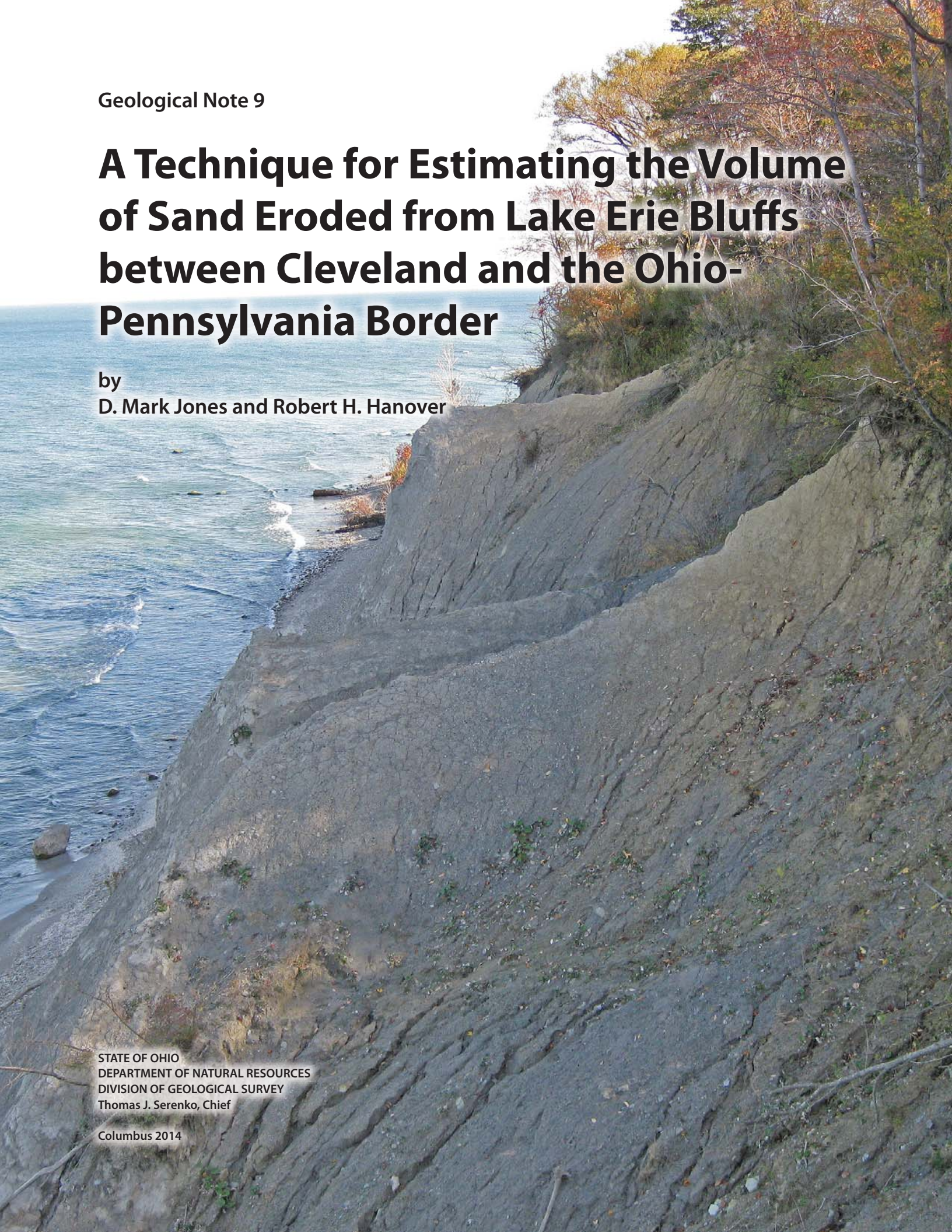
Geological Note 9

A Technique for Estimating the Volume of Sand Eroded from Lake Erie Bluffs between Cleveland and the Ohio-Pennsylvania Border

by
D. Mark Jones and Robert H. Hanover



STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
Thomas J. Serenko, Chief

Columbus 2014

ODNR DIVISION OF GEOLOGICAL SURVEY
2045 MORSE RD., BLDG. C-1
COLUMBUS, OHIO 43229-6693

(614) 265-6576
(614) 447-1918 (FAX)
geo.survey@dnr.state.oh.us
www.OhioGeology.com

SCIENTIFIC AND TECHNICAL STAFF OF THE DIVISION OF GEOLOGICAL SURVEY

Administration

Thomas J. Serenko, PhD, *State Geologist and Division Chief*
- **Michael P. Angle**, MS, *Assistant State Geologist and Assistant Division Chief*
- **Pattina R. Paisley-Collins**, BA, *Fiscal Officer*

Geologic Mapping & Industrial Minerals Group

Richard R. Pavey, MS, *Acting Geologist Supervisor*
- **Douglas J. Aden**, MS, *Geologist*
- **Franklin L. Fugitt**, BS, *Geologist*
- **Mark E. Wolfe**, BS, *Senior Geologist*

Energy Resources Group

Ronald A. Riley, MS, *Acting Geologist Supervisor*
- **Mark T. Baranoski**, MS, *Senior Geologist*
- **Matthew S. Erenpreiss**, BA, *Geologist*
- **Michael P. Solis**, MS, *Geologist*
- **Paul N. Spahr**, MS, *Geologist*

Technology Transfer Group

James McDonald, MS, *Supervisor*
- **Madge R. Fitak**, BS, *Customer Service Specialist*
- **Cynthia D. Flanagan**, MLIS, *Records Management Officer*
- **Robert H. Hanover**, BS, *GIS Specialist*
- **Charles R. Salmons**, MA, *Publications Editor*
- **Joseph G. Wells**, BA, *Database Administrator*

Geologic Hazards Group

D. Mark Jones, MS, *Acting Geologist Supervisor*
- **Aaron L. Evelsizor**, BA, *Geologist and H. R. Collins Laboratory Coordinator*
- **Michael C. Hansen**, PhD, *Ohio Seismic Network (OhioSeis) Coordinator*

An Equal Opportunity Employer - M/F/H

Disclaimer: This report was prepared by the Ohio Department of Natural Resources (ODNR), Division of Geological Survey under award NA11NOS4190075 from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration through the ODNR Office of Coastal Management Program. The statements, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the views of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Ohio Department of Natural Resources, or the Office of Coastal Management.

A Technique for Estimating the Volume of Sand Eroded from Lake Erie Bluffs between Cleveland and the Ohio-Pennsylvania Border

by
D. Mark Jones and Robert H. Hanover

Geological Note 9

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
Thomas J. Serenko, Chief

Columbus 2014

Editing: Charles R. Salmons
Graphic design and layout: Lisa Van Doren

Front cover: Example study-area bluff of till and sand along Lake Erie in Kingsville, Ashtabula County, Ohio.

Recommended bibliographic citation: Jones, D.M., and Hanover, R.H., 2014, A technique for estimating the volume of sand eroded from Lake Erie bluffs between Cleveland and the Ohio-Pennsylvania Border: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Geological Note 9, 18 p.

CONTENTS

Abstract 1
Introduction 1
Project area and purpose 1
Background 1
Methodology 3
Results 3
Future work and other applications 4
Acknowledgments 7
References cited 7
Appendix—Bar graphs of eroded sediment 9
Appendix references cited 9

FIGURES

1. Photograph showing example study-area bluff of till and sand along Lake Erie in Lake County, Ohio 1
2. Map showing locations and distribution of analyzed samples used in this study 2
3. Schematic diagram showing shore erosion quadrilaterals 3
4. Illustration showing the method for computation of the area of a quadrilateral using the Haversine formula and Bretschneider's formula 4
5. Map showing locations of bluff cross sections by 1:24,000-scale quadrangle between Cleveland and the Ohio-Pennsylvania border 5
6. Map showing the stretch of Lake Erie coast in Ohio used for validation of estimation technique 6
A-1. Explanation of bluff profile and overhead map symbology for figures A-2 through A-10 9
A-2. Bluff profile and map showing surficial geology and lakebed substrates for the East Cleveland quadrangle 10
A-3. Bluff profile and map showing surficial geology and lakebed substrates for the Eastlake quadrangle 11
A-4. Bluff profile and map showing surficial geology and lakebed substrates for the Mentor quadrangle 12
A-5. Bluff profile and map showing surficial geology and lakebed substrates for the Perry quadrangle 13
A-6. Bluff profile and map showing surficial geology and lakebed substrates for the Madison quadrangle 14
A-7. Bluff profile and map showing surficial geology and lakebed substrates for the Geneva quadrangle 15
A-8. Bluff profile and map showing surficial geology and lakebed substrates for the Ashtabula North quadrangle 16
A-9. Bluff profile and map showing surficial geology and lakebed substrates for the North Kingsville quadrangle 17
A-10. Bluff profile and map showing surficial geology and lakebed substrates for the Conneaut quadrangle 18

ABBREVIATIONS USED IN THIS REPORT

cubic meter(s)	m^3
cubic yard(s)	cy
foot (feet)	ft
kilometer(s)	km
meter(s)	m

A Technique for Estimating the Volume of Sand Eroded from Lake Erie Bluffs between Cleveland and the Ohio-Pennsylvania Border

by
D. Mark Jones and Robert H. Hanover

ABSTRACT

The Ohio Department of Natural Resources, Division of Geological Survey has developed a technique that uses existing data on bluff composition and morphology to quickly estimate the volume of coarse sediment, primarily sand, that enters the littoral zone through bluff erosion. When automated, the method is quick and can be adapted to solve several types of coastal management problems where sediment flux data are needed.

INTRODUCTION

Bluffs of unconsolidated Pleistocene materials (fig. 1) make up the shore along most of the northeastern Ohio coast. Poorly resistant to erosion, the bluffs consist primarily of glacial till; fine-grained, glaciolacustrine sediments; and sand and gravel; some of these bluffs are also the highest in Ohio. Erosion of these bluffs releases significant volumes of sediment into the littoral zone, where the finer materials are washed into deeper water and the sandy materials are transported by predominantly eastward littoral currents and reworked into beaches, dunes, and nearshore bars.

FIGURE 1. Example study-area bluff of till and sand, Lake County, Ohio.

Some of Ohio's fastest erosion occurs along the stretch of shore between Cleveland and the Ohio-Pennsylvania border as sand becomes trapped at harbor jetties rather than being more evenly distributed along the coast (Hartley, 1964). The release by bluff erosion of coarse-grained materials is recognized (see Mickelson and others, 2002) as an important issue in coastal management. Poor sand management in Ohio has also been implicated in erosion problems downdrift in Pennsylvania (NOAA, 2000).

PROJECT AREA AND PURPOSE

An important tool for coastal sand management is the sediment budget, an accounting of coastal sediment inputs and outputs (Morton, 2003). The Ohio Department of Natural Resources (ODNR), Division of Geological Survey (Ohio Geological Survey) has developed a technique to assist with such an accounting, by using existing data on grain size and bluff erosion rates to estimate how much sandy material is released into the nearshore environment for a given span of time or length of shore. The Ohio Geological Survey undertook a pilot project applying this technique to the Ohio shore between Cleveland and the Ohio border with Pennsylvania (fig. 2) and comparing a portion of the results with recent dredging data.

BACKGROUND

Recession rates are well-documented along the Lake Erie coast of Ohio thanks to aerial photography dating as far back as the 1930s and other shore surveys dating to the 1870s (Carter and Guy, 1983). Since 1996, the periodic measurement of recession rates has been mandated by the Ohio Revised Code, which requires the ODNR to undertake a program of bluff mapping at least every ten years, to calculate the rate of shore recession since the previous mapping, and to project future recession using past recession as a guide (ORC, Chapter 1506.06). Areas with a recession rate above a certain threshold are designated as Coastal Erosion Areas (CEAs), from which the mapping program takes its informal name.

The CEA program recession rates are determined using shore-perpendicular transects superimposed at 100-foot

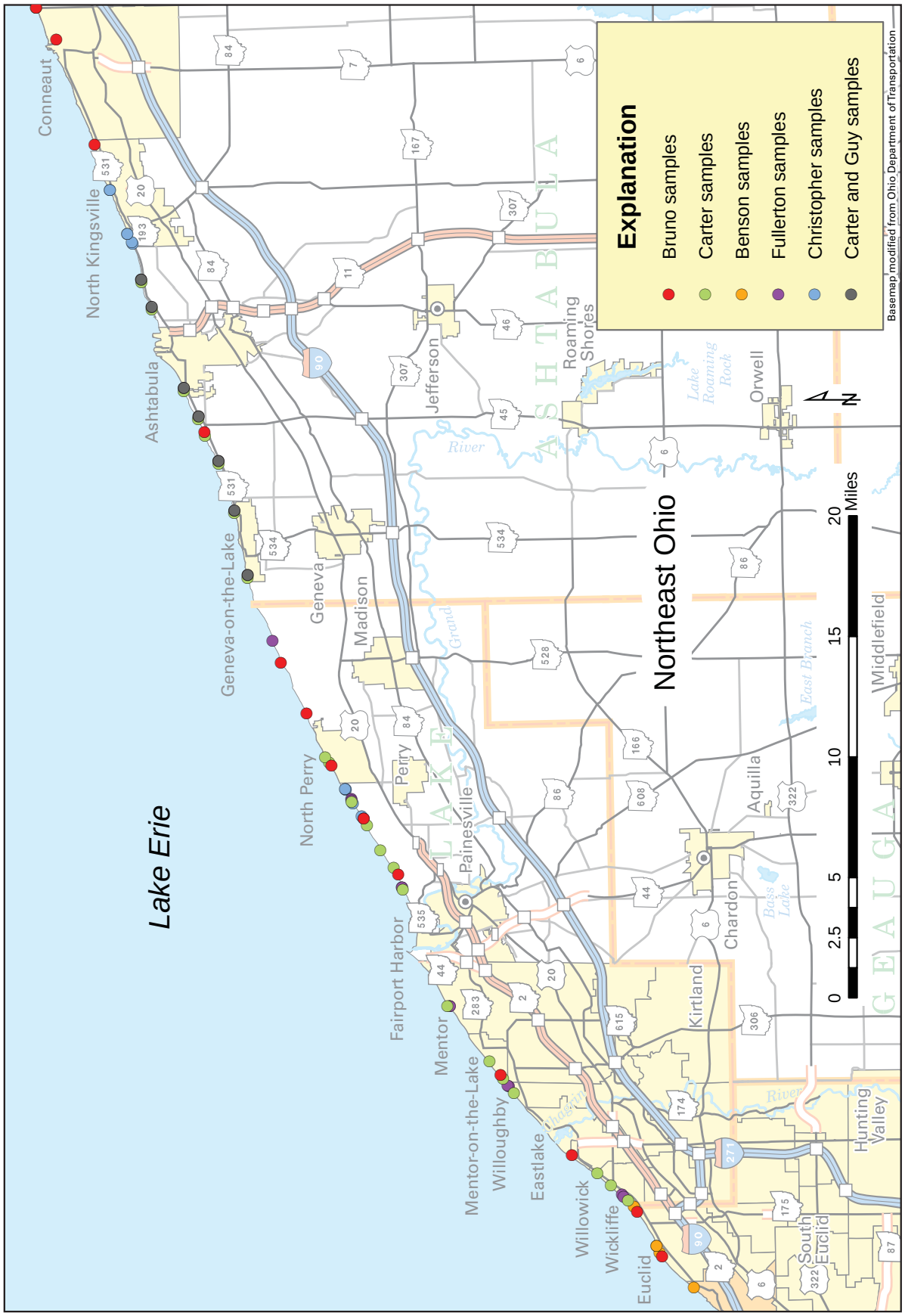


FIGURE 2. Locations and distribution of analyzed samples used in this study, compiled from past studies by Christopher, 1955, 1959; D. Fullerton, unpub. data, 1973; D J. Benson, unpub. data, 1974; Carter, 1976; Carter and Guy, 1983; Bruno, 1988.

