Journal of Coastal Research	2	1	17-23	Fort Lauderdale	Winter 1986

Lake Erie Shore Erosion: the Effect of Beach Width and Shore Protection Structures[1]

Charles H. Carter[a], Charles B, Monroe[b], and Donald E. Guy, Jr.[c]

[a]Department of Geology
University of Akron
Akron, Ohio 44325, USA

[b]Department of Geography
University of Akron
Akron, Ohio 44325, USA

[c]Ohio Geological Survey
Sandusky, Ohio 44870, USA

ABSTRACT

CARTER, C.H.; MONROE, C.B., and GUY, D.E., Jr., 1986. Lake Erie shore erosion: the effect of beach width and shore protection structures. *Journal of Coastal Research*, 2(1), 17-23. Fort Lauderdale, ISSN 0749-0208.

Erosion rates along the 286-km Ohio shore show an overall decrease from the early period (1876-1938) to the late (1938-1973) in spite of record-breaking high lake levels in the late period. Bivariate analyses show a consistent decrease in erosion rates as beach widths increase or as the number of shore protection structures increase for glaciolacustrine clay and till (the most common shore deposit). On the other hand, there is a less consistent decrease in rates for sand and shale. Multivariate analyses of the same variables show a more consistent overall decrease in erosion rates as both beach widths and shore protection structures increase. The decrease in erosion leads to an interesting scientific and social dilemma as the shore is the source of most of the beach sand.

ADDITIONAL INDEX WORDS: *Beach widths, Lake Erie, lake processes, shore erosion, shore protection structures.*

INTRODUCTION

Shore erosion is an international problem that is becoming increasingly acute because of human development of coastal areas (*e.g.* KUHN and SHEPARD, 1983; SHUISKY and SCHWARTZ, 1980; SUNAMURA, 1973; VALENTIN, 1954). Significant shore erosion problems exist on the Great Lakes of Canada and the United States (Environment Canada — Ontario Ministry of Natural Resources, 1975 and U.S. ARMY CORPS of ENGINEERS, 1973). For example, in 1970, 34% of the US shore of the Great Lakes and 38% of Lake Erie's Ohio shore were considered to have significant erosion problems (U.S. ARMY CORPS of ENGINEERS, 1973). To correct the problem, innumerable shore protection structures have been built along the coasts, the effects of which are often debatable. Furthermore, in spite of the relevance of the problem to geology and geologists, there are few published papers on the effects of beaches and shore protection structures on erosion rates along appreciable lengths of shore (DAVIDSON-ARNOTT and KEIZER, 1982; SUNAMURA and HORIKAWA, 1972; WOOD, 1978; ZABAWA, *et al.*, 1981). And, most importantly, we could not find any papers that specifically analyze the effect of beaches and/or shore protection structures on erosion rates along appreciable lengths of shore for long intervals of time. This leads to the purpose of this paper, a study of the effect of beach widths and shore protection structures on shore erosion along the 286-km Ohio shore of Lake Erie from 1876 to 1973 (Figure 1). A simultaneous analysis of beach widths and shore protection structures is necessary because in the coastal environment, they are closely associated with one another, and thus together can have a significant effect on shore erosion. This paper uses data from 3,125 evenly spaced points over two time periods to expand earlier research by the Ohio Geological Survey that showed in a general way the apparent effects of shore protection structures and/or beach widths on erosion rates (*e.g.* CARTER and GUY, 1983; CARTER *et al.*, 1981; BENSON, 1978). The Ohio shore of Lake Erie provides an excellent setting for this study because of the early

