that the greater part of the one-mile length of section consists of a plastic clay, irregularly interbedded with sand. In fact, blocks and fragments of this material crop out in the basal slump forms along the shore. It is also indicated, though not proved, that the lake is serving as the source of moisture found in these clays.

Morphologically, slumping in the area presents the typical stairlike topography. The slump blocks are linear and up to 100 feet long in a few localities. Elsewhere they are short, about 20 feet, and relatively thick. Block gliding as described by D. J. Varnes (1955, p. 29) also seems to occur on a modified scale. In this process the failing block undergoes a relatively larger horizontal
than vertical displacement as it creeps over a plastic clay substratum. Near the Saybrook township line in Geneva township, this type of behavior is probably encouraged by movement on the flat surface of the bedrock contact, which would tend to flatten the typical curved surface of shear that develops in isotropic clays undergoing failure.

The characteristic back scarp associated with slump develops normally in conjunction with a near vertical subsidence of 9 to 10 feet (Figure 64). Then translational movement gains dominance in the area lakeward of the scarp. About 30 feet from the back scarp, tensional fractures appear, increasing in number toward the basal scarp fronting the lake (Figure 65) where splitting off of the debris into the lake ensues. The waves and littoral currents act to redistribute the material as mud patches over the bedrock floor offshore. Apparently most of the subsurface movement occurs plastically without benefit of direct shear. However, the author has seen surfaces of shear underlying slump blocks sliding off a basal bench, 3 to 5 feet high, in the area. Likewise backward rotated blocks were also observed.

Northeastward into Saybrook township, creep and block glide phenomena become less in evidence. Apparently the decrease in moisture content and the thickening of the Upper Till have led to the development of the long, linear series of blocks shown in Figure 67.
Curiously, the retreat of the bluff here probably does not exceed a foot or so per year; yet in the southwestern part of the area, in Geneva township, the rate soars to 21 feet per year for the years 1954 to 1957.
Fig. 64. Slumping of bluff in Geneva twp. Site, 350 feet west of Saybrook twpline. Bluff is failing by combination of slump and flow. Observe lithologic discontinuity as featured by large massive block of pebbly clay. Back scarp is made of the Upper Till which overlies moisture bearing sandy clay that forms a very plastic substratum on which subsidence takes place. The front bench is caused by wave nipping. Height of bluff = 140 feet. Date: August, 1957. Water level: 573.5 feet.
Fig. 65. Immediately west of site of figure 64. View toward the SW. Observe tensional fractures developed in the slumping material. Fractures are more than 6 feet deep, and are apparently caused by lake-ward near horizontal flowage of underlying plastic clays.
Fig. 66. Saybrook township, 600 feet east of Geneva twp. Slump forms are developed as long, narrow slices, exceeding 100 feet in length. July, 1956. View toward the SE.
LITTORAL DEPOSITS AND SOURCES

In terms of littoral processes, water currents generated by winds predominate as the most active agent of transport in the study area. The direction of the littoral drift shifts from northeast to southwest, or vice versa, as the propelling winds move from the one quadrant to the other. As measured over the years between 1937 and 1948, winds blowing from the southwest, west and northwest, accounted for approximately 52 percent of the total wind duration, and 59 percent of the total wind movement. On the other hand, winds from out of the north and northeast accounted for only 20 percent of the wind duration, and 22 percent of the wind movement. Thus the net littoral drift was toward the northeast (House Doc. 351, p. 22). This conclusion remains valid, as is further substantiated by the accretion of all the active major beaches on the updrift side of the major jetties.

One may regard the littoral deposits, which now protect roughly one-half of the shore, as the accumulated product of past and present bluff erosion, combined with the material introduced from the hinterland. Today, the major streams, as the Grand, Ashtabula and Conneaut, contribute very little material to the littoral processes, since most of the fluvial sediments are trapped within the harbors by breakwaters. Nor do many of the larger small streams, i.e., Big (Arcola), Wheeler and Cowles creeks, and Red Brook, now add much
sediment, because rising lake waters have drowned their lower valleys; and the swamps, consequent thereon, act as settling basins for the river-derived deposits. Finally data collected from the investigative work by the personnel of the Ohio Division of Shore Erosion have, up to now, revealed no positive evidence for shoreward movement of sediments from the deep basin areas (H. J. Fincus, 1953, p. 119). Thus it appears that the exposed bluff is the presently active contributor of material to the littoral stream, to which one may add that minor amount yielded by the small streams eroding the Lake Plain.

Apparently, an enormous amount of material that has been added to the littoral stream in the past from bluff erosion is permanently lost to the area. The author estimates that about 1,900,000 cubic feet of sand forms the beaches between the breakwater at Fairport and that at Ashtabula (Appendix C). On the same length of shore stand 6,350,000 square feet of bluff, at most 20 percent of which consists of material suitable for beach building (House Doc. 351, p. 17). Thus, on this basis, only 40 feet of overall bluff retreat is needed to account for all exposed beach deposits in the area. This is a relatively small amount over post-glacial times when compared with the published values of bluff retreat between the years 1876 and 1948, wherein the bluff from Perry township to Ashtabula Harbor has undergone an average 55 feet of recession in only 72 years (House Doc. 351).
Description of the Beach Deposits of the Area

Of the eight townships ranging from Painesville in the southwest to Conneaut in the northeast, only eastern Perry, Madison and Conneaut townships possess shores fringed by a continuum of abundant sand deposits. The locations of these two stretches of beach coincide with the presence of the 20 to 35-foot thick beds of sand crowning the bluff in the area immediately behind the beaches, and in the area stretching to the southwest. Elsewhere in the study area, small and large beaches occur controlled by streams, bedrock highs and jetties, but long lengths of wave-eroded, bluff-bound shore separate them more often than not.

The bulk of the littoral deposits hugs the shore as it drifts with a net movement toward the northeast. Where an excess of sand is supplied to the system, beaches apparently grow without the aid of impediments to the littoral flow. Otherwise, in the presence of an adequate amount of sand, various obstacles such as transecting stream currents, boulder pavements, bedrock highs, man-made structures and even fallen trees may act as beach retainers. For the sake of discussion, the author groups these beaches into three categories: (1) stream-mouth, (2) jetty, and (3) shingle and bedrock defended beaches.

Stream-mouth Beaches Many of the larger streams in the study area, especially those with drowned valleys, display well-developed beaches across their mouths. Most of these beaches are located in Madison, Geneva and Saybrook townships, at Chapel Big (Arcola),
Wheeler and Cowles creeks, and Red Brook. Apparently, two factors influence the deposition of sand at these localities. Foremost, perhaps, is the physical presence of the valley lying athwart the littoral path. Sand and larger particles, rolling in the zone of wave transport, fall into the valley until it is filled. The other factor constitutes that presented by the mass of the stream, which on encountering the littoral flow acts as a hydraulic jetty. The dissipation of energy caused by the collision of stream torrent and waves serves to reduce the competency of both carriers to the benefit of the depositional environment. Thus sand deposits in the form of bars and submerged spits may develop in a site so affected. The author has witnessed the above described situation, and Gordon (1956, p. 56-60) has described a similar development at the mouth of the Chagrin River. Figure 67 portrays the turbulence caused by the meeting of waves driven by northeast winds and the outflow from Big (Arcola) Creek. Figure 68 illustrates the jetty effect exercised by the flow from Wheeler Creek on the littoral drift.

The pattern of deposition and erosion about such streams emptying into the lake obeys the general principle of accretion and growth of beaches on the updrift side of the barrier, and depletion on the leeward side. Characteristically, these beaches assume an asymmetrical, birdlike morphology, whereby the volumetric and areal body of the sand deposit lies in the valley, and the wings extend
Fig. 67. Meeting of stream torrent and wave front at Big (Arcola) Creek, Madison twp. Incoming wave front is bent into a "Y" opening toward the observer around point of contact with stream entering from lower left corner of photo. View toward the northwest. Wind from the northeast, 5 m.p.h. Lake level = 573 feet. August, 1956.
Fig. 68. View toward the northeast at the mouth of Wheeler Creek, Geneva twp. Stream mouth beach, undergoing accretion on the northeast side and erosion on the southwest side. Wind is from the northeast, 5 m.p.h. Lake level = 573 feet. August, 1956.
as thin beaches fronting the bluff. Additionally, sand driven into
the valley by onshore winds accumulates as dunes at the rear of the
beach, where it is anchored by vegetation against a background of
marsh and bluff.

**Beaches Impounded by Jetties** In all probability the three
major beaches at the west breakwaters of Fairport, Ashtabula and
Conneaut harbors, also originated as stream-mouth forms. However,
at the present time only that distributed about the mouth of the
Conneaut River retains a semblance of the former morphology, and
only to the extent that continuous stretches of sandy beach flank
the Conneaut Harbor breakwaters both to the southwest and north­
east. Typically, large beaches lie to the southwest of the break­
waters, and very little other than bluff-eroded shore occupies the
shore to the northeast. Thus to the southwest of the Grand River
lies the 9,000 foot-long beach of the Mentor Headlands State Park,
which also attains a width of at least 600 feet and a depth of 30
feet. Likewise, the beach to the southwest of the Ashtabula River
includes a length of 2,500 feet, a maximum width of 300 feet and a
depth of 13 feet.