(ft; 30-meter [m]) intervals upon a basemap of the shore[1]. Current and past shore positions are digitized where transects cross them. An application developed by the Ohio Geological Survey (McDonald and others, 2011) then measures shore displacement and calculates the recession rate. The application runs in ArcGIS software by Esri. By combining recession rate data with coastal bluff grain size data, one may estimate the amount of bluff material (clay, silt, sand and gravel) that has eroded, or may erode, into the nearshore zone.

METHODOLOGY

Grain size analyses of unconsolidated bluff materials from sixty-eight sites were compiled from past studies (Christopher, 1955, 1959; D. Fullerton, unpub. data, 1973[2]; D. J. Benson, unpub. data, 1974[3]; Carter, 1976; Carter and Guy, 1983; Bruno, 1988). The selected sites are representative of the approximately 69-mile (mi; 111-kilometer [km]) reach of shore (3,648 transects) from Cleveland to the Ohio-Pennsylvania border. From these analyses the percentage of sand-and-larger size materials (>1 millimeter in diameter) was determined for each site and the percentages were interpolated across the study area.

Heights of bluffs in the study area were obtained from data collected by B. D. Stone and R. R. Pavey (unpub. data, 1996[4]) and Fuller and Foster (1998), who recorded bluff heights at transects that correspond directly or very nearly with the 100-ft-spaced CEA transects used to calculate recession. Recession rate data was obtained from the aforementioned CEA program.

Having compiled bluff-material textural data, bluff heights, and recession rates, a technique was developed to calculate the volume of bluff materials eroded per 100-ft (30-m) bluff segment, on average, per year. The technique consists of selecting one transect pair at a time and calculating the lengths of the sides and diagonals of the erosion quadrilateral (fig. 3) formed by an older shoreline, a newer shoreline, and two adjacent transects using the Haversine formula (Sinnott, 1984). The Haversine formula (fig. 4) computes great-circle distances between two points on a sphere using their latitudes (ø) and longitudes (*x*). The area of the quadrilateral is calculated using Bretschneider's formula (Ivanoff, 1960; fig. 3). From the area, the following values are derived:

1. Total volume of sediment eroded – Determined by multiplying the total quadrilateral area by the average bluff height for each transect pair.
2. Volume eroded per year – Determined by dividing the total volume by the number of years between the older shoreline and the newer shoreline.
3. Total volume of sand-and-larger size sediment eroded – Determined by multiplying the total eroded volume by the percentage of sand-and-larger size sediment.
4. Volume of sand-and-larger size sediment eroded per year – Determined by dividing the total volume of sand-and-larger size sediment by the number of years between the older shoreline and the newer shoreline.

Given the large number of transects in the study area, the calculations were automated by the use of an ArcGIS script in Python programming language. The script generated a table of sediment volumes eroded from each transect. This table was written to the attribute table of the transect feature class in ArcGIS.

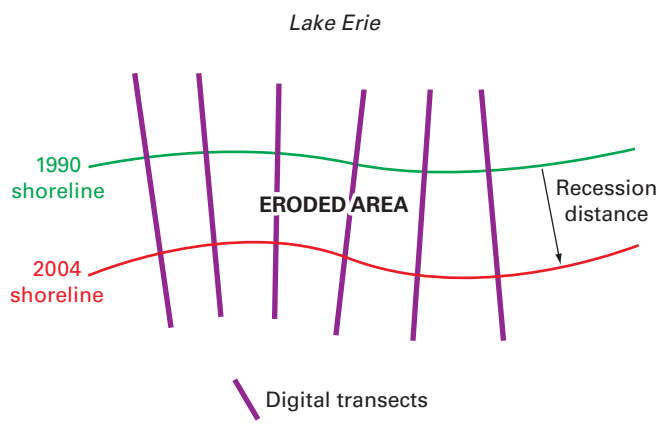


FIGURE 3. Schematic diagram showing shore erosion quadrilaterals used to calculate the bluff materials eroded per year along the Lake Erie shore between Cleveland and the Ohio-Pennsylvania border.

RESULTS

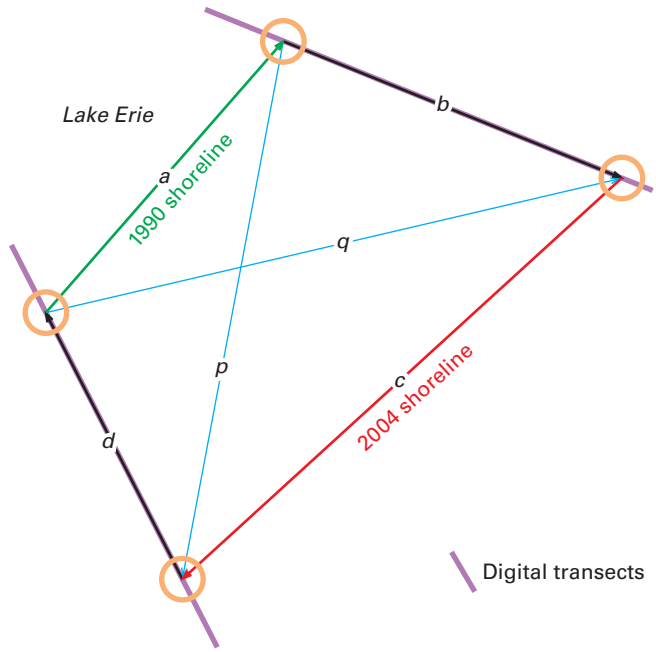
The foregoing technique was used to compute eroded sediment volumes for the shore of the nine 1:24,000-scale quadrangles spanning the Lake Erie coast from eastern Cleveland to the Ohio-Pennsylvania border (fig. 5). The shoreline data used were from 1990 and 2004, for a 14-year period under study. Historical profile data indicated an average bluff composition of 18.9 percent sand-or-larger size particles. Volumes of eroded sediment averaged 94 cubic yards (cy) or 72 cubic meters (m^3) per year per 100-ft (30-m) segment. Total erosion volume for the 3,648 100-ft segments in the study area averaged 344,213 cy (263,170 m^3) per year, about 4,982 cy (3,809 m^3) annually for each mile (1.6 km) of coast.

[1]See **www.OhioDNR.com/CEAm** for an example of completed coastal erosion area maps.

[2]Stratigraphic descriptions of bluffs in Lake County, Ohio, unpublished field data on file at the ODNR Division of Geological Survey.

[3]Stratigraphic descriptions of bluffs in Cuyahoga County, Ohio, unpublished field data on file at the ODNR Division of Geological Survey.

[4]Map of surficial materials in the Lake Erie coastal area, northeastern Ohio, unpublished 1:100,000-scale map on file at the ODNR Division of Geological Survey.



A. $$\text{Length} = 2r \arcsin\left(\sqrt{\sin^2\left(\frac{\phi_2 - \phi_1}{2}\right) + \cos(\phi_1)\cos(\phi_2)\sin^2\left(\frac{x_2 - x_1}{2}\right)}\right)$$

B. $$\text{Area} = \tfrac{1}{4}\sqrt{4p^2q^2 - (b^2 + d^2 - a^2 - c^2)^2}$$

FIGURE 4. Computation of the area of a quadrilateral using A. the Haversine formula and B. Bretschneider's formula. Modified from Weisstein (2013).

Results were validated by comparison with a section of the study area for which recent data were available—a stretch of coast, about 9 mi (14.5 km) in length, from Fairport Harbor to the Village of North Perry (fig. 6). Since 2010, sand dredging and bypassing have taken place on a frequent basis at North Perry's lakefront park, enabling an accounting of the amount of sand entering the nearshore zone between Fairport Harbor and the park (Office of Coastal Management, 2013)[5].

The estimate of sand entering the nearshore zone for this reach—26,404 cy (20,187 m^3) annually—compares closely to the 28,225 cy (21,580 m^3) actually dredged during 2011. Given that the 2011 dredge volume includes sand that accumulated in the last 51 days of 2010 (November 10 being the last time the park was dredged that year), the amount of sand actually accumulated during 2011 for this reach is likely even closer to the calculated estimate.

[5]Unpublished data on file at the ODNR Office of Coastal Management, Sandusky, Ohio.

FUTURE WORK AND OTHER APPLICATIONS

The technique has been preliminarily validated by evaluating the results for a specific reach. Future efforts include incorporating additional stratigraphic data. Although for the pilot project it was assumed that the bluff consists of a single stratum of material, additional profile data will reflect the composition and thicknesses of the major units that make up the bluffs. A means of further validating the technique will also be developed, most likely by comparing field data on short-term accretion rates at other reaches to calculated results. Based on the preliminary validation, this method is expected to withstand real-world comparisons very well, with differences mainly attributable to deficiencies in the available grain size data.

This technique does not account for erosion of the bluff toe nor for lakebed downcutting; future validation work may determine whether the method needs to accommodate these factors. Other variables not accounted for are the contribution of wind-blown sediment and the breakdown of gravel and cobbles into

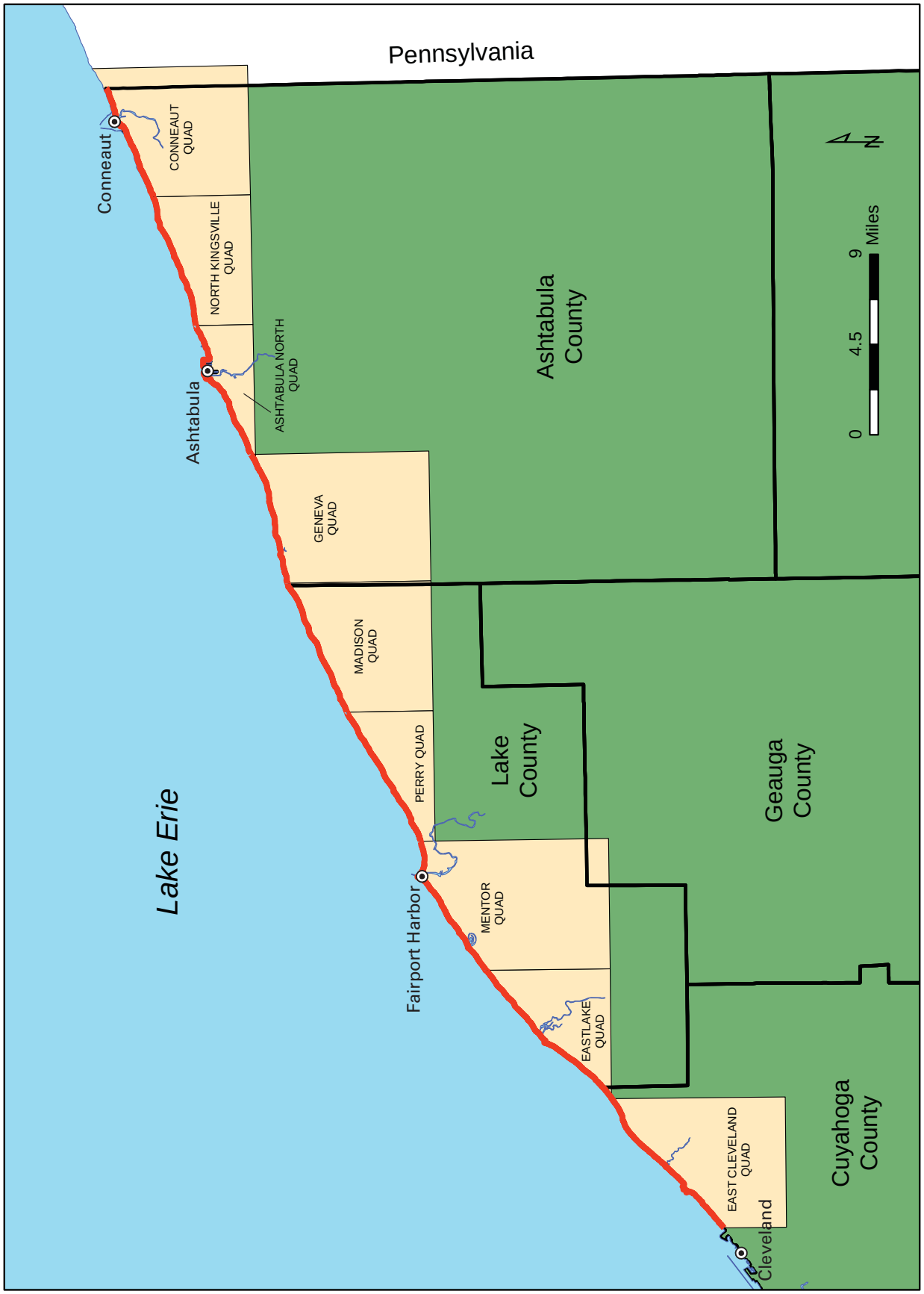


FIGURE 5. Locations of bluff cross sections (see Appendix) by 1:24,000-scale quadrangle between Cleveland and the Ohio-Pennsylvania border.