[1]*85010 received 15 April 1985; accepted in revision 6 June 1985.*

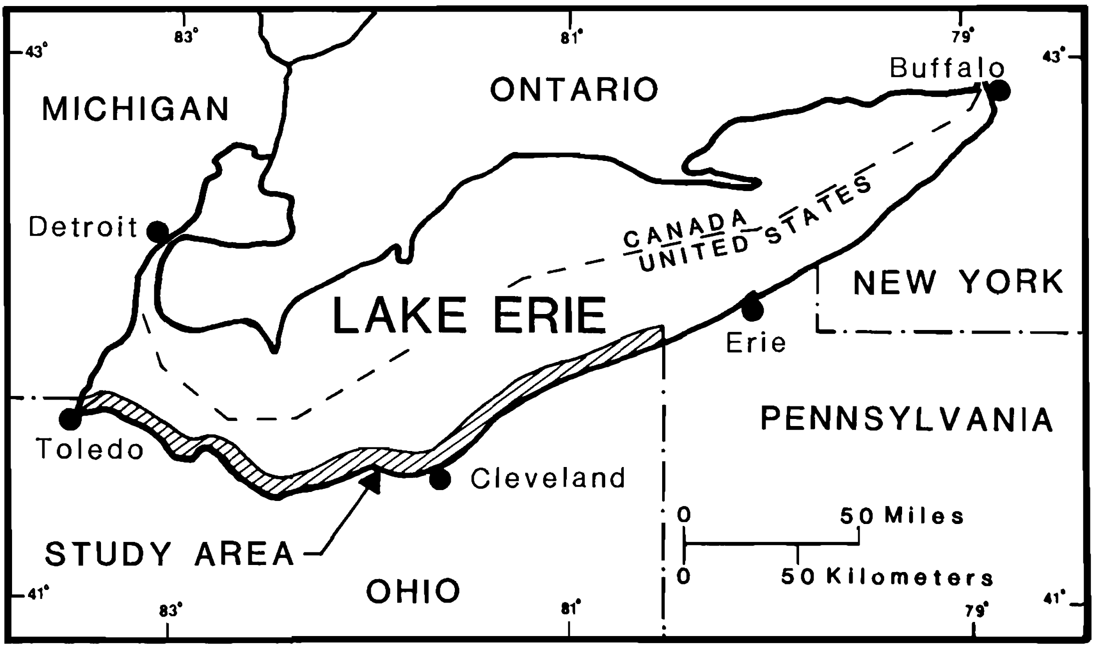

Figure 1. Lake Erie and the Ohio shore.

(1800's) development of the shore which included the construction of shore protection structures.

METHODS

The data set used in this study consists of estimates of the density of shore protection structures and measurements of subaerial beach widths and erosion rates made at 91.5 m lengths along the 286-km Ohio shore of Lake Erie (Figure 1). The data were taken from 1876-1877 lake charts at 1:10,000 and from 1937-1940 and 1973 vertical aerial photographs at 1:8,000 and 1:4,800 respectively. Erosion rates were determined by enlarging the smaller scale charts and photographs to the 1973 photograph scale, mapping the position of the recession (bluff) lines, and using the distance and period of time between the lines at a given point to determine the rate (CARTER and GUY, 1983). Rates were calculated for an early period (1876-77 to 1937-40) and a late period (1937-40 to 1973). Within the periods the rates vary in general with lake level fluctuations; accelerated erosion is usually associated with high lake level periods and decelerated erosion with low lake level periods (CARTER and GUY, 1981).

The density of shore protection structures was mapped from the charts and photographs for 1876-77, 1937-40, and 1973. Low density indicates that less than ⅓ of a stretch was protected by structures, moderate density ⅓ to ⅔ of a stretch, and high density that greater than ⅔ of the stretch was protected by structures. The shore protection structures are largely of two types: groins and seawalls. Groins retard or trap the longshore transport of sand and thus contribute to increased beach widths adjacent to the structures, but they can also cause decreased beach widths and thus greater erosion along downdrift stretches. On the other hand, seawalls increase the resistance of the shore to wave attack, but by deflecting some wave energy downward can cause increased scour at the base of the structures that leads eventually to greater wave energy reaching the shore. Furthermore, and perhaps most importantly along the Great Lakes shores, the seawalls by armoring the shore reduce the supply of sand entering the system and lead to narrower beaches. The total number of shore protection structures has increased along the Ohio shore from about 60 in 1876-77 to about 1600 in 1937-40 and 3600 in 1973.