On the other hand, at Conneaut Harbor lies not only the Conneaut
Township Park beach, a triangular form, 2,500 feet long, 500 feet
wide, and 5 to 7 feet deep, on the western side of the breakwater,
but also a continuous strip of beach, 7,600 feet long, 75 feet wide
(average), and 4 to 5 feet deep, fringing a virtually all-till bluff
on the northeastern side of the Harbor. A great deal of the eastern
beach is overgrown with trees, estimated to be at least 30 years old. The author believes that this beach came into existence before the introduction of the present breakwaters that have cut off the littoral drift from the southwest, and thus represents the north-easterly wing of a former river-mouth beach that lay astride of the Conneaut River mouth. The author attributes the preservation of this beach to the flat nature and elevation of the bedrock surface, which lies just below water level (573 feet) for several hundred feet off the present shore. The broad shelf acts to dissipate the energy of waves rolling over its surface, and thus to protect the beach deposits already emplaced. Thus the eastern beach survives as a somewhat fossil form, since it is now separated from its source area by the harbor structures.

The present major beaches on the western side of the three harbor breakwaters, by their very size, pay tribute to the effectiveness of such structures in intercepting the littoral drift. The jetties on the Grand River illustrate this. A pier was emplaced out from the west bank of the river at the shoreline in 1826. By 1891, or 65 years later, the shoreline along the west side of the pier had advanced 1,500 feet, for a rate of 23 feet per year, as a result of the accumulation of sand by impounding of the littoral drift (House Doc. 596, App. IX, 1950, p. 13). A high rate of accretion still continues as shown on the map of Plate IV, wherein the rate of shoreline advance west of the west breakwater of Fairport Harbor amounted to 12 feet per year during the years between 1947 and 1954.
Plate IV. Mentor Headlands State Park Beach, Fairport, Ohio. Fence diagram of beach deposits and map showing shoreline changes as a result of accretion.
, Fairport, Ohio.
shoreline changes
The author uses the term "beach promontory" to refer to any of a group of naturally formed beaches in the study area that possess a stable, horizontally rounded, apical, lakeward projecting shoreline, from which lateral bluff-fringing beaches extend in both directions; about which erosion and accretion of beach materials shift from one side to the other; and from which a submerged sand spit or bar trends down the predominant drift, i.e., northeastward, for an unspecified distance (see plates XIV and XV).

Each of the townships possesses at least one of these beaches, and of these, Geneva and Kingsville include two, and Conneaut township four. All beaches are characterized by an abundance of boulders and cobbles, which, locally, account for up to 80 percent of the sediment by volume and weight. Virtually all of the beach promontories studied in the area between Madison township and the Pennsylvania border have their apices resting on boulder-strewn, bedrock anticlinal flexures, and perhaps erosional highs. The author cannot say with certainty that bedrock highs also control the beach of North Perry Village (east of Antioch Road), and that lying astride the Painesville-Perry township line, because the specific bedrock elevations there are not known. All of the beaches extend lakeward from bluffs that retain the evidence of former wave erosion, such as arrested slump blocks and terraces, straight bluff-line, and steep faces.
Three of the beach promontories reveal paired apices. These are the Painesville-Perry border area beach, the one at Geneva-on-the-Lake, and the one at Indian Creek of Geneva township (Figure 69). Like the single apical type, the double forms of Geneva township, at least, rest on paired bedrock highs, believed to be anticlinal flexures in the shale.

The author has traced sand bars or submerged spits that begin just offshore of the apex, and extend northeasterly for distances that exceed 3,000 feet. Those of Madison, Geneva (Indian Creek), and Saybrook townships are mapped as shown in Plates XIV and XVI. That at Geneva-on-the-Lake is portrayed in Figure 71.

When and how these beach promontories were formed remains problematical to the author's knowledge. The bluffs forming the rear of the beaches still retain signs of former wave erosion. Moreover, since several of these bluffs have straight fronts, projections of their topographic traces northeast and southwest beyond the beach promontories produce bluff-lines that lie 200 to 350 feet lakeward of the bluff lines in the areas flanking the beach promontories. This indicates to the author that the stretches of shore flanking the beach promontories have been eroded back that many feet by waves since initiation of the beaches. For example, the bluff-line behind the beach promontory at Indian Creek lies about 200 feet lakeward of the bluff to the southwest, and about 250 feet lakeward of the bluff to the northeast. According to the offshore comparative profile measurements made by the Corps
Fig. 69. Map of Indian Creek beach promontory. Note double spires. Geneva twp., Ashtabula County.
Fig. 70. View toward the NW overlooking the northeast promontory of the natural beach lying astride the Painesville-Perry township line. The bluff fringing beach is ephemeral. Its presence at the time of the photo was caused by action of NE winds which had been blowing for some days. At the time of the photo it was undergoing redistribution down-drift with the return of waves driven by NW winds. July, 1955. Lake level: 573 feet.
Fig. 71. Breaker line on underwater spit trailing toward the northeast from the eastern apex of the Geneva-on-the-Lake beach promontory. August, 1956. Lake level = 573 feet. View toward the NW.
of Engineers, the bluff to the northeast of the promontory, specifically the point at the Saybrook-Geneva township line, i.e., 4,500 feet to the northeast, has retreated 190 feet between 1876 and 1948 (House Doc. 351, 1952, p. 24). Thus it appears that the Indian Creek beach promontory, at the least, pre-dates 1876, especially if one assumes that the shoreline in the area was relatively straight.

With respect to the "how" of formation, the author assumes that the bluff had retreated in customary fashion under the impact of wave erosion. However, the landward recession took place over an upwarped surface of bedrock, which, as it became more exposed and closer to lake level, developed strong frictional forces on the waves as they passed over. Boulders and cobbles left behind by the retreating bluff also took their toll of wave energy and began to exercise a barrier effect on the littoral drift. A sandy beach anchored by the boulder pavement on the bedrock surface subsequently developed as a nucleus around which further expansion has taken place. In the meanwhile, wave erosion continued its degradational work on the flanking stretches of bluff.

**Mechanical and Heavy Mineral Analyses of Bluff and Beach Samples**

In accordance with the procedure described by Krumbein and Pettijohn (1938, ch. 14 and 15), the author separated the heavy minerals in the 0.25 to 0.62 mm. size range from nine of the bluff samples, and obtained their relative percentages by grain count.
under the microscope. About 300 grains per sample were counted. The six most important minerals in terms of their frequencies are presented under Table IV (Appendix B). As shown, pyrite, amphibole and clinopyroxene dominate the suite.

According to Sindowski's (1949, p. 8) table of "Resistance of heavy minerals to weathering," the amphiboles and clinopyroxenes are highly weatherable, i.e., unstable, and they occupy Group II of his seven-fold classification, in which the most stable minerals are listed under Group VII. The author's study seems to verify Sindowski's work with respect to the clinopyroxenes as shown below. That the sampled garnets, another of Sindowski's Group II minerals, do not show signs of corrosion may perhaps be attributed to the extreme youth of the glacial deposits.

Both the bluff and beach deposits contain the same heavy mineral suite (Table III), which suggests that beach deposits are by-products of bluff erosion. However, the till samples are characterized by a high percentage of pyrite (21.7 to 41.3), most of which is authigenic. As viewed in slides, the pyrite occurs as minute pyritohedrons and cubes, globules and amorphous forms found as individual units, but more often in grains of corroded pyroxenes and amphiboles.

The percentage of clinopyroxene generally exceeds that of amphibole; and since most of the corroded minerals appear to be clinopyroxenes, it appears that this mineral must have dominated the suite at the time of deposition of the tills. Nevertheless, this generalization
does not apply to the topmost till of Kingsville township, where the ratio amphibole/clinopyroxene ranges from 2.57 to 4.42, as compared with the 0.65 to 1.88 for the Upper and Lower Tills.

As shown on the map of Plate IV, Figure 74, beach samples were collected from the Madison-Geneva township length of beach (9551-9557), from the beach at Red Brook in Saybrook township (9560-9563) and from the beaches west of Ashtabula Harbor (9564-9566).

In general, the median size of the sampled beach sand ranges from 0.21 to 0.50 mm., and decreases toward the northeast, i.e., the direction of the predominant littoral drift, for each of the locations of continuous beaches, including the Conneaut Township Park beach (Plate V). Pettijohn and Ridge (1933) and Metter (1953, p. 41) also record a comparable trend for the median size of the sand on the western portion of the beach at Cedar Point. There the trend is in the opposite direction, in keeping with the westerly littoral drift there.