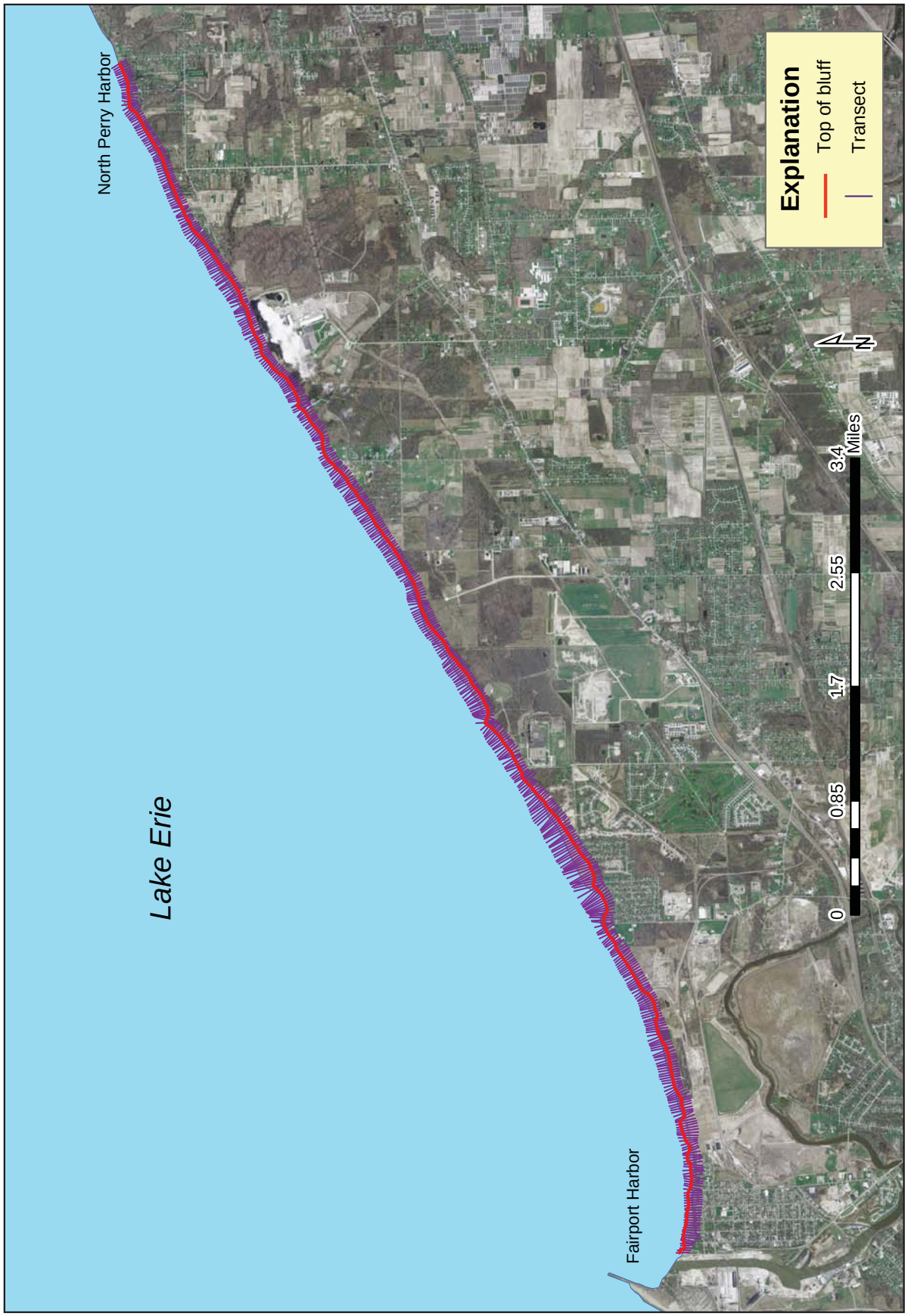


FIGURE 6. Location of stretch of coast, from Fairport Harbor to North Perry (Lake County), used for application validation in this study.

smaller grain sizes by wave action, although these are thought to be negligible.

This technique was designed to be adaptable and it can be expanded upon in a number of ways. For example, if more data become available (such as more grain size analyses to supplement the 68 sites in the pilot project), a programming script can easily interpolate additional data points. It is also possible to expand the area of consideration to—or beyond—the entire Ohio coast or to focus on a limited area of interest, such as a single littoral cell—anywhere sufficient textural, recession, and bluff height data exist.

This technique could also be adapted to estimate the amount of sand transported or accreted by littoral processes, either sub-aerially or in the nearshore zone. Another potential is to assess various scenarios. For example, the technique can be used to determine how much more sand might be expected to enter the nearshore zone for a given recession rate. The method could also be used to support the design and review of various coastal construction proposals, such as determining how much sand would be prevented from entering the nearshore zone by the construction of a revetment or estimating the annual cost of sand bypassing at a new harbor structure. ODNR could eventually deploy this technique through interactive maps on the World Wide Web, where it will assist engineers and researchers with questions such as these.

As an example of how the technique's output could be presented to potential users, the Appendix (p. 9) contains graphs of eroded sediment volume and recession rates for each quadrangle in this study.

ACKNOWLEDGMENTS

Many thanks to Scudder D. Mackey for suggesting the initial concept for, and lending support to, this project and for his helpful suggestions throughout.

Partial funding for mapping the North Kingsville 1:24,000 quadrangle was provided by the U.S. Geological Survey, Great Lakes Geologic Mapping Coalition Grant G12AC20242.

REFERENCES CITED

Bruno, P.W., 1988, Mineralogy and lithofacies of the Ashtabula Till in Lake and Ashtabula Counties, Ohio: Akron, Ohio, University of Akron, M.S. thesis, 207 p.

Carter, C.H., 1976, Lake Erie shore erosion, Lake County, Ohio—Setting, processes, and recession rates from 1876 to 1973: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Report of Investigations 99, 105 p.

Carter, C.H., and Guy, D.E., 1983, Lake Erie shore erosion, Ashtabula County, Ohio—Setting, processes, and recession rates from 1876 to 1973: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Report of Investigations 122, 107 p.

Christopher, J.E., 1955, An investigation of Lake Erie shore erosion between Fairport and the Mentor Yacht Club, Lake County, Ohio: Columbus, The Ohio State University, M.S. thesis, 100 p.

Christopher, J.E., 1959, Geology of the Ohio shore of Lake Erie between Fairport and the Pennsylvania border: Columbus, The Ohio State University, Ph.D. dissertation, 238 p.

Fuller, J.A., and Foster, D.S., 1998, Sidescan sonar differentiation of Ohio's nearshore (Lake Erie) surficial sediments: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Map LE-1, scale 2½ inches equals about 10 miles.

Hartley, R.P., 1964, Effects of large structures on the Ohio shore of Lake Erie: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Report of Investigations 53, 30 p.

Ivanoff, V.F., 1960, Solutions to problem E1376—Bretschneider's Formula: Washington, D.C., The American Mathematical Monthly, v. 67, p. 291–292.

McDonald, James, Harbulak, Paul and Mackey, S.D., 2011, New GIS tools for mapping Ohio's Lake Erie coastal erosion areas, *in* Digital Mapping Techniques '09—Workshop Proceedings, Morgantown, W. Va., May 10–13, 2009: U.S. Geological Survey Open File Report 2010-1335, p. 195–205, last accessed February 6, 2014, at <http://pubs.usgs.gov/of/2010/1335/pdf/usgs_of2010-1335_McDonald.pdf>.

Mickelson, D.M., Brown, E.A., Edil, T.B., Meadows, G.A., Guy, D.E., Liebenthal, D.L., and Fuller, J.A., 2002, Comparison of sediment budgets of bluff/beach/nearshore environments near Two Rivers, Wisconsin, on Lake Michigan, and at Painesville, Ohio, on Lake Erie: Geological Society of America Abstracts with Programs, v. 34, no. 2, p. A-12.

Morton, R.A., 2003, An overview of coastal land loss—With emphasis on the southeastern United States: U.S. Geological Survey Open File Report 03-337, 29 p.

National Oceanic and Atmospheric Administration (NOAA), 2000, Federal consistency helps Pennsylvania restore sand to the shoreline: Coastal Services, v. 3, no. 6, last accessed February 6, 2014, at <http://www.csc.noaa.gov/magazine/2000/06/penn.html>.

Ohio Revised Code (ORC), Chapter 1506.06, Preliminary and final identification of Lake Erie coastal erosion areas, effective date May 8, 1996: State of Ohio, last accessed February 6, 2014, at <http://codes.ohio.gov/orc/1506.06>.

Sinnott, R.W., 1984, Virtues of the Haversine: Sky and Telescope, v. 68, no. 2, p. 158.

Weisstein, E.W., 2013, Bretschneider's Formula: MathWorld—A Wolfram Web Resource, last accessed February 6, 2014, at <http://mathworld.wolfram.com/BretschneidersFormula.html>.

INTENTIONALLY BLANK

APPENDIX—BAR GRAPHS OF ERODED SEDIMENT

The following bluff profiles (B. D. Stone and R. R. Pavey, unpub. data, 1996[6]; Fuller and Foster, 1998) have been combined with bar graphs illustrating the volumes of sediment released through bluff erosion between 1990 and 2004. The bars are divided to depict sand-and-gravel sized and finer materials. Clusters of tall bars indicate areas of rapid erosion. A bar graph of recession rates (as a red line) is also included. The bar graphs are georeferenced to the profiles, so they correspond directly to the adjacent portion of the profile. The profiles are ordered from southwest to northeast (fig. 5 in the report text). The view through each profile faces roughly northward, as though looking through the bluff, towards Lake Erie.

Accompanying each profile is a location map showing the upland surficial geology (overlaid on a basemap of aerial photography) and the substrates making up the lake bed (overlaid on a basemap of lake bottom bathymetry [NOAA, 1998]). Data on lake bottom materials were derived from core and sediment samples collected by the Ohio Geological Survey from the 1950s through the 1970s (Herdendorf, 1978) and from side-scan sonar from the 1990s (Fuller and others, 1995). Data on surficial upland geology were derived from the Ohio Geological Survey SG-2 map series, 1:100,000-scale maps that depict the unconsolidated materials above bedrock (Brockman and Schumacher, 2006; Larsen and others, 2006).

For the entire stretch of coast from western Cleveland, Ohio, to Buffalo, New York, the dominant longshore drift is from west to east; therefore, sand that erodes from the bluff and enters the nearshore zone tends to travel eastward. Structures that extend into the lake above water level (such as groins and jetties) intercept part of this eastward flow, causing sand to accumulate on their western sides. Where such accumulation occurs, the shore on the downdrift (eastern) side of the structure becomes starved of sand, leaving it without a beach to protect the bluff toe from storm waves. These effects can be observed at several places on the bar graphs.

Detailed discussions of each bluff profile follow. An explanation of bluff profile and overhead map symbology is provided (fig. A-1).

[6]Map of surficial materials in the Lake Erie coastal area, northeastern Ohio, unpublished 1:100,000-scale map on file at the ODNR Division of Geological Survey.

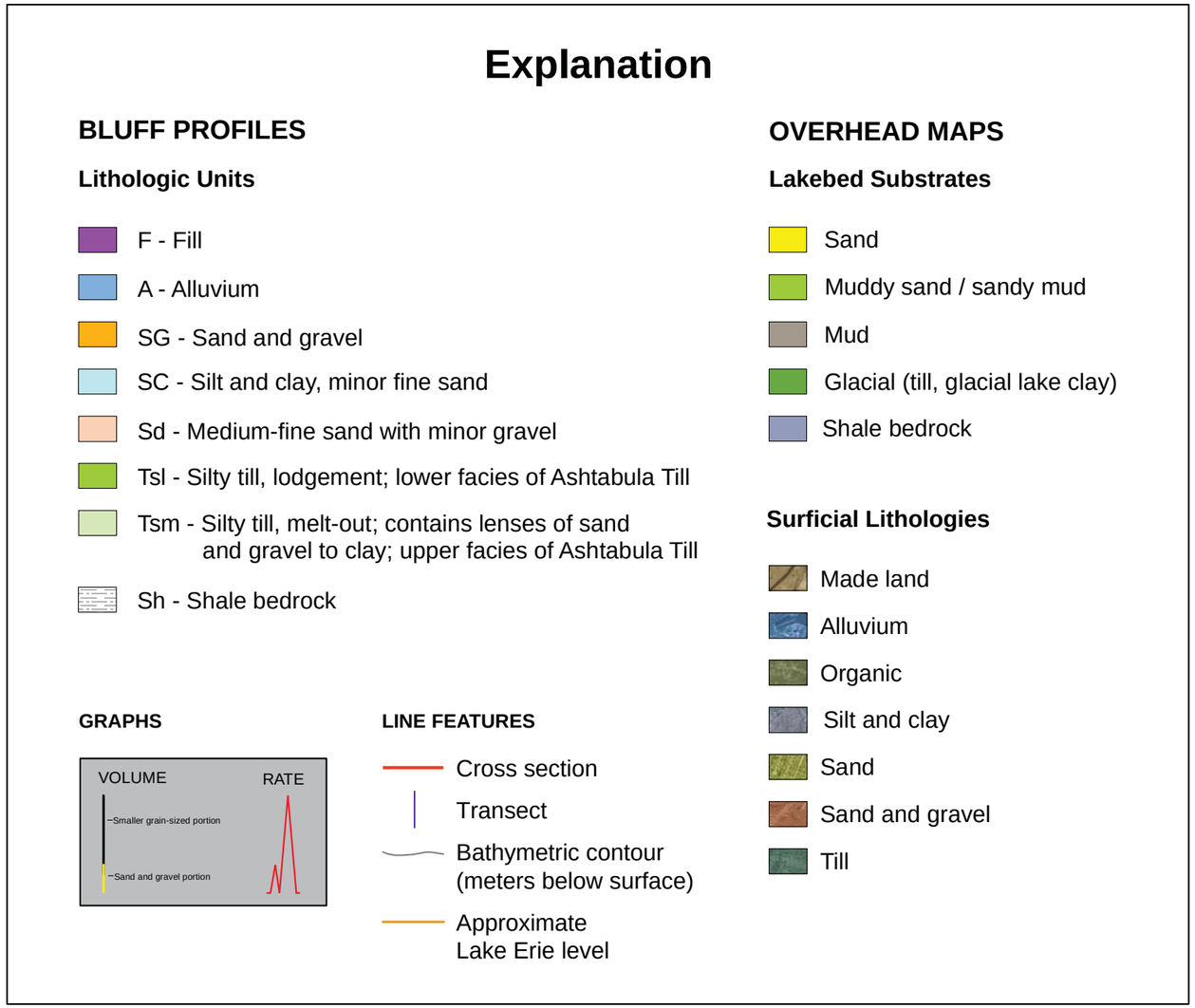


FIGURE A-1. Explanation of bluff profile and overhead map symbology for figures A-2 through A-10.

REFERENCES CITED

Brockman, C.S., and Schumacher, G.A., 2006, Surficial geology of the Cleveland North 30 x 60 minute quadrangle: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Map SG-2 Cleveland North, map (scale 1:100,000).

Fuller, J.A., and Foster, D.S., 1998, Sidescan sonar differentiation of Ohio's nearshore (Lake Erie) surficial sediments: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Map LE-1, scale 2½ inches equals about 10 miles.

Fuller, J.A., Circé, R.C., and Oldale, R.N., 1995, The Geologic Framework of the Ohio area of Lake Erie: U.S. Geological Survey Open-File Report 95-220, 21 p. and 55 map sheets.

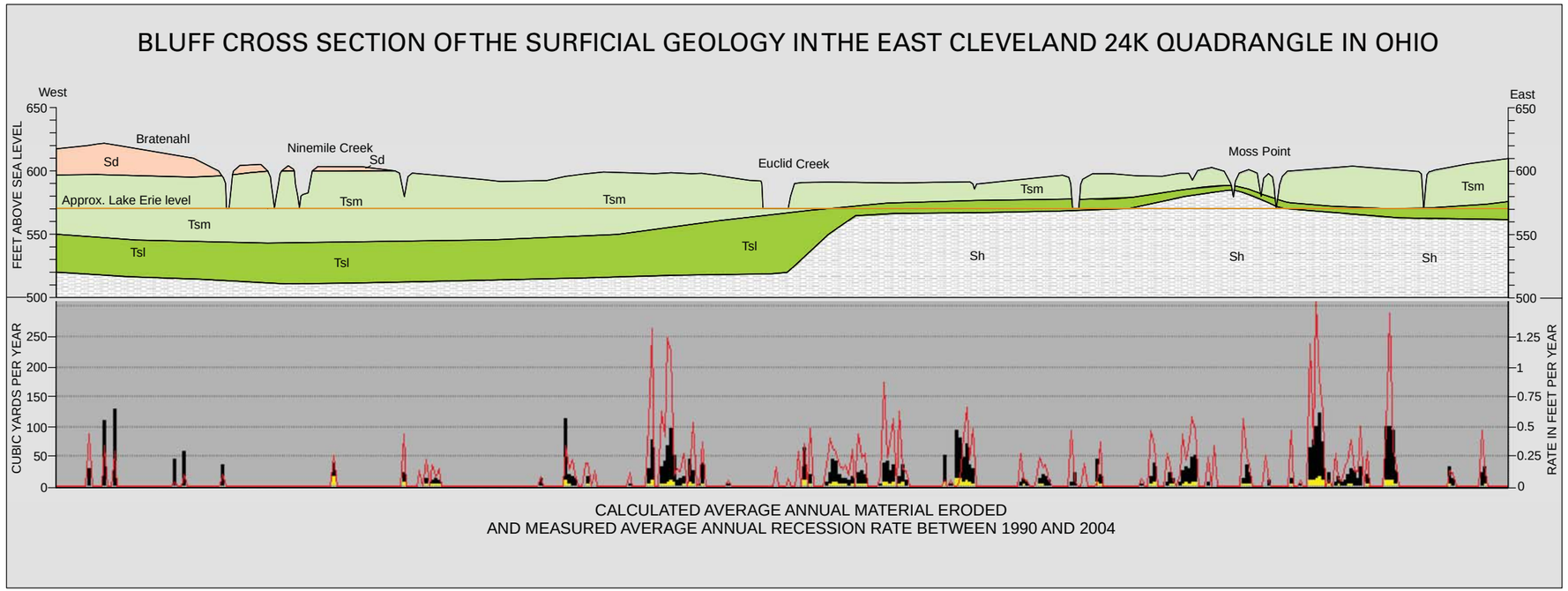
Herdendorf, C.E., 1978, Descriptions of sediment samples and cores from the Michigan and Ohio waters of Lake Erie: Columbus, The Ohio State University, Center for Lake Erie Area Research, Technical Report 85, 445 p.

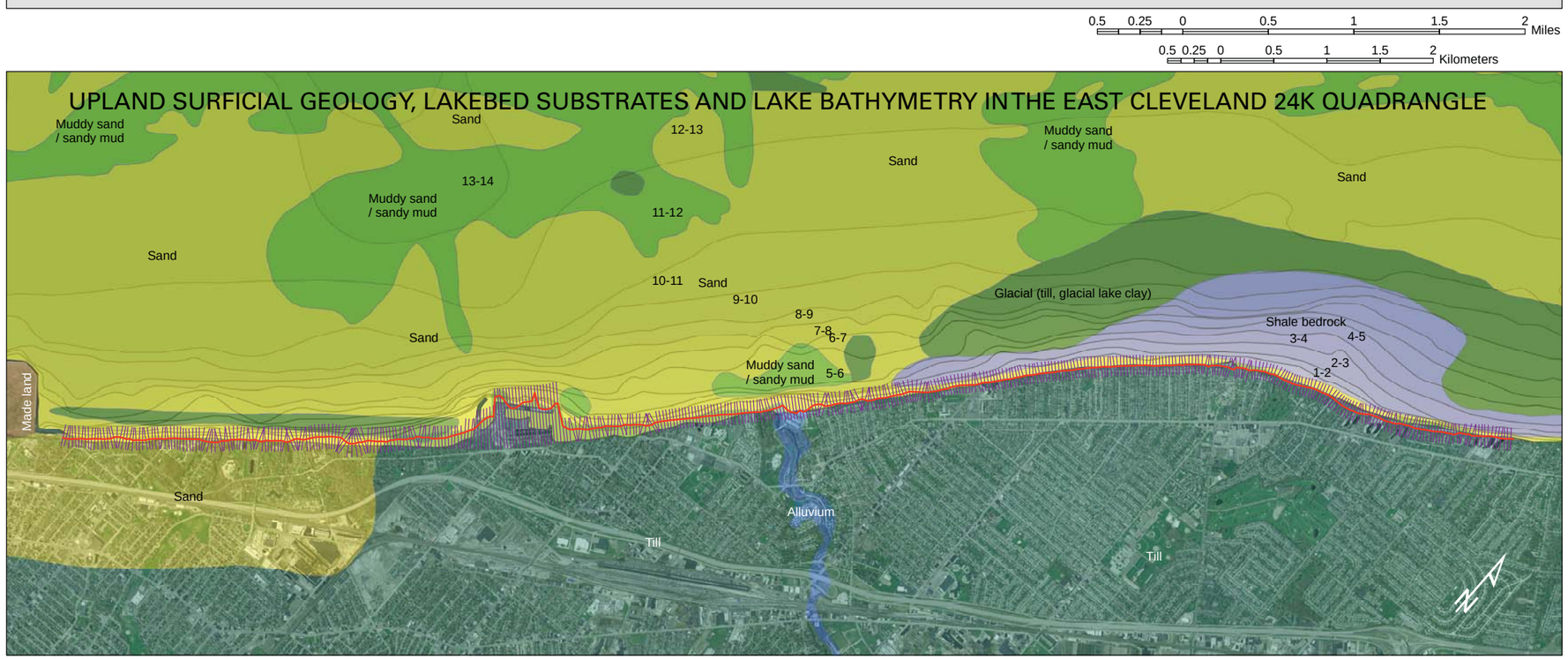
Larsen, G.E., Schumacher, G.A., Shrake, D.L., Venteris, E.R., Swinford, E.M., 2006, Surficial Geology of the Ohio portions of the Ashtabula 30 x 60 minute quadrangle: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Map SG-2 Ashtabula, map (scale 1:100,000).

National Oceanic and Atmospheric Administration (NOAA), 1998, Bathymetry of Lake Erie and Lake Saint Clair (map): NOAA National Geophysical Data Center, Report MGG-14 <http://www.ngdc.noaa.gov/mgg/greatlakes/erie.html>.

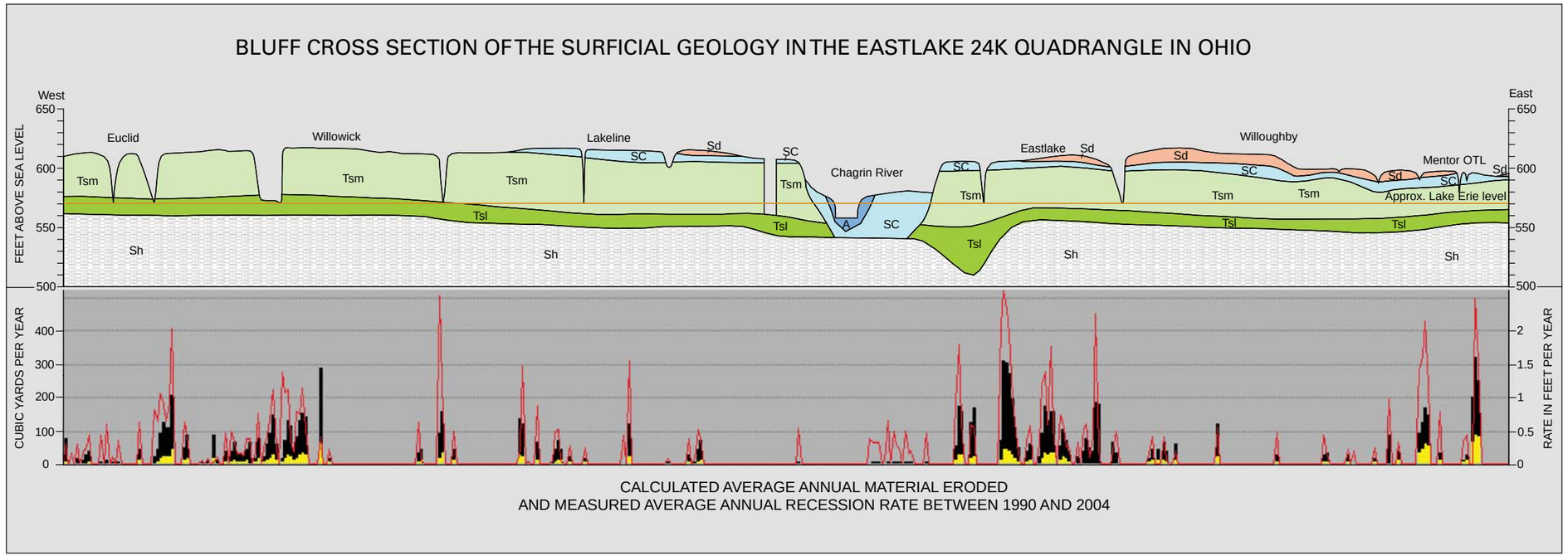
FIGURE A-2. EAST CLEVELAND QUADRANGLE

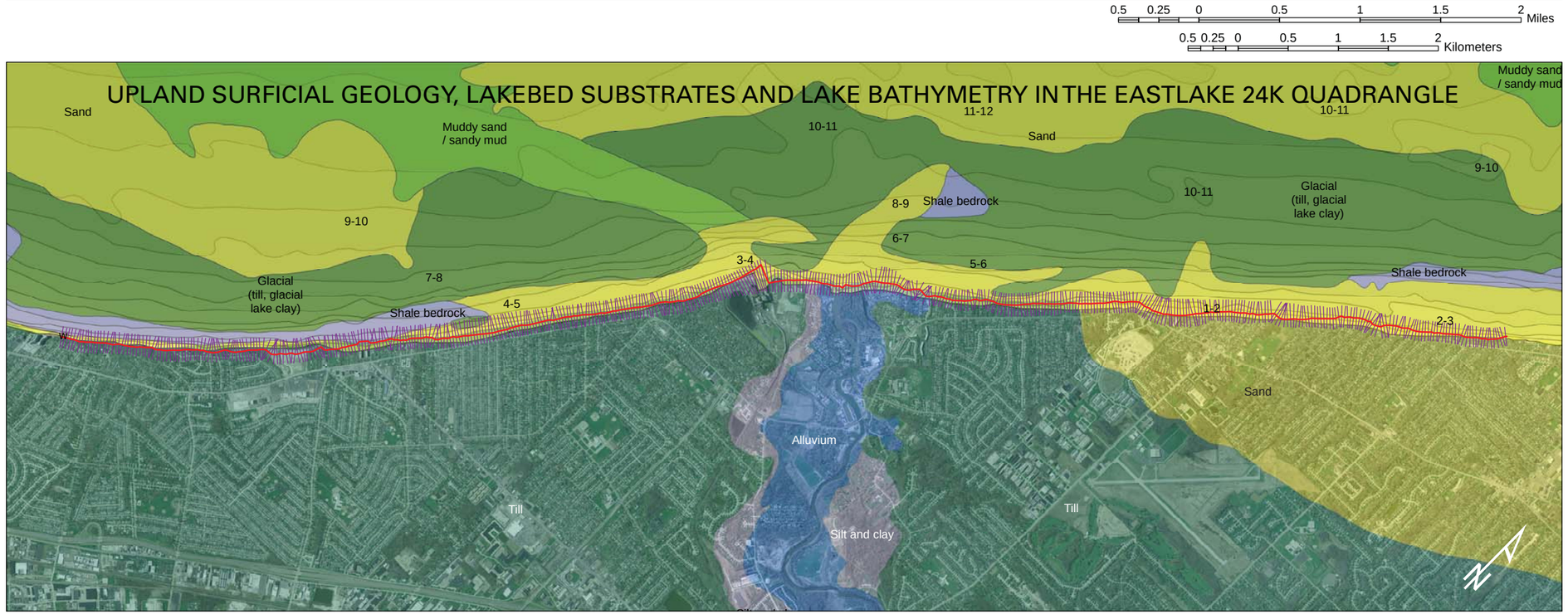
The profile depicts continuous deposits of Ashtabula Till in two facies: a lodgement facies that consists of till deposited beneath a glacier directly against bedrock and a melt-out facies consisting of materials released from the glacier as it melted. The tills are deposited on an eroded surface of shale bedrock, probably a terrace above the preglacial Dover River buried valley, which is not shown but occurs a few miles to the west. Bedrock does not rise above lake level except east of Euclid Creek, where it forms a resistant headland known as Moss Point. Bedrock there extends offshore several hundred feet, beyond which glacial till outcrops in the lakebed. The profile is incised by many minor creeks and drainages, which probably contribute some sand to the nearshore zone.