All of the samples taken reveal good sorting as described by Trask's sorting coefficient, $S_0$, which formulates a geometric quartile deviation:

$$S_0 = \sqrt{Q_1/Q_3},$$

where $Q_1 =$ the first quartile
$Q_3 =$ the third quartile

A value less than 2.5 indicates good sorting (Krumbein and Pettijohn, ch. 9).
Although a systematic study was not made, inspection of the beach samples under the microscope reveals that quartz, shale and sandstone fragments dominate the suite. Rock fragments outweigh the quartz particles by an outright to narrow margin in the pocket beaches. On the other hand, quartz gains the majority in the larger and more permanent beaches. Texturally, the quartz fragments range from sharply angular to very rounded and from crystal clear to thoroughly frosted; however, the clear, angular varieties greatly predominate over the others.

Concerning the beach heavy mineral suite, the author examined only the 1/4 to 1/8 mm. size, because this group is common to all of the samples. Additionally, since the median size and sorting coefficient of the samples share the same general order of magnitude, one fixed size group suffices as a basis of comparison (Rubey, 1933, p. 28). Moreover, the choice of this size group rather than the smaller 1/8 to 1/16 mm. size, which is not common to all of the samples, reduces significantly the percentage of magnetite, ilmenite and garnets. These minerals, though often vividly displayed in local spots along the shore, e.g., at the mouth of Big (Arcola) Creek, are apparently concentrated in response primarily to a highly local sorting environment. Thus they pose a complex regional pattern, and therefore in the author's opinion, are better omitted rather than included in a regional study of heavy mineral trends.
Pyrite, the dominant mineral of the bluff heavy mineral suite, falls to insignificance in the beach samples. However, exceptions exist. Beach sediments newly derived from the bluff contain a high percentage of pyrite; e.g., the pocket beach sample, 9550, includes 27.1 percent of pyrite. The major glaring exception involves the four samples, 9568 to 9571, of Conneaut Township Park. The pyrite percentage of these samples follows an increasing trend toward the northeast; i.e., away from the bluff source, save for one small creek, and ranges from 9.1 to 22.0 (Plate ?). It has been observed at the Mentor Headlands State Park beach, just southwest of Fairport Harbor, that offshore deposits contain more pyrite and corroded pyroxenes than do beach deposits, and that these deposits, as sand bars, are frequently driven inshore by changed wave conditions (Christopher, 1955, p. 66). Thus it is possible that the typical beach deposits at the Conneaut Township Park might have been contaminated by such onshore movement just prior to sampling.

Magnetite-ilmenite and pyrite share the same general characteristics of size, shape and density. Thus if 80 and 90 percent concentrations of magnetite and ilmenite occur in beach deposits for mechanical reasons, then certainly similar concentrations of pyrite should also be found. This not being so, one must assume that the chemical response of these minerals to their environment supplies the discriminating factor. In the active zone of wave action, pyrite, a sulphide, is readily oxidized to limonite, as revealed by many grains of partially altered pyrite in the beach
samples. Limonite, of course, hardly tolerates any abrasion, and is readily carried away in suspension.

Amphibole, hornblende in particular, retains the dominant position in the heavy mineral suite of the beach sands, and shows a tendency to decrease down-drift at the Red Brook and Conneaut beaches.

**Field and Laboratory Observations on Littoral Transport of Sediments**

With the general source of the beach sediments and their sites of deposition located, their specific path in the littoral environment, in great measure, remains obscured by the host of variables acting on them. The study of wave motion and the boundary conditions existing between sediment and water medium, and between water and atmosphere, entails much experimentation, time, patience, funds and mathematical sophistication and insight, all of which lie beyond the resources of the author and the scope of this work. Thus by necessity, the author's investigation into this area is limited to some field and experimental observations, from which a few tentative conclusions may be deduced.

Following a suggestion by H. J. Pincus that the wave tank designed originally for work in terrestrial photogrammetry also be used for model studies of beach behavior, the author attempted to reproduce certain field beach situations, such as the relationship of wave steepness to the development of sand bars, the angle
| TABLE III |
| List of Heavy Mineral Species in Bluff and Beach Samples |

<table>
<thead>
<tr>
<th>Amphibole</th>
<th>Magnetite-Ilmenite</th>
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<tbody>
<tr>
<td>Hornblende; green</td>
<td>Garnet, pink, red, colorless</td>
</tr>
<tr>
<td>Hornblende; brown</td>
<td>Pyrite</td>
</tr>
<tr>
<td>Tremolite</td>
<td>Limonite = Hematite</td>
</tr>
<tr>
<td>Actinolite</td>
<td>Epidote</td>
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</table>

<table>
<thead>
<tr>
<th>Pyroxene</th>
<th>Rare Minerals</th>
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</thead>
<tbody>
<tr>
<td>Augite-Diopside</td>
<td>Monazite</td>
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<tr>
<td>Hypersthene-Enstatite</td>
<td>Leucoxene</td>
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<td></td>
<td>Titanite</td>
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<td></td>
<td>Zircon</td>
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<td>Andalusite</td>
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<td>Kyanite</td>
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<td></td>
<td>Rutile</td>
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Plate V, Fig. 72, Fig. 73, Fig. 74. Location map, grain size and heavy mineral data of beach and bluff samples, Fairport to Ashtabula, Ohio.
Plate VI, Fig. 75, Fig. 76. Grain size and heavy mineral data of beach samples, Conneaut township, Park beach, Ohio. (Samples collected by H. J. Pincus)
of incidence of wave orthogonals to beach erosion, and the effect of bedrock highs on the stability or development of beach promontories.

The beach model was developed in a wave tank 25 feet long, 1 foot wide and 1 foot deep, that was constructed and described by Kelley (1956, p. 46-48). The drive mechanism is modeled after the design of Coyer (1953), but modified to perform as an oscillator producing simple harmonic waves. The wave generating baffle is hinged at the bottom and made to oscillate back and forth on the hinge. Waves produced by this type of oscillator are deep water in type, but it is expected that because of the shallow depth of water used (7 to 8 inches), and the length of passage (18 feet), that the waves developed shallow water characteristics before breaking.

After a series of preliminary experiments in which field beach and offshore phenomena were reproduced in miniature, fixed, vertical, stereo-photographs from a height of 10 feet above the model beach were taken, and provide the data from which the maps of Figures 77 to 81 were constructed. The setting up of cameras and the plotting were performed by Professors A. Brandenberger and F. J. Doyle of the Institute of Geodesy, Photogrammetry, and Cartography, The Ohio State University.

From his experimental studies with beaches and waves, J. W. Johnson (1949) concludes that waves which possess a steepness ratio, i.e., the ratio of deepwater height to deep water length (Ho/Lo),
exceeding 0.03, produce a storm profile, wherein the foreshore is eroded and longshore bars are developed. On the other hand, waves with a ratio of less than 0.025 cause deposition on the foreshore and form profiles lacking the longshore bars. The author successfully reproduced these relationships as shown in Figures 77 and 78.

The contours of Figure 77 display longshore bars separated from the foreshore by scour depressions, as erected by steep waves ($\frac{H_o}{L_o} = 0.033$). When the waves were flattened ($\frac{H_o}{L_o} = 0.011$), the incoming rollers exercised a shaving motion on the top of the bars, flattening them by sweeping the sand from off the tops into the troughs, and beyond to the shore. Thus the shoreline represented by the 1.85 foot contour advances (fig. 78), as have the 1.80 and 1.75 foot contours. On the other hand, the contours (1.60 to 1.70) immediately lakeward of the bar of Figure 77, have moved shoreward in response to the erosion on that part of the offshore area. Farthest offshore, there has been a shift of contours (1.50 to 1.35) away from the shore into the area beyond wave scour. Thus the foreshore in Figure 78 is built out at the expense of the bar. Nevertheless, a net loss of material to the deep part of the tank has taken place.

The factor of wave steepness and its effect on the initiation or destruction of offshore bars has been examined by Bascom (1953), in terms of the pressure gradient that exists on the bottom between the crest and trough of a passing wave. He states that the greater the steepness, the greater the driving force that is exerted on
Figures 77, 78. The comparison of beach profiles for steep (Fig. 77) and low (Fig. 78) waves for a given depth of water, and a beach perpendicular to wave orthogonals.

Wave Tank Data

<table>
<thead>
<tr>
<th></th>
<th>Fig. 77</th>
<th>Fig. 78</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water level (inches)</td>
<td>8.25</td>
<td>8.25</td>
</tr>
<tr>
<td>Period (seconds) (T)</td>
<td>0.84</td>
<td>1.0</td>
</tr>
<tr>
<td>Wave Height (H) in feet</td>
<td>0.125</td>
<td>0.057</td>
</tr>
<tr>
<td>Wave steepness ratio (H_o/Lo)</td>
<td>0.033</td>
<td>0.011</td>
</tr>
<tr>
<td>where Lo = 5.12 T^2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Running time (hours)</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Original slope of beach</td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>
the water in orbit, since the pressure gradient becomes greater. Moreover, a higher steepness ratio increases the rate of delivery of water to the beach, and correspondingly maintains more material in suspension. Thus a strong return of water makes its way to the offshore area; conceivably, not only because of the increased volume of water on the beach, but also because of the consequent reduction of permeability of the beach. These render the beach susceptible to erosion to the advantage of the bar and offshore area in general.