Projection of data is Ohio coordinate system, north zone, North American Datum, 1983. Not to be used for navigation.





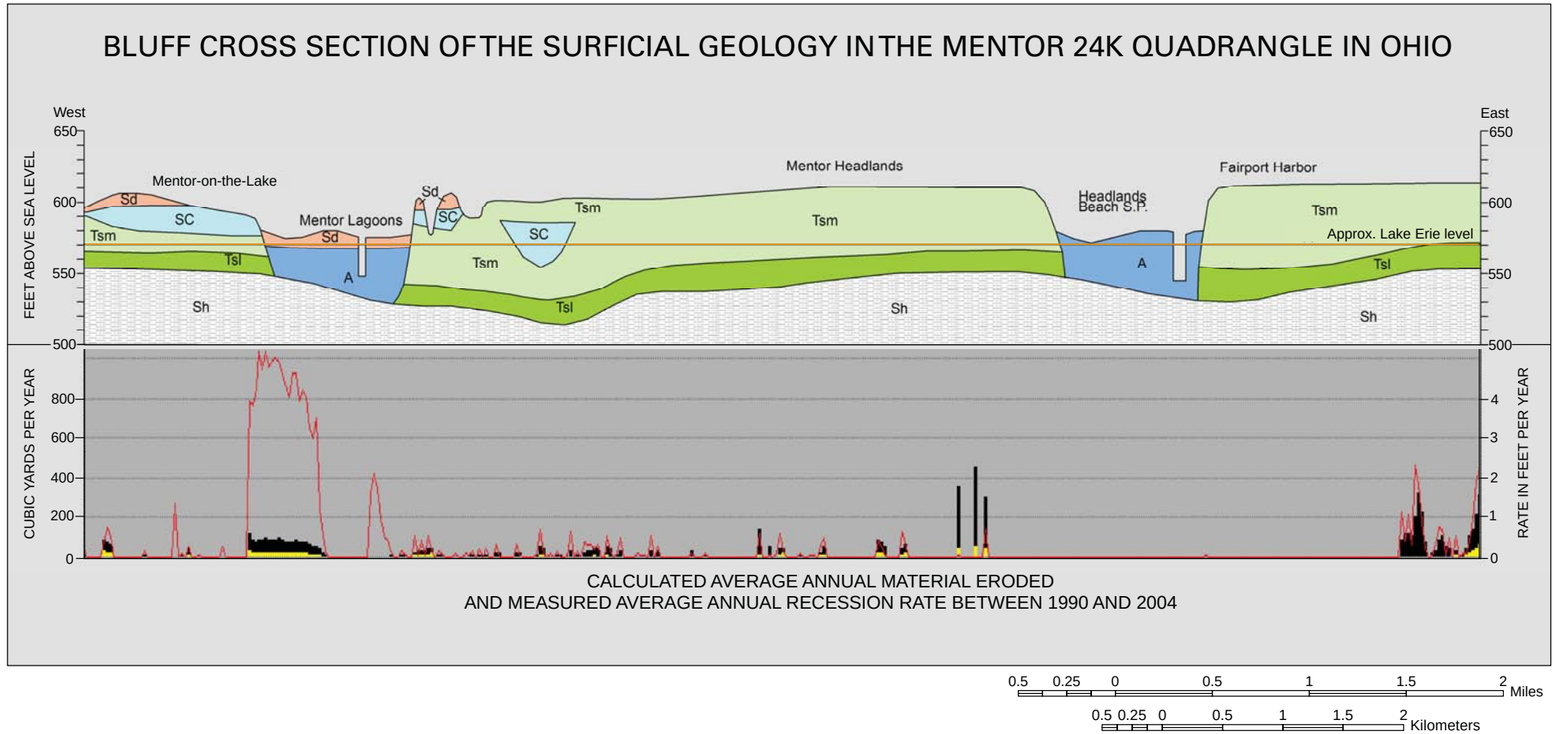
Projection of data is Ohio coordinate system, north zone, North American Datum, 1983. Not to be used for navigation.

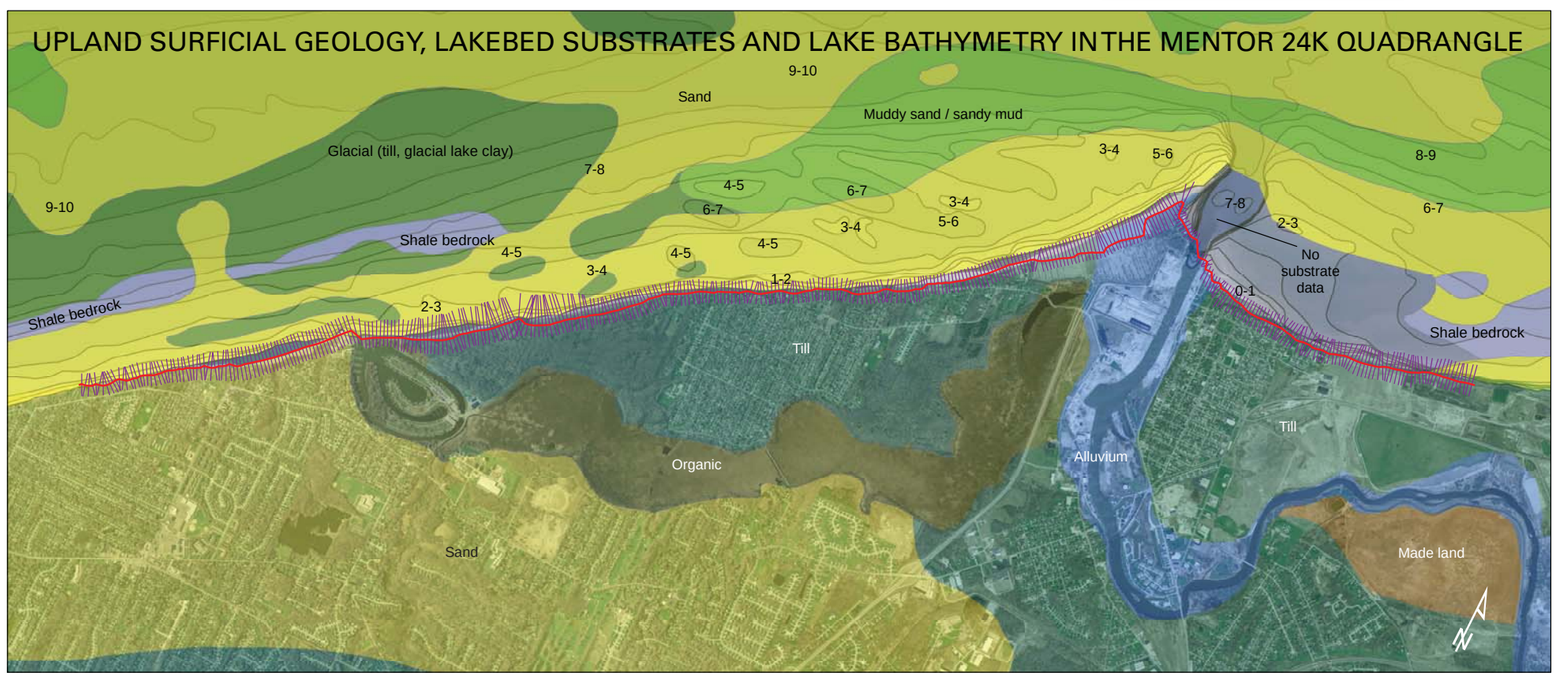
FIGURE A-3. EASTLAKE QUADRANGLE

Continuous deposits of Ashtabula Till occur across the profile, except where cut through by the mouth of the Chagrin River, which has redeposited silts and clays in its floodplain. Near the mouth of the Chagrin, an older precursor to the modern river cut into the shale bedrock, leaving a channel form filled with Ashtabula Till. The till in the central and eastern portion of the profile is capped by sand, silts, and clays—lake plain deposits left behind by glacial lakes that predated modern Lake Erie. Erosion of sandier materials at the top of the bluff contributes to the broad band of sand along the shoreline. Sand has accumulated as a broad beach on the updrift (west) side of breakwaters that protect the water intake of a power generation station just west of the mouth of the Chagrin River. The breakwaters and beach protect the bluff from erosion for a short distance (note the lack of vertical bars below the mouth of the river in the profile), but tall bars east of that indicate an area of higher erosion rates.