With respect to the study area on Lake Erie, low waves prevail most of the summer, and it is not until in August that higher waves become more frequent. Yet even then, the strong waves breaking against the shore seldom exceed 3 feet in amplitude, and are more of the order of 2 to 2.5 feet. At this time the period is of the order of 4 to 4.2 seconds. Goodman (1936, p. 83) has also made similar observations for the area near Lorain, Ohio. The steepness ratio of these waves accordingly ranges between 0.023 and 0.034 as computed by the author. These values lie within the transition zone steep and low waves of Johnson (op. cit.), i.e., between 0.025 and 0.03.

The development of bars off the beaches in the study area is further complicated by the generally oblique orientation of the shore to the direction of the dominant winds. This tends to inhibit the lakeward return of water perpendicularly to the shore, and to favor a shift of the water mass downstream under the impetus of the littoral current.
Fig. 79. Walnut beach, located on the southwestern side of the West breakwater of Ashtabula Harbor. The lines of breakers offshore represent the sites of offshore bars, over which waves driven by NE winds are breaking obliquely in the same manner that they are shooting along the shore. The swash marks represent new material added from the up-drift end of the beach. Waves are 1 to 2 feet high. July, 1955.
Fig. 80. The northeastern end of Walnut Beach. View toward the NE after the 2 day period of high waves driven by NE winds. Sand eroded from here was transferred down-drift as described under figure 79. July, 1955.
At the large beach immediately southwest of the west breakwater of Ashtabula Harbor, the author explored the offshore area just after waves of the order cited above and driven by strong northeast winds had eroded the eastern end of the beach. These waves had also carved furrows or giant ripples into the bars, 10 inches between the crests, and 1 to 5 inches deep, aligned parallel to the bars. Moreover, the bars were traced on a line that approached the shore obliquely to a small beach projection about 1,500 feet southwest of the breakwater, beyond which no bars were found. Beach erosion had occurred at the northeastern portion of the beach, whereas deposition had taken place on the southwestern part by transfer of sediments downdrift (Figures 79 and 80).

Apparently the bars are formed in the area toward the northeast where an abundant sand supply, both onshore and offshore, is impounded against the breakwater. Toward the southwest, the sand cover thins to a veneer on the bedrock of shale. Under the impetus of the obliquely striking northeast wind-driven waves, the shoreline of the southwestern portion of the beach grows lakeward. By the same force, the bars are extended toward the southwest, but the decreasing sand supply forces them to form nearer and nearer inshore, until both shore and bar approach a junction. Beyond, the beach benefiting by the double sources of supply continues its growth downdrift.

The steep waves accompanying strong winds from the northwest or west reverses the littoral drift and the associated erosional
and depositional patterns. Supposedly, the advance of the shoreline at the northeastern half of the beach occurs in conjunction with the retreat of the offshore bars lakeward. This was not investigated fully in the field, although the relationship is suggested by the increased distance between bar and shore at such a time.

During this period of strong northeast winds, the impounding effect of the west breakwater at Ashtabula Harbor causes a pile-up of water against it. This in turn induces a strong hydraulic gradient directed lakeward along the structure. The author has attempted to duplicate this condition in the wave tank as outlined under Table VI and portrayed in Figure 81, as an inquiry into the nature of sedimentation along the structure at such a time.

The model beach was aligned at an angle of 45 degrees to the orthogonals of waves with a steepness ratio of 0.05. Under the impact of the steep waves, the shoreline on the west side of the beach was rapidly eroded back, and a storm profile of bar and trough was carved on the offshore profile (I). The waves were deflected toward the east along the shoreline, and the swash formed a stream as its volume was increased by the successive addition of water from the wave front striking the shore in a delayed time continuum from west to east (IV). Where the flow impinged against the east wall of the tank, it swung toward the offshore area, building a tongue of sand or delta outward into deeper water (III). Area II of the map had a series of miniature channels running straight down from the top of the shelf to the bottom of the slope, down which
Fig. 81. The effect of waves and currents on a shore angled at 45 degrees to the wave orthogonals.

Wave Tank Data

Water level: 8.25 inches
Period (T) in seconds: 0.73
Wave Height in feet: 0.135
Ho/Lo (Lo = 5.12T²): 0.05
Running time in hours: 1
Original slope of beach: 2:1
coarser sand particles and small pilecypod shells slid. The beach
surface of Area IV was covered by a concentrated layer of magnetite
and garnet, the lag product of sheet erosion of the beach, in which
the light minerals were swept away and the heavy minerals left.

By qualitative transfer to the beach at Ashtabula Harbor, the
author postulates that a similar situation as that in area III
of the model exists along the west breakwater; i.e., northwesterly
to southwesterly wind-impelled littoral flow is removing lakeward
a great deal of the sediments derived from the southwestern part
of the study area. It is probable that very little of this material
is returned when the drift is reversed. According to Krumbein and
Osheik (1950), in their study of sediments impounded by harbor
jetties at Waukegan and Wilmette, Illinois, on Lake Michigan, about
30 to 50 percent of the shore drift escapes around these structures.
Likewise, the U.S. Corps of Engineers (House Doc. 596, 1950, p. 33)
estimates that the west breakwater at Fairport, Ohio, loses 45,000
cubic yards of the 110,000 cubic yards of material brought to it
annually by the littoral drift.

Under the third series of experiments, the author has attempted
to reproduce the beach promontories discussed earlier in the chapter,
on the basis of the postulate that such beaches are controlled by
bedrock highs.

In this experiment, the author graded the foreshore and immedi­
ate offshore area of the beach to a slope of 1:14, and covered the
area with roofing asphalt tile. The granulated surface of the tile
was left exposed to provide the bottom roughness factor presented by the boulders and cobbles in the field situation. The center of the tiled area was given a slight dome, just enough to bring it within 0.07 foot below water level, as shown in the map of Figure 82. The backshore area was left uncovered to provide for a source of sand.

Because of the sand deficiency in the offshore area of the model beach, true bars could not come into existence, even under the conditions of steep waves. Instead, a small spit grew toward the east from the supply area on the berm at the west side of the tank. The spit grew only to the size shown, and the excess material was swept shoreward to a small beach. The labeled "bedrock" high of Figure 82 acted to diminish wave energy, so that the shore behind it was adequately protected.

Under the regime of low wave steepness (0.002) and continued introduction of sand to the west shore by the author, the beach kept toward deep water and over the bedrock high to form a beach promontory (Figure 83). However, the author could not reproduce the long, characteristic, submerged spit trailing downdrift because of size limitations in the equipment used.

Submerged Spits As mentioned in the section of this paper dealing with beach promontories, virtually all of these beach types have linear submerged spits extending downdrift from their apices. Most of these spits are flanked and floored by bedrock, possess a
Figures 82, 83. The effect of a shallow bedrock shelf on the development of a beach under conditions of steep (Fig. 82) and flat (Fig. 83) waves

Wave Tank Data

<table>
<thead>
<tr>
<th></th>
<th>Fig. 82</th>
<th>Fig. 83</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water level in inches</td>
<td>7.125</td>
<td>7.125</td>
</tr>
<tr>
<td>Period (T) in seconds</td>
<td>0.75</td>
<td>2.0</td>
</tr>
<tr>
<td>Wave height in feet</td>
<td>0.094</td>
<td>0.052</td>
</tr>
<tr>
<td>( H_o/L_o ) ( (L_o = 5.12T^2) )</td>
<td>0.032</td>
<td>0.002</td>
</tr>
<tr>
<td>Running time in hours</td>
<td>3.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Original slope</td>
<td>1:114</td>
<td></td>
</tr>
</tbody>
</table>
relatively unbroken front for at least 1,000 feet, and attain lengths exceeding 3,000 feet. In all of them the shore curves abruptly away from the point of attachment at the apex, and then straightens out. After periods of prolonged wave action from the predominant northwest to southwest directions, the bars become strongly developed, and the area immediately to the lee of the beach apex becomes a sheltered cove.

Apparently the littoral drift possesses an inertial quality that enables it to resist partially the tendency to follow the shoreline around the sharp bend of the beach apex; but, instead, directs it to maintain its original heading into the lake for several thousands of feet. However, winds from the northeast act to disrupt this trend, and tend to break up the portions of the spits near their junction with the beach, and drive the sand inshore to the beach. Likewise, it is probable that the submerged spits can be extended in a northeasterly direction for only a certain distance before instability is incurred. At this point the material may be swept to sea or shore. The author believes that the beach at Red Brook in Saybrook township receives much of its nourishment by periodic destruction of the submerged spit running from the beach promontory near Saybrook Township Park (Plate xv).
SUMMARY

The Lake Plain, a depositional surface constructed of a thin layer (5 to 75 feet) of Cary and post-Cary lacustrine beds and glacial tills capping the surface of the Upper Devonian Chagrin shale, is newly emergent and in an erosional stage of topographic youth. Controlled by the northwesterly regional slope of 10 to 20 feet per mile, most of the drainage flows as consequent streams across the plain to Lake Erie, all of which occupy youthful valleys over most of their lengths.

Along the southeastern flank of the area rises the band of Late Cary Lake Escarpment moraines with a relief somewhat under 100 feet. Into the northern flank of these moraines the rather bold bluff of Lake Whittlesey has been cut to a maximum height of about 60 feet. Farther to the northwest, and running between the bluff of Lake Erie and that of Lake Whittlesey, the sand-rich shore of glacial Lake Warren forms a bench 15 to 30 feet high.

Extensive sand and gravel deposits, up to 60 feet thick locally and more generally 35 feet thick, cover the bedrock floor of Madison, Kingsville and Conneaut townships, and the beach ridge of glacial Lake Warren.

The bedrock surface rises through the mud of the lake, at an elevation of about 500 feet, on a long uneven, concave slope under the Lake Plain to the Appalachian Escarpment at 870 feet. Exposures
of the bedrock occur in the major valleys, the larger valleys of the small streams and along the Lake Erie shore in eastern Ashtabula township.

A product of erosion and mass wasting, the bluffs of Lake Erie present a vertical stratigraphic cross-section of the Lake Plain. Glacial till dominates the lithology across Painesville, eastern Perry, Geneva, Saybrook, western Ashtabula and eastern Conneaut townships. Elsewhere in the study area, lacustrine deposits constitute the upper half or virtually all of the section; and of these, fine sand forms the dominant constituent. Stratigraphically, post-Cary lacustrine interbedded sand, silt and clay overlie Late Cary glacial tills. These tills, two in number where recognizable, are generally separated one from the other by interbedded lacustrine beds, 1 to 18 feet thick, or by a boulder pavement or a zone of red clay and pockets of an unidentified, pebbly till. The author has dated the major tills as Late Cary under the assumption that they are preWhittlesey in age and of the same age as the Late Cary Lake Escarpment moraines.

Lithologically, the tills consist of a pebbly to bouldery, silty to sandy clay, as indicated by visual inspection, hydrometer and sieve analyses, and their Atterberg limits. However, lateral consistency of the sand, silt and clay ratios appears as the exception rather than the rule. On the whole the tills possess medium strength and low sensitivity.
The degradational processes acting on the bluff include:

1. Chemical and physical weathering;
2. Mass wasting; and
3. Erosion by water and wind.

Weathering in terms of freezing and thawing, oxidation, hydrolysis, hydration and solution, attacks the tills most, since metamorphic and igneous rock fragments, and silt constitute a high percentage of the tills. Mass wasting is expressed in a variety of types that include the fall of sand grains, vertical collapse of tons of wave-undermined blocks of till, small mudflows and extensive creep and slump.

Sandy bluffs of Perry, Madison and most of Ashtabula County northeast of the harbor are largely undermined by basal or intrastatal contact springs plucking and transporting sand, and causing adjacent and superjacent portions to fall from lack of support. Wind deflation also detaches much sand from the bluff, most of which falls as talus.

Bluffs composed of well compacted tills lacking a permeable basal contact zone accessible to ground-water, possess low permeability, rise vertically, and fail by direct wave undermining which causes vertical shearing off of segments along joint surfaces. This type of failure is typified by the bluffs of western Perry township.

Failure by creep of a one to 2 1/2 foot thick layer of the entire bluff face occurs in bluffs associated with a low sand content and high silt percentage (40 to 67) in a matrix of clay. Freezing
and thawing in conjunction with wave scavenging is postulated to keep the process in motion. This phenomenon was observed in the bluff of the Saybrook-Ashtabula township border area, and that of Ashtabula township northeast of Ashtabula Harbor.

Slumping affects three types of stratigraphic sections:

1. That represented by 20 to 35 feet of lacustrine clay super-jacent to till. The lacustrine clay slumps and its surface of shear develops on the till contact 10 to 15 feet above the beach, as exhibited in central Perry township.

2. That consisting from top to bottom of (1) lacustrine beds, (2) "Upper" till, (3) intertill lacustrine beds, and (4) a salient 15 to 25 foot high "Lower" till. Here permeable beds in (3) yield to the softening and plucking effect of ground water seepage. Their yielding causes the overlying beds to slump. This category of slumping typically occurs in Ashtabula County.

3. That which consists mostly of till resting on rather thick lacustrine beds near or at lake-level. Slumping here is a major development of that which occurs under "b," since the entire bluff-section is affected. Moisture, again the villain, permeates the lacustrine material and is postulated to seep from surface meteoric sources in the hinterland (Painesville township) and from the Lake (Geneva-Saybrook townships).
The products of bluff erosion and stream erosion of the Lake Plain and Lake Escarpment Moraines end in the lake. Of these the far greater contribution comes from the bluffs. According to the data from heavy mineral analyses, the heavy mineral suites of the glacial tills and beach include the same minerals, except that the suite belonging to the tills contain a higher percentage (40%) of pyrite than do typical beach deposits (5%). The median size distribution of the beach sand, wherein for a given stretch of beach grain size decreases downdrift, indicates that the littoral drift toward the northeast excercises a sorting action on sediment in transport similar to that of streams.

About one-half of the shore is protected by permanent beaches. These the author has grouped into two categories;

1. stream-mouth - those controlled by the hydraulic barrier effect of streams issuing into the lake

2. beach promontories - those controlled by bedrock highs

The large stream-mouth beaches on the western side of the breakwaters at the Grand, Ashtabula, and Conneaut rivers, have had their widths multiplied by the presence of the harbor structures. Because of the huge volume of onshore and offshore sand comprising these beaches, they conform to the "typical" beaches of oceanographic researchers in that storm profiles of sandbars and troughs come and go with changes in the wind-vector and wave steepness.

On the other hand, the beach promontories are associated with only a moderate sand supply. Most of the sand is concentrated on
the beaches and in submerged spits that trail off downdrift (north-east) on a rocky bottom away from the lakeward projecting heads of the beaches. Sand transferred downdrift via the submerged spits may eventually be moved inshore, if the bottom remains shallow, or may become partially lost offshore.
CONCLUDING REMARKS

SHORE EROSION IN THE AREA.

Today's problem of eroding shore along the lake began in the 1940's with a 1 to 2 foot elevation increase of the water-level. This has been only the latest of such episodic rises. McDonald (1953, p. 251) attributes this high stage of the lake to a persistent trend of above normal rainfall during the 10-year period preceding 1951, in which the rainfall average exceeded that for the years since 1900 by 2.23 inches. Moreover, in 1950 and 1951, the rainfall was nearly 6 inches above that average. The author has not investigated this aspect of the problem, but has found no serious objection to this correlation.

However, the problem is not only one of high lake levels, but also one of a diminishing sand supply. Under the natural economy, the income of sand should at least match the outgo of material from the beaches which suffer continuous attrition by comminution of particles, a continual loss of sediments to the deep parts of the lake, and to areas downdrift of the study area. As has been established earlier in this paper the bluffs form virtually the only source of new material to the beaches.

For every large stretch of beach-protected shore in the study area, there is a similar length of wave-eroded bluff updrift. As the area undergoes greater residential and industrial development,
more attempts are made to stem bluff erosion by the addition of protective structures. The higher the efficiency of these structures, the lower becomes the amount of sediment available for down-drift nourishment of beaches. Thus in terms of beach development for a given lake-level, there seems to be a limit to the shore length of bluff for which protection is desirable.

Fortunately for the study area, the shore in the lee of the three major harbor structures is owned by major industrial concerns that have land and economic resources enough to combat bluff recession as they see fit. Likewise, most of the land in the receding shore areas of Painesville, Perry, eastern Ashtabula and western Kingsville townships consists of large undeveloped holdings. From the viewpoint of beach accretion this is as it should be. In the author's opinion, no permanent building on the Lake Plain should be built within 1,000 feet of the bluff in these areas unless the owner can cope with the engineering problems involved with wave erosion and the processes of bluff failure.

The heavily inhabited shore of eastern Geneva and western Saybrook townships represents the most critical locale in the study area with the possible exception of Painesville township just east of the Township Park. The peculiar nature of bluff slumping here may involve measures of correction too costly and perhaps too late to save the houses near the edge of the bluff. The indications
are, as has been discussed previously, that the zone of failure extends down to bedrock. Perhaps a retaining seawall anchored in the bedrock might be a partial solution.
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APPENDIX A

LAKE PLAIN WELL LOGS USED IN TEXT (From the files of the Ohio Div. of Water, Columbus, Ohio. See Plates VII to X for locations)

Section 1

Location: Northside of U.S. Route 20, one-half mile southwest of Perry Park Road, Perry township, Lake County.