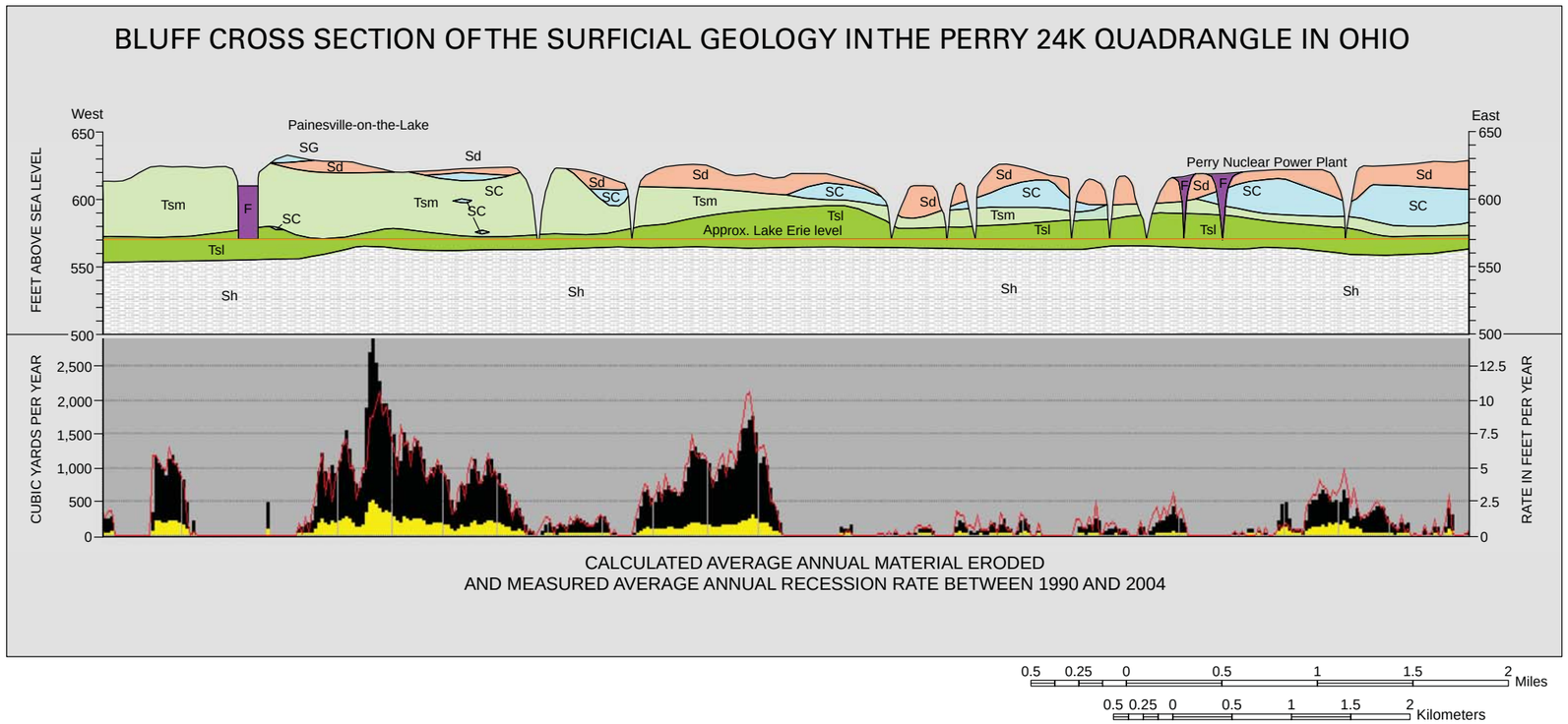
FIGURE A-4. MENTOR QUADRANGLE

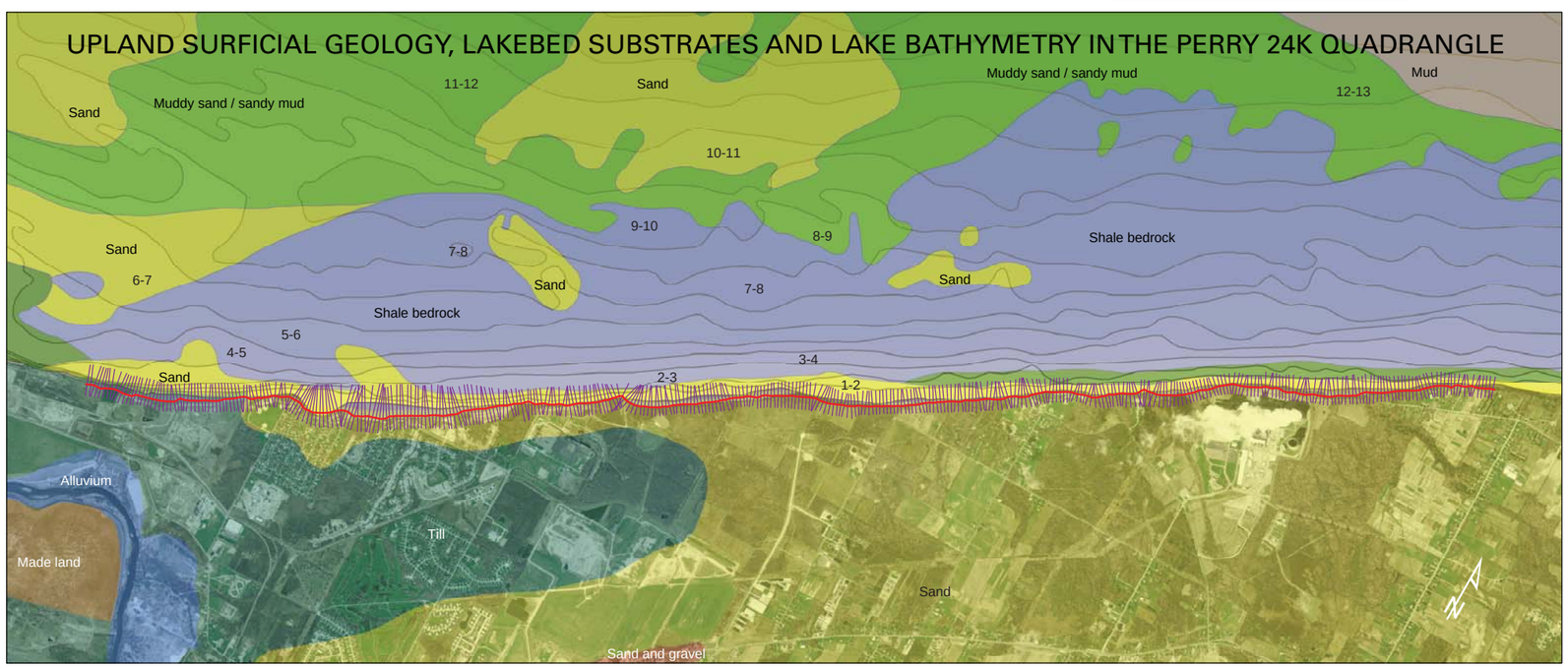
The profile shows two outlets into Lake Erie; one, at Mentor Lagoons, is a former mouth of the Grand River; the other, farther east, is the current mouth of the Grand River, the earlier mouth having been abandoned by the river sometime prior to the first survey of the area in 1796. Both river mouths are infilled with alluvium, indicated by blue in the profile. Jetties protect Fairport Harbor (the modern mouth of the river) from shoaling but have caused large amounts of sand to accrete just west of the harbor, creating a large and popular bathing beach (Headlands Beach State Park) but also leaving points east starved of beach-building sand. Although much sand accumulates in this quadrangle, erosion contributes very little sand to the nearshore zone, owing to relatively low recession rates. The only place on the quadrangle with high recession rates is just east of Mentor Lagoons; however, this is not bluff recession but is due to the migration of a barrier beach and therefore it contributes little sediment to the nearshore. Unlike all other profiles in this collection, this profile shows very little evidence of dissection by minor streams and drainages. Streams that normally would dissect the lake bluff instead drain into the lowlands of Mentor Marsh.





Projection of data is Ohio coordinate system, north zone, North American Datum, 1983. Not to be used for navigation.





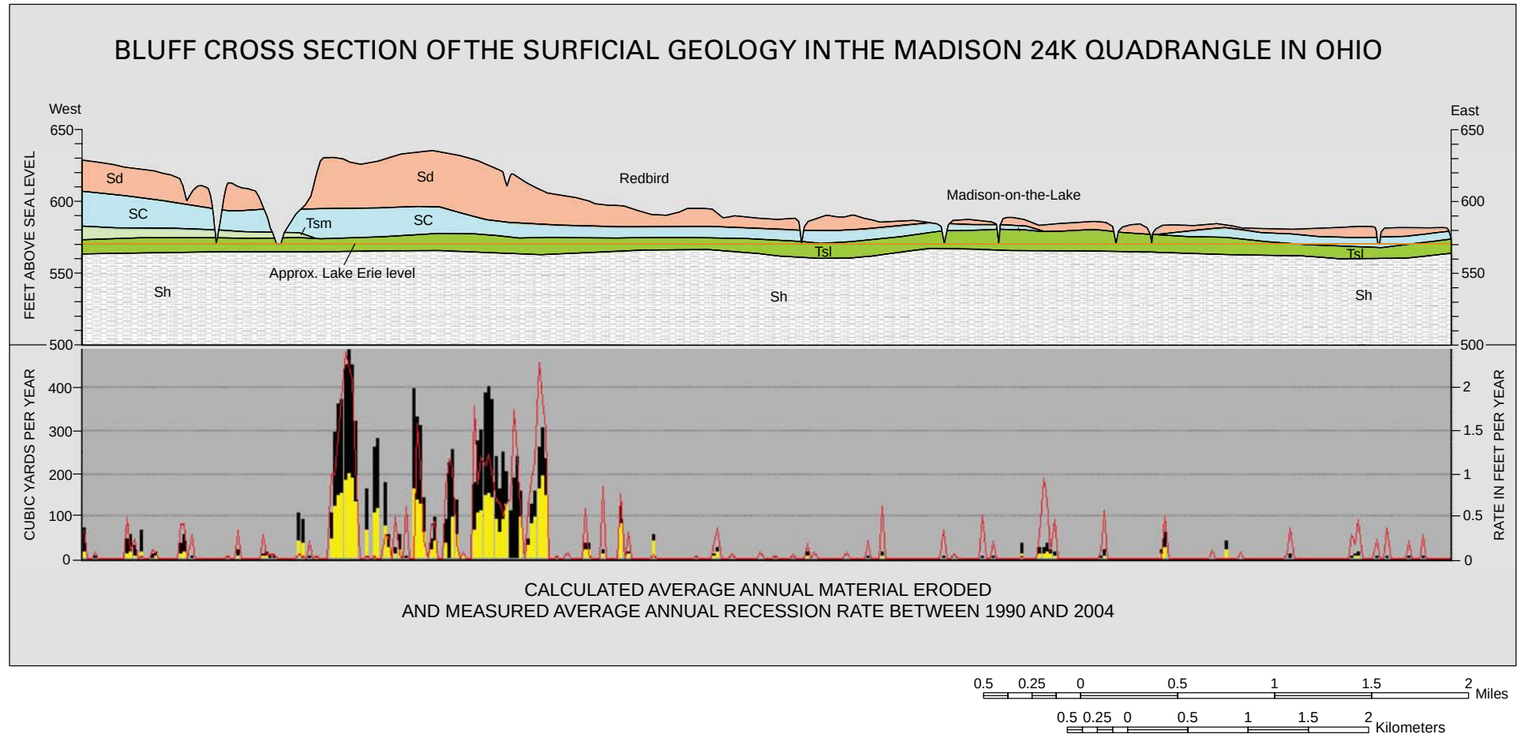
Projection of data is Ohio coordinate system, north zone, North American Datum, 1983. Not to be used for navigation.

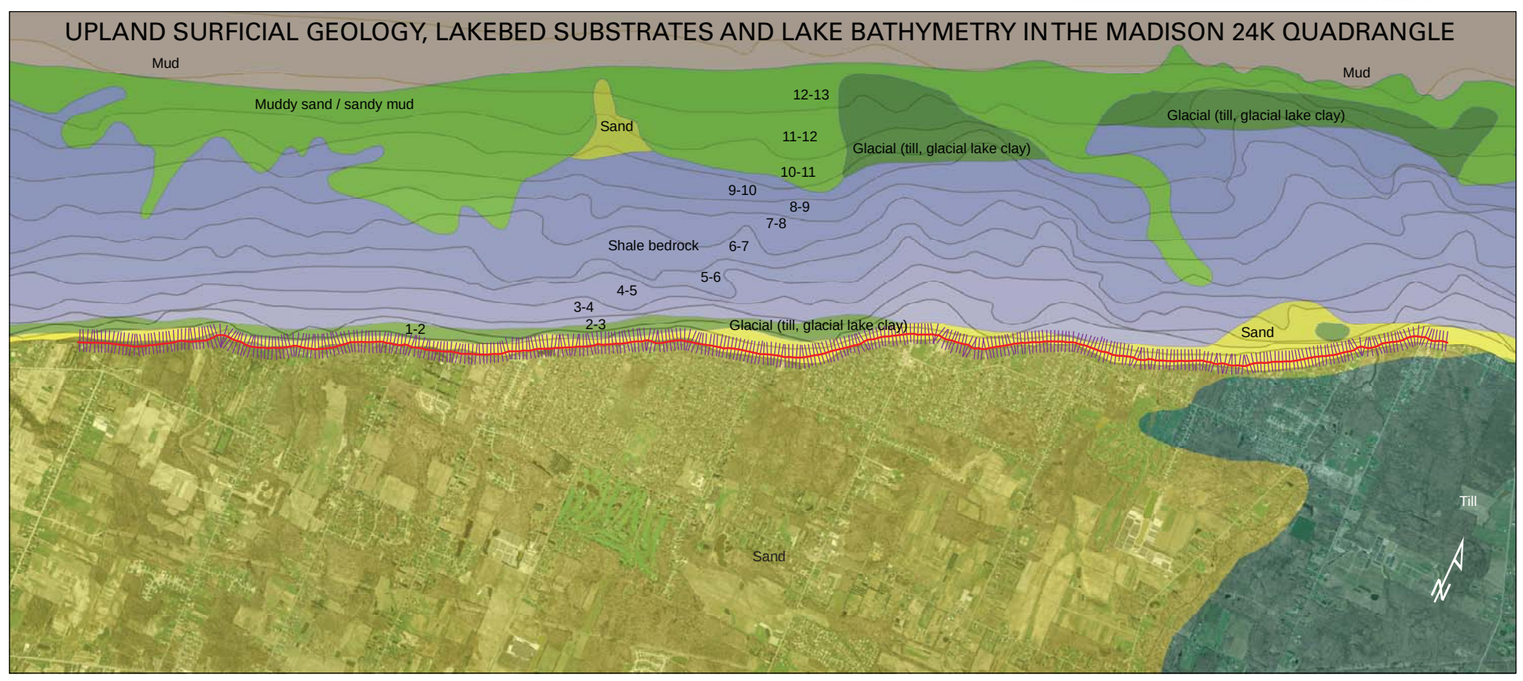
FIGURE A-5. PERRY QUADRANGLE

The bulk of the area used for preliminary validation of the volume-estimating technique occurs in this quadrangle, from the western end to about halfway across the profile (the extreme eastern end of the Mentor profile was included as well). Among the highest erosion rates in Ohio occur along this Fairport Harbor-to-North Perry reach, where the graph shows two broad clusters of tall bars. This is the sediment contribution predicted by the technique and preliminarily validated by dredging data at North Perry (just east of the Perry Nuclear Power Plant in the figure). Note that in the eastern half of the figure, recession rates and amounts of eroded sediment decrease markedly. This appears to be due to increased development of the area (where more properties use erosion protection) and lower bluffs, although differences in bluff composition cannot be ruled out.