Top (Elevation: ca. 685 feet) Feet
1. Sand and gravel (Lake Warren beach) .................. 15
2. Blue clay (till?) ................................................. 75
3. Gravel .......................................................... 10

Section 2

Location: East side of Bowhall Road, 1/5 mile north of Madison Ave., City of Painesville, Painesville township, Lake County.

Top (Elevation: ca. 695 feet) Feet
1. Yellow clay ..................................................... 4
2. Sandy yellow clay ............................................ 11
3. Brown sand and gravel ..................................... 4
4. Blue clay bound with sand and gravel (till?) ....... 2
5. Blue hard pan (till) ........................................... 6

Section 3 (Auger boring - Ohio Div. Shore Erosion)

Location: Intersection of New London Road and Meyers Road, Geneva township, Ashtabula County

Top (Elevation: 632 feet) Feet
1. Sand and silt .................................................. 7

235
2. Lacustrine clay ........................................ 5
3. Till (to bedrock) ..................................... \frac{1}{16}

Section 4 (Auger boring, Ohio Div. Shore Erosion, Columbus, Ohio)
Location: Gore Road and State Route 45, Saybrook township, Ashtabula County.

Top (Elevation: 626 feet)

1. Till, containing granules and small pebbles.  
   Depth of leaching = 2 1/2 feet (to bedrock?) ........ 19

Section 5
Location: Lake Whittlesey bed, 1 mile west of the confluence of the Grand River and Kellogg Creek.

Top (Elevation: ca. 720 feet)

1. Sand ...................................................... 10
2. Clay ..................................................... 40
3. Quick sand .......................................... 25
4. Till ..................................................... 25
5. Clay ................................................... 20
6. Sand and gravel ................................. \frac{5}{125}

Section 6
Location: Southside of State Route 307; 1/4 mile east of junction with northerly road to the town of Perry. Distance from edge of river bluff = 1/4 mile.

Top (Elevation: ca. 830 feet)

1. Yellow clay (weathered till and loam) .......... 19
2. Blue clay (till) .................................... 26
3. Gravel ................................................. 2
Section 7
Location: West side of Route 528, about 500 feet south of junction with Route 307 East, Madison township, Lake County

<table>
<thead>
<tr>
<th>Top (Elevation: ca. 850 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Yellow clay (loam and weathered till)</td>
<td>19</td>
</tr>
<tr>
<td>2. Blue clay (till)</td>
<td>45</td>
</tr>
<tr>
<td>3. Gravel, clay, some sand</td>
<td>16</td>
</tr>
<tr>
<td>4. Shale (Elevation: ca. 775 feet)</td>
<td>70</td>
</tr>
</tbody>
</table>

Section 8 (U. S. Army Corps of Engineers)
Location: About 1,000 feet northwest of junction of Route 723 and 307, Harpersfield township, Ashtabula County

<table>
<thead>
<tr>
<th>Top (Elevation: 848.9 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Brown silty loam</td>
<td>2</td>
</tr>
<tr>
<td>2. Silty clay with fragments of sandstone and shale (till)</td>
<td>68</td>
</tr>
<tr>
<td>3. Fine to medium sand with clay and water</td>
<td>2</td>
</tr>
<tr>
<td>4. Sandy clay</td>
<td>9</td>
</tr>
<tr>
<td>5. Sandy shale (Elevation: 767.9 feet)</td>
<td>81</td>
</tr>
</tbody>
</table>
**Section 9 (U.S. Army Corps of Engineers)**

Location: About 1,000 feet west of first junction west of the town of Harpersfield on Route 307, Harpersfield township, Ashtabula County

<table>
<thead>
<tr>
<th>Top (Elevation: 861.4 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Brown silty loam</td>
<td>1.0</td>
</tr>
<tr>
<td>2. Silty clay with fragments of sandstone (till)</td>
<td>16.3</td>
</tr>
<tr>
<td>3. Medium to coarse sand with clay</td>
<td>0.7</td>
</tr>
<tr>
<td>4. Silty clay (till?)</td>
<td>48.0</td>
</tr>
<tr>
<td>5. Coarse sand and fine gravel and clay</td>
<td>1.0</td>
</tr>
<tr>
<td>6. Silty clay (till?)</td>
<td>26.0</td>
</tr>
<tr>
<td>7. Fine sand, free of clay</td>
<td>2.0</td>
</tr>
<tr>
<td>8. Sandy clay with fragments of shale and sandstone (till)</td>
<td>2.3</td>
</tr>
<tr>
<td>9. Thin bedded gray sandy shale (Elevation: 767.1 feet)</td>
<td>97.3</td>
</tr>
</tbody>
</table>

**Section 10 (U.S. Army Corps of Engineers)**

Location: About 2,000 feet north-northwest of first junction with north-south road and Route 307 east of the town of Harpersfield, Harpersfield township, Ashtabula County

<table>
<thead>
<tr>
<th>Top (Elevation: 860.5 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Silty loam</td>
<td>6.0</td>
</tr>
<tr>
<td>2. Silty clay (till)</td>
<td>90.0</td>
</tr>
<tr>
<td>3. Coarse sand, water bearing</td>
<td>3.0</td>
</tr>
<tr>
<td>4. Gray silty clay (till?)</td>
<td>21.0</td>
</tr>
<tr>
<td>5. Gray sand</td>
<td>2.5</td>
</tr>
<tr>
<td>6. Gray clay</td>
<td>8.9</td>
</tr>
</tbody>
</table>
### Section 11 (U.S. Army Corps of Engineers)

**Location:** About 1/3 mile north of Route 307, 3/4 mile northeast of intersection of Route 307 and the west border of Austinburg township, Austinburg township, Ashtabula County

**Top (Elevation: 814.3 feet)**

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Brown silty loam</td>
<td>3.0</td>
</tr>
<tr>
<td>2. Silty clay with fragments of shale and sandstone (till)</td>
<td>69.0</td>
</tr>
<tr>
<td>3. Gray sandy clay</td>
<td>27.0</td>
</tr>
<tr>
<td>4. Fine to medium sand</td>
<td>6.0</td>
</tr>
<tr>
<td>5. Fine to medium sand with some clay</td>
<td>3.0</td>
</tr>
<tr>
<td>6. Silty clay with fragments of sandstone and shale (till)</td>
<td>21.0</td>
</tr>
<tr>
<td>7. Silty clay</td>
<td>24.0</td>
</tr>
<tr>
<td>8. Sandy clay</td>
<td>3.0</td>
</tr>
<tr>
<td>9. Thin bedded gray sandy shale with some layers of dark shale (Elevation: 690.0 feet)</td>
<td>156.6</td>
</tr>
</tbody>
</table>

### Section 12 (U.S. Army Corps of Engineers)

**Location:** About 300 feet north of Route 307, 0.9 miles west-southwest of intersection of Routes 307 and 45 in the town of Austinburg, Austinburg township, Ashtabula County

**Top (Elevation: 819 feet)**

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Brown sandy loam</td>
<td>0.5</td>
</tr>
<tr>
<td>2. Sandy clay</td>
<td>17.5</td>
</tr>
<tr>
<td>3. Fine, calcareous sand, little clay</td>
<td>3.0</td>
</tr>
<tr>
<td>4. Sandy clay</td>
<td>3.0</td>
</tr>
<tr>
<td>Section 13</td>
<td>Location: 1.15 miles northeast of section 12, 0.5 mile west of Route 45, 0.3 mile north of Route 307, Austinburg township, Ashtabula County</td>
</tr>
<tr>
<td>------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Top (Elevation: 854.4 feet)</td>
<td>Feet</td>
</tr>
<tr>
<td>1. Silty loam</td>
<td>3</td>
</tr>
<tr>
<td>2. Silty clay</td>
<td>45</td>
</tr>
<tr>
<td>3. Coarse sand</td>
<td>3</td>
</tr>
<tr>
<td>4. Gray silty clay</td>
<td>21</td>
</tr>
<tr>
<td>5. Gray sand, water bearing</td>
<td>3</td>
</tr>
<tr>
<td>6. Gray sandy clay</td>
<td>6</td>
</tr>
<tr>
<td>7. Very fine sand, water bearing</td>
<td>18</td>
</tr>
<tr>
<td>8. Coarse sand</td>
<td>3</td>
</tr>
</tbody>
</table>

### Section 13 (U.S. Army Corps of Engineers)

5. Very fine sand with some clay; water 6.0
6. Silty clay 12.0
7. Fine sand 0.5
8. Fine gravel, little clay, water bearing 10.0
9. Silty clay with fragments of sandstone shale (till) 16.0
10. Fine sand, water 3.5
11. Very fine sand 3.0
12. Sandy clay 3.0
13. Fine sand, little clay 3.0
14. Silty clay 15.0
15. Sandy clay with fragments of sandstone and shale (till) 4.0

Total 100.0
Section 14

Location: About 1,000 feet north-northwest of the road junction at Munson Hill, Austinburg township, Ashtabula County

Top (Elevation: ca. 860 feet) Feet
1. Clay (Till) ....................................................... 90
2. Sand ................................................................. 18
3. Gravel .............................................................. 112
## Section 15

Location: Southwest side of northwest - southeast road crossing Coffee Creek; 2.2 miles northeast of southwest corner of Plymouth township, and 2.3 miles southwest of northwest corner of Plymouth township.

<table>
<thead>
<tr>
<th>Top (Elevation: ca. 800 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Clay (till)</td>
<td>44</td>
</tr>
<tr>
<td>2. Gravel</td>
<td>2</td>
</tr>
<tr>
<td>3. Shale</td>
<td>56</td>
</tr>
</tbody>
</table>

## Section 16

Location: Conneaut township. Intersection of Route 7 and South Ridge Road in the town of Farnham.

<table>
<thead>
<tr>
<th>Top (Elevation: ca. 838 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Top dirt (loam and weathered till)</td>
<td>10</td>
</tr>
<tr>
<td>2. Gravel-clay (till)</td>
<td>48</td>
</tr>
<tr>
<td>3. Water bearing sand</td>
<td>8</td>
</tr>
<tr>
<td>4. Bedrock (Elevation: ca. 762 feet)</td>
<td>58</td>
</tr>
</tbody>
</table>

## Section 17

Location: Conneaut township, About 1,000 feet north of the intersection of South Ridge and Furnace Roads, south of the city of Conneaut.

<table>
<thead>
<tr>
<th>Top (Elevation: ca. 830 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Yellow clay (loam and weathered till)</td>
<td>20</td>
</tr>
<tr>
<td>2. Gravelly blue clay (till)</td>
<td>63</td>
</tr>
<tr>
<td>3. Sand</td>
<td>7</td>
</tr>
<tr>
<td>4. Blue clay</td>
<td>8</td>
</tr>
<tr>
<td>5. Shale (elevation: ca. 758 feet)</td>
<td>92</td>
</tr>
</tbody>
</table>
### Section 19

**Location:** Saybrook township. About 1/4 mile west of junction of Routes 15 and 84, on the south side of Route 84

<table>
<thead>
<tr>
<th>Top (Elevation: ca. 754 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Clay (till?)</td>
<td>40</td>
</tr>
<tr>
<td>2. Gravel</td>
<td>20</td>
</tr>
<tr>
<td>3. Clay</td>
<td>4</td>
</tr>
<tr>
<td>4. Sand and gravel</td>
<td>8</td>
</tr>
<tr>
<td>5. Clay</td>
<td>8</td>
</tr>
<tr>
<td>6. Shale (elevation: ca. 575 feet)</td>
<td>80</td>
</tr>
</tbody>
</table>

### Section 20

**Location:** Saybrook township, about 0.3 mile west of Saybrook township, 0.3 mile north of Plymouth township, and 0.5 mile south of Route 84

<table>
<thead>
<tr>
<th>Top (Elevation: ca. 790 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Clay (till)</td>
<td>30</td>
</tr>
<tr>
<td>2. Sand and Gravel</td>
<td>35</td>
</tr>
<tr>
<td>3. Bedrock (elevation: ca. 730 feet)</td>
<td>65</td>
</tr>
</tbody>
</table>

### Section 21

**Location:** Saybrook township, about 1,000 feet south of Route 20 on Brown Road

<table>
<thead>
<tr>
<th>Top (Elevation: ca. 690 feet)</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sand</td>
<td>12</td>
</tr>
<tr>
<td>2. Blue Clay</td>
<td>32</td>
</tr>
<tr>
<td>3. Sand</td>
<td>12</td>
</tr>
</tbody>
</table>
4. Till ........................................... 17

5. Sand and Gravel (end of hole, elevation: ca. 600 feet) . 14

Remarks on sections: Statements in parentheses following driller's lithologic description represent the author's interpretation.

Elevations where not precisely stated have been determined from the U. S. Geological Survey topographic sheets of Plates VII-X.
### Table IV. Mechanical Analyses and Atterberg Values of Bluff and Lake Plain Glacial Till Samples (Samples 9603 to 9652 and their values were obtained from the Ohio Division of Water, Columbus, Ohio). Locations of bluff samples plotted on Plates 2-5 and location of Lake Plain samples plotted on Plates 26-30.

<table>
<thead>
<tr>
<th>SAMPLE NUMBERS - BLUFF</th>
<th>9603</th>
<th>9605</th>
<th>9610</th>
<th>9611</th>
<th>9613</th>
<th>9617</th>
<th>9631</th>
<th>9632</th>
<th>9635</th>
<th>9637</th>
<th>9638</th>
<th>9642</th>
</tr>
</thead>
<tbody>
<tr>
<td>RETAINED ON TYLER NO. 4 SIEVE (%)</td>
<td>12.6</td>
<td>5.06</td>
<td>5.92</td>
<td>3.31</td>
<td>1.17</td>
<td>5.2</td>
<td>3.4</td>
<td>0.91</td>
<td>9.82</td>
<td>4.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO. 10 SIEVE (%)</td>
<td>9.53</td>
<td>8.55</td>
<td>13.05</td>
<td>18.43</td>
<td>10.20</td>
<td>6.71</td>
<td>4.6</td>
<td>2.26</td>
<td>6.64</td>
<td>15.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO. 40 SIEVE (%)</td>
<td>12.59</td>
<td>13.66</td>
<td>5.89</td>
<td>19.21</td>
<td>13.34</td>
<td>9.43</td>
<td>6.65</td>
<td>4.28</td>
<td>5.90</td>
<td>1.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO. 200 SIEVE (%)</td>
<td>12.6</td>
<td>13.66</td>
<td>5.89</td>
<td>19.21</td>
<td>13.34</td>
<td>9.43</td>
<td>6.65</td>
<td>4.28</td>
<td>5.90</td>
<td>1.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SILT (50-5 μm) (%)</td>
<td>27.6</td>
<td>32.4</td>
<td>30.4</td>
<td>26.5</td>
<td>34.0</td>
<td>40.2</td>
<td>61.0</td>
<td>31.8</td>
<td>40.0</td>
<td>32.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLAY ≤ 5 μm (%)</td>
<td>36.8</td>
<td>39.2</td>
<td>46.0</td>
<td>31.8</td>
<td>33.0</td>
<td>42.8</td>
<td>17.3</td>
<td>60.8</td>
<td>29.3</td>
<td>34.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LIQUID LIMIT (%)</td>
<td>37.0</td>
<td>32.0</td>
<td>30.0</td>
<td>29.0</td>
<td>29.0</td>
<td>40.0</td>
<td>32.0</td>
<td>26.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLASTIC LIMIT (%)</td>
<td>22.7</td>
<td>22.0</td>
<td>17.0</td>
<td>17.0</td>
<td>18.0</td>
<td>23.0</td>
<td>23.0</td>
<td>18.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLASTICITY INDEX (%)</td>
<td>14.3</td>
<td>10.0</td>
<td>13.0</td>
<td>12.0</td>
<td>11.0</td>
<td>17.0</td>
<td>9.0</td>
<td>7.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**APPENDIX B**

**SAMPLE DATA**
as and Atterberg Values of Bluff
Los (Samples 9646 to 9652 and
the Ohio Division of Water,
Bluff samples plotted on Plates
lotted on Plates