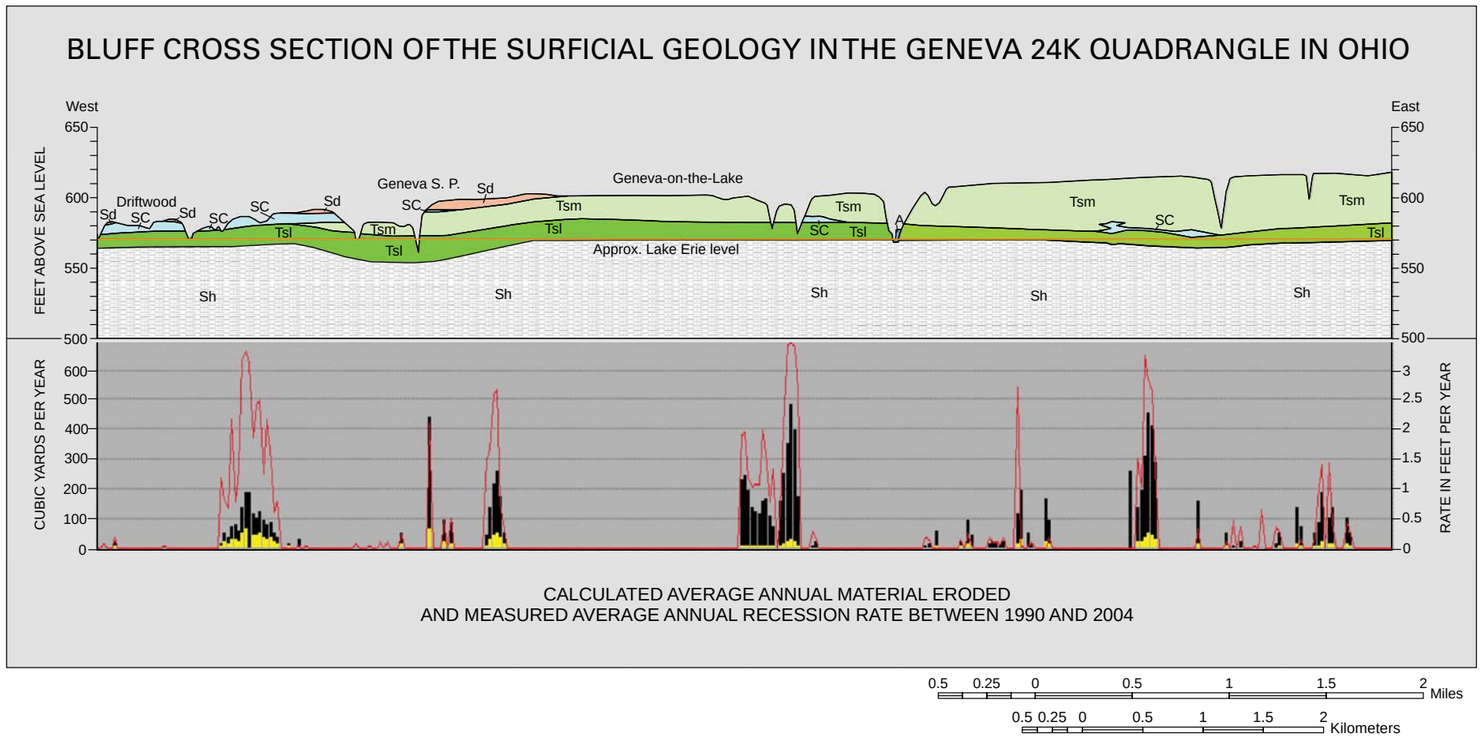
FIGURE A-6. MADISON QUADRANGLE

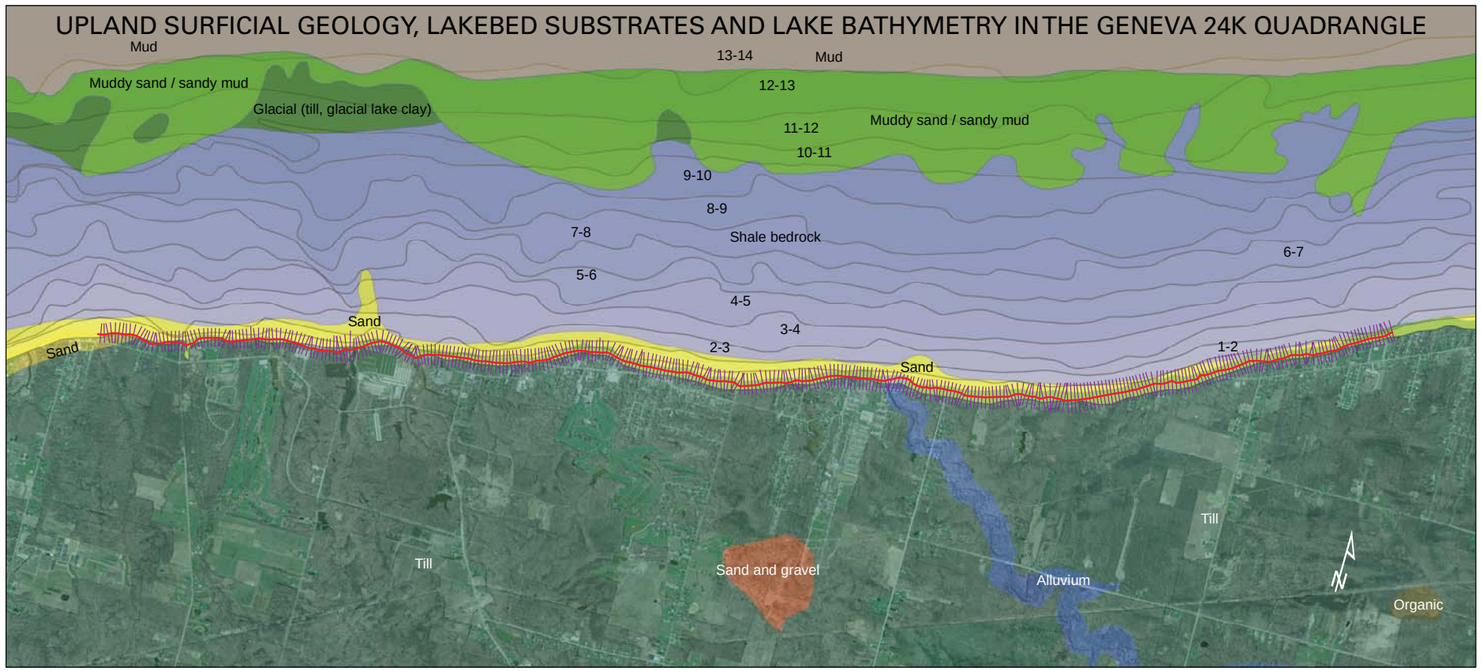
Thick deposits of fine lacustrine sands overlie Ashtabula Till in the western half of this quadrangle and contribute significant amounts of sand to the nearshore zone. Note the broad exposure of shale and the lack of sandy substrate on the lake bottom throughout most of this quadrangle—this is the persistent effect of sand becoming trapped at Fairport Harbor, two quadrangles to the west. Throughout the western half of this reach, glacial till crops out in the lakebed just offshore, where it is vulnerable to wave erosion by lakebed downcutting. However, this quadrangle is heavily developed, which has tended to keep erosion rates moderate as residents take measures to limit land loss.





Projection of data is Ohio coordinate system, north zone, North American Datum, 1983. Not to be used for navigation.





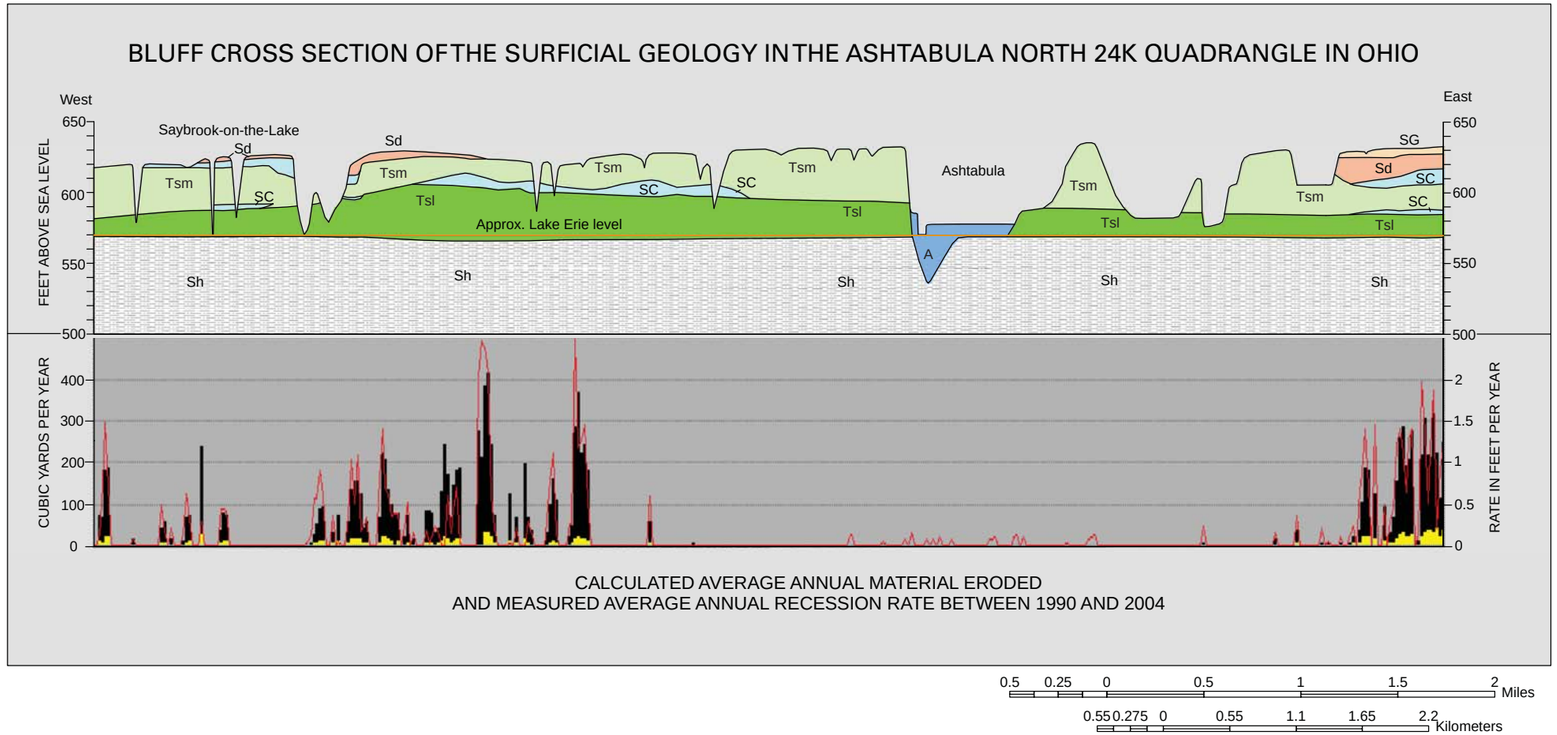
Projection of data is Ohio coordinate system, north zone, North American Datum, 1983. Not to be used for navigation.

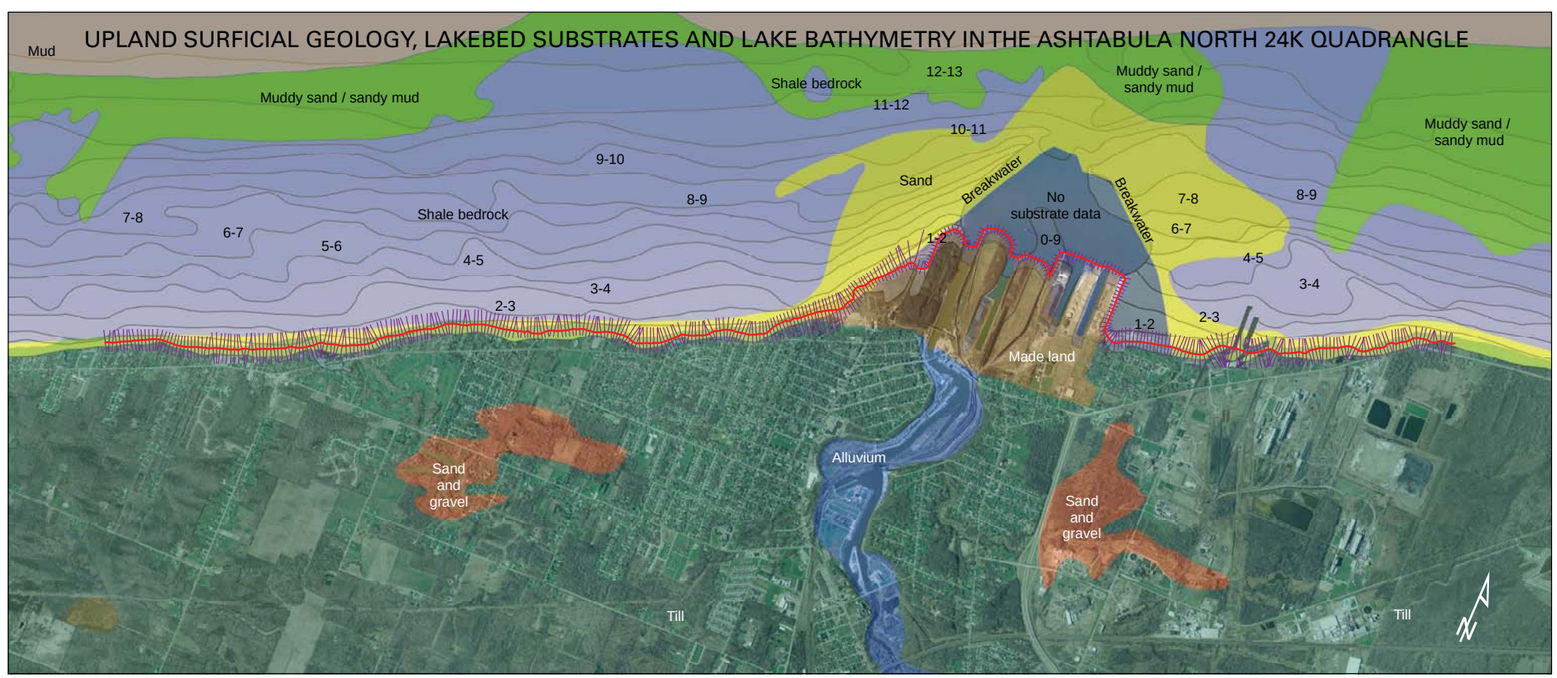
FIGURE A-7. GENEVA QUADRANGLE

Lower bluffs with fewer sandy materials at the top contribute relatively little sand to the nearshore zone throughout this quadrangle. Consequently, even where recession rates are high (red line on the bar graph), the amounts of sediment eroded are relatively small. Similar to Fairport Harbor, a small harbor at Geneva State Park (S. P.) traps sand on its west side and discourages the formation of beaches eastward. East of Geneva S. P., shale bedrock rises to near lake level, which has a somewhat protective effect for the bluff toe, especially when lake levels are lower than average.

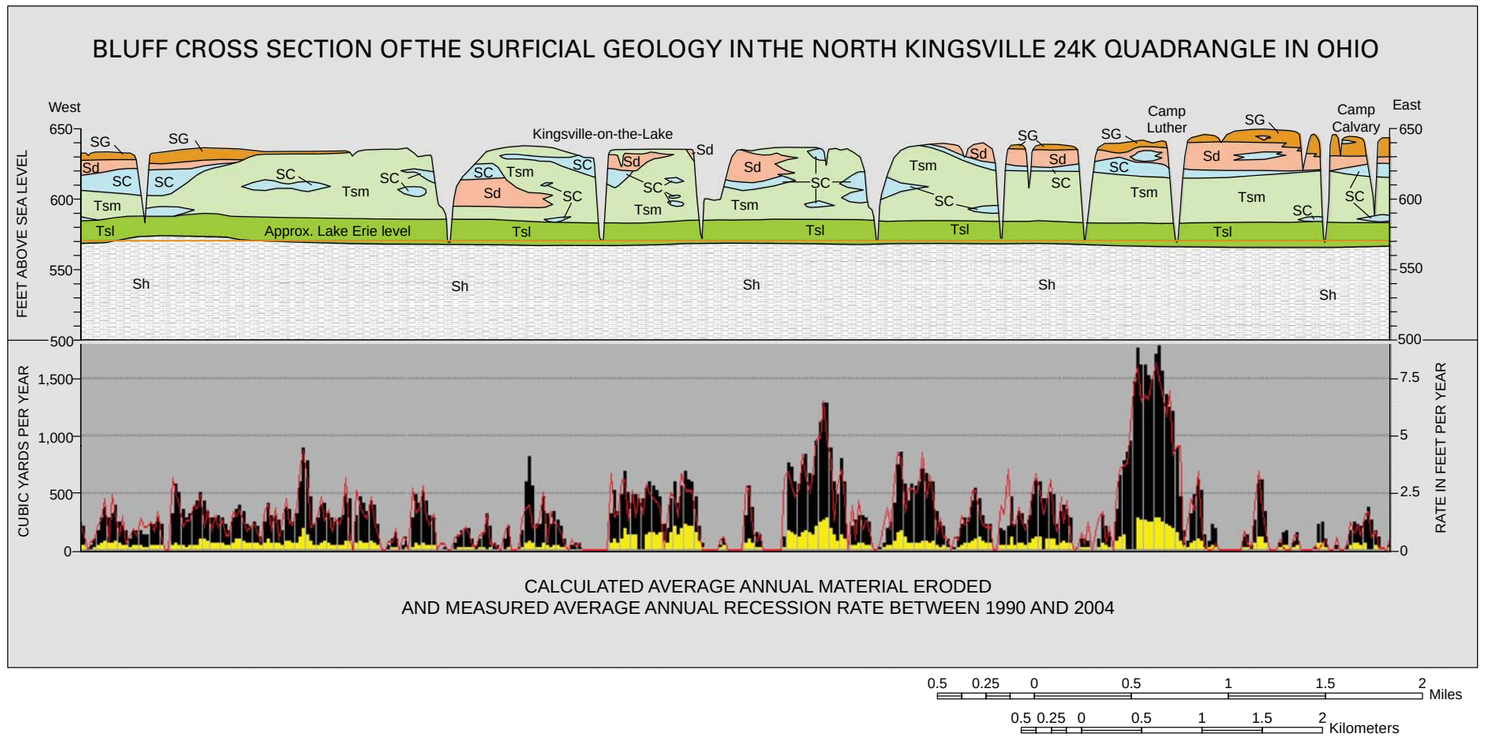
FIGURE A-8. ASHTABULA NORTH QUADRANGLE

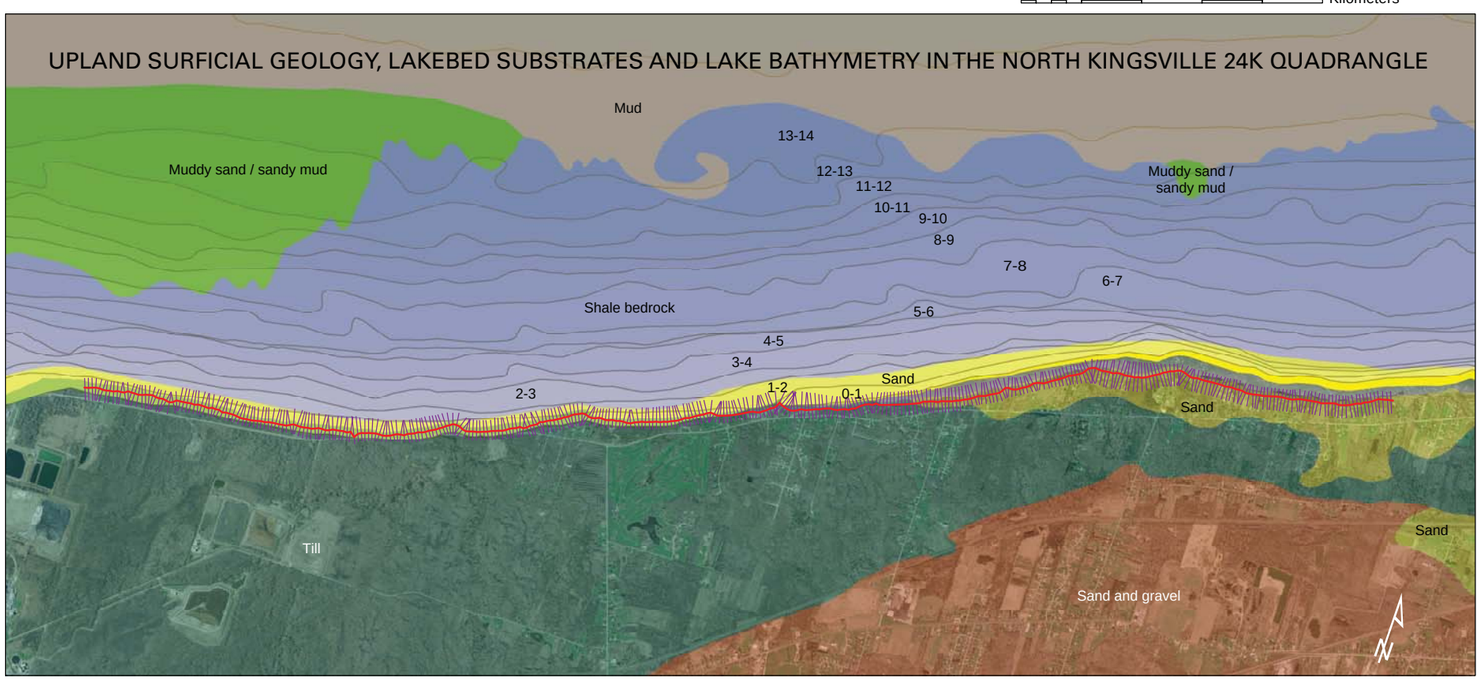
The dominant feature of this quadrangle is Ashtabula Harbor, where long jetties that extend into the lake at the mouth of the Ashtabula River prevent shoaling of the harbor, keeping it open to shipping. A broad beach has accumulated updrift of the west jetty, creating a public bathing beach and providing protection for the bluff near the harbor. The broad gap in the bar graph shows that the lands near the harbor erode very little, if at all.





Projection of data is Ohio coordinate system, north zone, North American Datum, 1983. Not to be used for navigation.





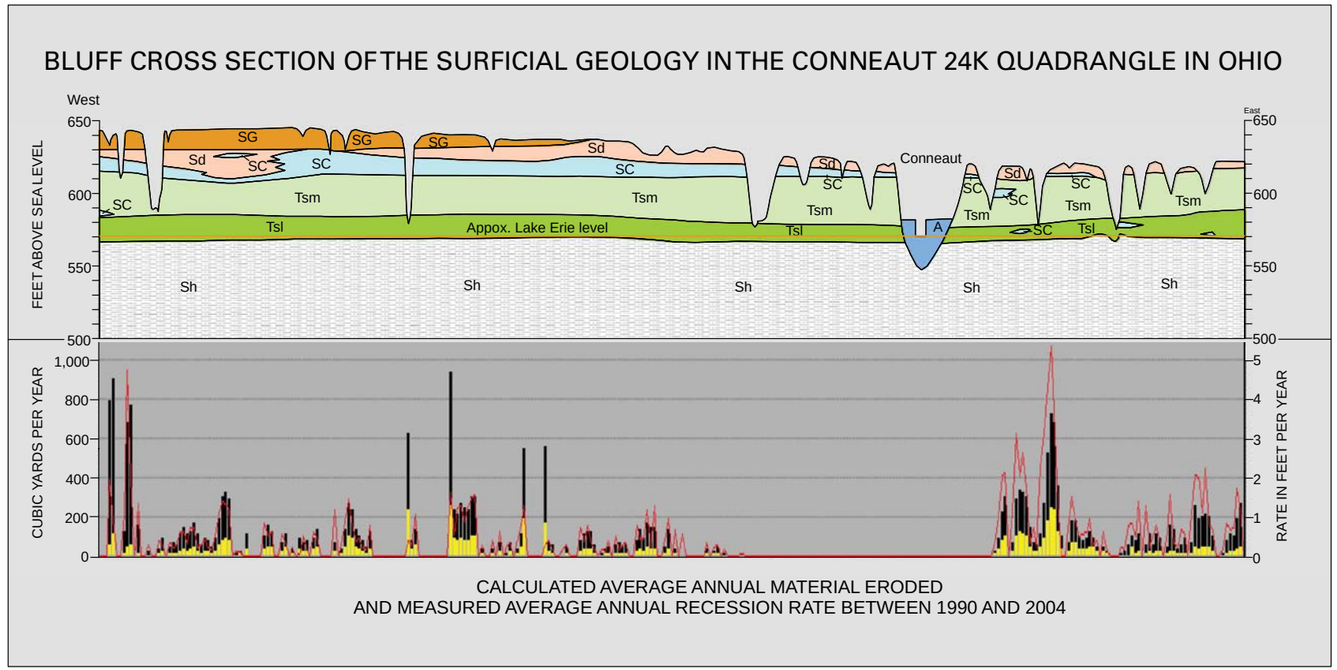
Projection of data is Ohio coordinate system, north zone, North American Datum, 1983. Not to be used for navigation.

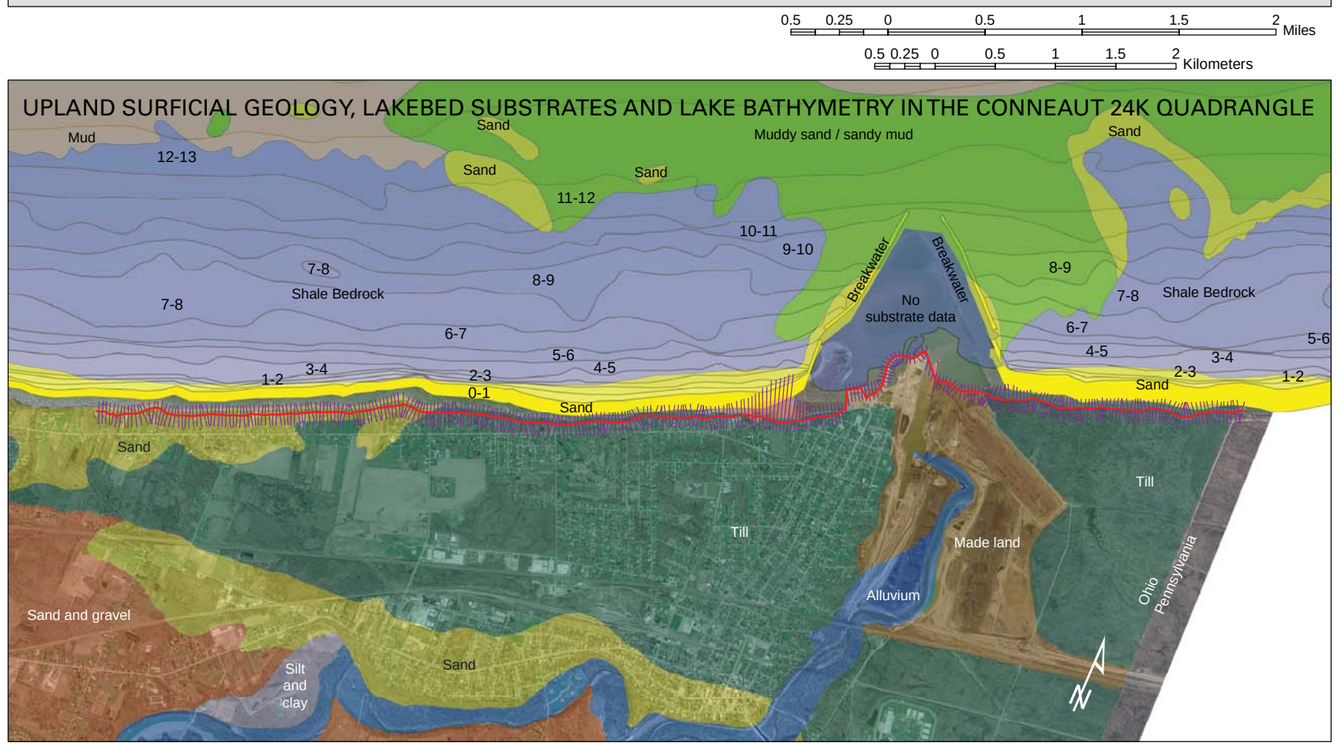
FIGURE A-9. NORTH KINGSVILLE QUADRANGLE

Bluffs are as high as 65 ft (20 m) in this quadrangle and the stratigraphy is quite complicated, with lenses of fine sands, silts, and clays interspersed throughout the melt-out facies of the Ashtabula Till. A sand-and-gravel unit occurs at the top of the bluff at the western and eastern ends of the quadrangle. Despite the height of the bluff, numerous stream channels have deeply cut through it down to lake level. Erosion rates are rapid here due to several factors including a lack (relative to other quadrangles) of constructed shore protection, incision by the aforementioned stream channels, and a meager supply of sand just offshore.

FIGURE A-10. CONNEAUT QUADRANGLE

A large harbor exists where Conneaut Creek meets Lake Erie. As is the case at other large harbors (Fairport and Ashtabula), sand is trapped here on the updrift (west) side of the harbor. As the substrate map shows, little of this sand passes the harbor to continue on eastward, thus starving the shore downdrift (east) of the harbor and increasing erosion rates there as well, for some distance into Pennsylvania.





Projection of data is Ohio coordinate system, north zone, North American Datum, 1983. Not to be used for navigation.