<table>
<thead>
<tr>
<th>SAMPLE NUMBERS - BLUFF</th>
<th>LAKE PLAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>665 9610 9611 9613 9617 9631 9632 9635 9637 9639 9640 9641 9643 9646 9647 9648 9649 9650 9651 9652</td>
<td>0.3 1.0 0.1 1.3 1.2 0.3 0.3</td>
</tr>
<tr>
<td>2.58 5.06 5.92 3.31 1.17</td>
<td>5.2 3.4 0.91 9.82 4.11 8.9 7.7</td>
</tr>
<tr>
<td>3.53 8.55 18.05 18.48 10.28</td>
<td>6.71 4.6 2.28 6.64 15.9</td>
</tr>
<tr>
<td>2.59 13.66 5.59 19.21 13.34</td>
<td>9.43 6.65 4.23 1.90 7.2</td>
</tr>
<tr>
<td>7.6</td>
<td>19.8 14.9</td>
</tr>
<tr>
<td>6.8</td>
<td>10.6 19.3 27.0 15.3 4.6 7.9 9.7</td>
</tr>
<tr>
<td>32.4 30.4 26.5 34.0</td>
<td>40.2 61.0 31.8 40.0 32.5</td>
</tr>
<tr>
<td>44.7 49.0</td>
<td>40.2 31.6 26.0 33.3 40.4 61.7 35.7</td>
</tr>
<tr>
<td>39.2 46.0 31.8 33.0</td>
<td>42.8 17.3 60.8 29.3 34.5</td>
</tr>
<tr>
<td>21.6 29.0</td>
<td>40.3 39.1 34.7 43.4 48.2 28.4 48.5</td>
</tr>
<tr>
<td>32.0</td>
<td>30.0 29.0 29.0 40.0 32.0 26.0</td>
</tr>
<tr>
<td>22.0</td>
<td>22.2 21.5 20.9 24.0 33.3 19.7 25.2</td>
</tr>
<tr>
<td>10.0</td>
<td>16.2 15.6 15.1 16.3 23.0 15.8 16.9</td>
</tr>
<tr>
<td>13.0 12.0 11.0</td>
<td>17.0 9.0 7.5</td>
</tr>
<tr>
<td>6.0 5.7 5.4 7.7 10.3 3.9 8.3</td>
<td></td>
</tr>
<tr>
<td>MINERAL</td>
<td>9605</td>
</tr>
<tr>
<td>---------------------</td>
<td>------</td>
</tr>
<tr>
<td>Pyrite</td>
<td>35.8</td>
</tr>
<tr>
<td>Amphibole</td>
<td>19.8</td>
</tr>
<tr>
<td>Clinopyroxene</td>
<td>16.0</td>
</tr>
<tr>
<td>Orthopyroxene</td>
<td>4.5</td>
</tr>
<tr>
<td>Magnetite-Illmenite</td>
<td>12.5</td>
</tr>
<tr>
<td>White Garnet</td>
<td>3.8</td>
</tr>
<tr>
<td>Pink Garnet</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Table V. Heavy Mineral Species Percentage (by grain count of Bluff Samples.)
<table>
<thead>
<tr>
<th>MINERAL</th>
<th>SAMPLE NUMBER:</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>MEAN SIZE (mm)</th>
<th>TRASK'S SORTING COEF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9550</td>
<td>9551</td>
<td>9552</td>
<td>9553</td>
<td>9554</td>
<td>9555</td>
<td>9556</td>
<td>9557</td>
<td>9558</td>
<td>9559</td>
<td>9560</td>
<td>9561</td>
</tr>
<tr>
<td>PYRITE</td>
<td>27.1</td>
<td>3.2</td>
<td>2.8</td>
<td>0.9</td>
<td>4.2</td>
<td>3.6</td>
<td>3.5</td>
<td>4.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMPHIBOLE</td>
<td>26.7</td>
<td>36.6</td>
<td>42.0</td>
<td>36.9</td>
<td>48.9</td>
<td>13.9</td>
<td>37.0</td>
<td>37.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLINOPYROXENE</td>
<td>26.0</td>
<td>23.9</td>
<td>25.8</td>
<td>26.0</td>
<td>27.9</td>
<td>5.4</td>
<td>36.0</td>
<td>42.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ORTHOPYROXENE</td>
<td>6.6</td>
<td>12.0</td>
<td>13.1</td>
<td>11.0</td>
<td>14.8</td>
<td>6.0</td>
<td>12.5</td>
<td>11.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAGNETITE-ILMENITE</td>
<td>6.2</td>
<td>0.6</td>
<td>1.6</td>
<td>0.6</td>
<td>0.3</td>
<td>14.2</td>
<td>0.6</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PINK GARNET</td>
<td>1.4</td>
<td>6.5</td>
<td>3.2</td>
<td>8.2</td>
<td>0.6</td>
<td>21.0</td>
<td>1.6</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHITE GARNET</td>
<td>2.4</td>
<td>14.3</td>
<td>7.2</td>
<td>13.3</td>
<td>2.6</td>
<td>14.2</td>
<td>3.6</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HEAVY MINERAL</td>
<td>0.05</td>
<td>0.10</td>
<td>0.5</td>
<td></td>
<td>0.44</td>
<td>19.0</td>
<td>0.14</td>
<td>9.8</td>
<td>0.10</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEDIAN SIZE (mm)</td>
<td>0.44</td>
<td>0.50</td>
<td>0.50</td>
<td>0.42</td>
<td>0.42</td>
<td>0.34</td>
<td>0.38</td>
<td>0.35</td>
<td>0.35</td>
<td>0.33</td>
<td>0.32</td>
<td>0.24</td>
</tr>
<tr>
<td>TRASK'S SORTING COEF</td>
<td>1.09</td>
<td>1.15</td>
<td>1.25</td>
<td>1.16</td>
<td>1.10</td>
<td>1.08</td>
<td>1.17</td>
<td>1.14</td>
<td>1.19</td>
<td>1.67</td>
<td>1.14</td>
<td>1.16</td>
</tr>
</tbody>
</table>

Table VI. Heavy Mineral Species Percentage (by grain count, 0.25 - 0.125 mm.), Median Size and Trask's Sorting Coefficient of Beach Samples. Locations plotted on Plates.
APPENDIX B-1

Calculation of amount of bluff erosion needed to account for beach deposits in the area

Length of shore Fairport to Ashtabula in feet -

<table>
<thead>
<tr>
<th>Height of bluff</th>
<th>x 50</th>
<th>x 20</th>
<th>x 45</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3,250,000</td>
<td>760,000</td>
<td>2,340,000</td>
</tr>
</tbody>
</table>

Area of Bluff = 6,350,000 square feet.

Percentage of beach contributable material in bluff = 20 (House Doc. 351, 1952).

Footage of bluff material of volume equivalent to that found in the beach deposits

\[ = 48,708,850 \times \frac{1}{1,270,000} = 38 \text{ feet.} \]

*Computed by author*
APPENDIX C

Glossary of Soil Mechanics Terms used in Text

**Creep** A slow motion of the upper few feet of strata of a generally unloaded soil with respect to the underlying strata; and which may move en masse, or may consist of two or more portions of variable firmness or consistency which may or may not move with respect to each other (after Krynine and Judd, 1957, p. 657-558).

**Liquid Limit** That moisture content in a sediment, at which it loses the capacity to flow as a liquid, but at which it can be readily molded to hold its shape. It is expressed in percent of dry weight (Krynine, 1941, p. 40).

**Plastic Limit** Lowest water content in percent of dry weight, at which the sediment can still be rolled out into threads with a diameter of 1/8 inch. (Terzaghi, K., 1955, p. 562).

**Plasticity Index** The numerical difference between the plastic limit and the liquid limit. The greater the plastic index, the more plastic is the soil.

**Preconsolidation** The state of compaction developed in a sediment by the greatest unit load which has acted on the sediment in the course of its history (Terzaghi, K., 1955, p. 614).

**Sensitivity** The ratio between the unconfined compressive strength of the material in an undisturbed and in a remolded state. Its value may range between 1 ("insensitive") and more than 16 ("quick") (1955, p. 565).

**Slump** The downward slipping of a mass of rock or unconsolidated material of any size, moving as a unit or as several subsidiary units, usually with backward rotation on a more or less horizontal axis parallel to the slope from which it descends (Sharpe, C., 1938, p. 65).

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I, James Ellis Christopher, was born in Philadelphia, Pennsylvania, July 30, 1925. I received my secondary school education in the private schools of Kingston, Jamaica, and my undergraduate training at the Jersey City Junior College and Columbia University. Columbia College granted me the Bachelor of Arts degree in 1950. From The Ohio State University, I received the Master of Science degree in 1955. While in residence there, I was assistant to the department of geology during the years 1955-56, 1957-58, and 1958-59. Additionally, in October of 1954, I was appointed John Hay Whitney Foundation Fellow for one year, and in October, 1956, John A. Bownocker scholar in geology at The Ohio State University. In May, 1959, I was elected a member to The Society of the Sigma Xi.
PLATE XIII SHEET 2 OF 3
BLUFF GEOLOGIC SECTION AND MAP
LAKE ERIE SHORE OF ASHTABULA, KINGSVILLE, AND CONNEAUT TOWNS, ASHTABULA COUNTY, OHIO
SCALE 1 IN. = 200 FT
VERTICAL EXTS. 10X BASE MAP FROM TOWNSHIP
GEOLOGIC SECTION BY J.E. CHRISTOPHER
SHORELINE ELEVATION
573.2 FEET.

PLATE XIV  SHEET 1 OF 3
MAP OF BEACH PROMONTORY
BETWEEN GREEN AND REDBIRD
ROADS, MADISON TOWNSHIP,
LAKE COUNTY, O.

SCALE IN FEET
200 100 0 100 200

BASELINE: LAKE COUNTY, OHIO 'DIV. SHORE EROSION, 1943.'

TOPOGRAPHY & HYDROGRAPHY: J.E. CHRISTOPHER
JULY, 1957  J. WATSON
SHORELINE ELEVATION

HYDROGRAPHY BETWEEN SURVEY POINTS TIED INTO THE COUNTY BASELINE, OHIO DIVISION OF CORONAL, 1946.
BEDROCK

SAWTOOTH

F E E T

AT I O N . 8 - 18 - 55 = 574.2 FEET

BETWEEN STAS. 2 AND 5A
RAMS MADE ALONG THE PLANS AS SHOWN.

ED INTO THE ASHTABULA
, OHIO DIVISION OF SHORE