Beach widths were also obtained from the charts and photographs for 1876-77, 1937-40, and 1968. Photographs from 1968 were chosen over 1973 because the 1968 lake level was much closer to the long term mean lake level and the 1876-77 levels, and is thus more representative of long term beach width than the 1973 level, which was about 0.8 m above the long term mean. For each period at each point along the shore, the beach widths at the beginning of the period and at the end of the period were averaged and then grouped into classes of 6 m width. Wide beaches, and associated nearshore bars and gentle nearshore slopes provide the best natural protection from wave attack. The bars and gentle slopes cause the waves to deform and break offshore thus dissipating wave energy; the remaining wave energy is then absorbed by the beach and not at the toe of the slope or bluff.

The data were analyzed by shore deposit types because the type of shore deposit has a major effect on erosion (YATSU, 1966; CARTER, 1976). Till fronts about 47% of the shore length, sand 22%, shale 21%, and glaciolacustrine clay and limestone/dolostone each 5%. Because of the narrow beaches that front the limestone/dolostone — 93% of the beaches are in the narrowest class — the limestone/dolostone observations are not included in the analysis.

LAKE PROCESSES

Lake level, for a given physical setting, is the most important erosion variable. This is because that for a given wave, the higher the lake, the closer the wave breaks to the shore, and thus the greater the shore erosion. On Lake Erie, the long term (changes over a few years or more) fluctuations appear most significant, and in a geologic sense can be quite pronounced. For example, in December 1934 the mean lake level was about 173.0 m above MSL, whereas in December 1972, after several up-and-down cycles, the mean lake level was about 174.5 m (LAKE SURVEY CENTER, 1973). The marked effect of lake level was demonstrated along the Lucas County, Lake Erie shore, when between 1957 and 1968 the mean lake level was 173.7 m and the mean erosion rate was 0.8 m, whereas between 1968 and 1973 the mean lake level was 174.2 m and the mean erosion rate was 2.9 m. Moreover, in spite of the much lower erosion rates, the 1957-1968 period had the largest and most frequent storms. For example, in the 1957-1968 period there was one storm with a setup of 1.5-1.8 m, no storms with setups of 1.2 to 1.5 m, and 6 storms with setups of 0.9-1.2 m whereas in the 1968-1973 period here were no storms with a wind setup of more than 1.2 n and only two storms with a setup of 0.9-1.2 m (BENSON, 1978).

Storm waves are the second most important erosion variable. These waves erode material at the base of the lakeshore deposits thus maintaining an unstable slope. The waves are produced by northeast winds generated by low-pressure systems that pass south of the lake. Because of the relatively long (about 300 km) fetch these winds produce the largest waves along the Ohio shore. Storm waves commonly have periods of 5 to 7 seconds and heights of 1 to 2 m in the breaker zone.

Shore erosion, however, is necessary to maintain the flux of sand in the beach and nearshore zones as the shore, unlike most coastal areas, is the principal source of the beach sand. This is due to the postglacial rise in lake level that has drowned most of the stream mouths; the stream gradients are just too low for the development of sufficient current strengths to transport much sand and gravel size sediment to the lake. Furthermore, what little coarse sediment reaches the lake is usually dredged from the stream mouths and deposited in a diked disposal area or else far offshore.

BEACH WIDTH AND EROSION RATE RELATIONSHIPS

The relationship between beach width and erosion rate is fairly consistent for each deposit for both periods (Figure 2). In the early period, clay shows the greatest decrease in erosion rate with increasing beach widths; till shows a decrease in erosion rate as well as the most consistent trend; and sand shows inconsistent changes in erosion rates. In the late period, clay again shows the greatest decrease in erosion rates with increasing beach widths; till shows a decrease similar to that of the early period; and sand shows a marked decrease in erosion rate as well as a fairly consistent trend in contrast to the early period.

STRUCTURE DENSITY AND EROSION RATE RELATIONSHIPS

The relationship between structure density and erosion rate is best defined in the late period when structures were much more common (Figure 3). In the early period, clay shows the greatest decrease in erosion rate with increasing structure density, and sand, till, and shale all have similar trends with an increase in erosion rate at a low structure density followed by a decrease in erosion rate at higher structure densities. In the late period, clay, till, and

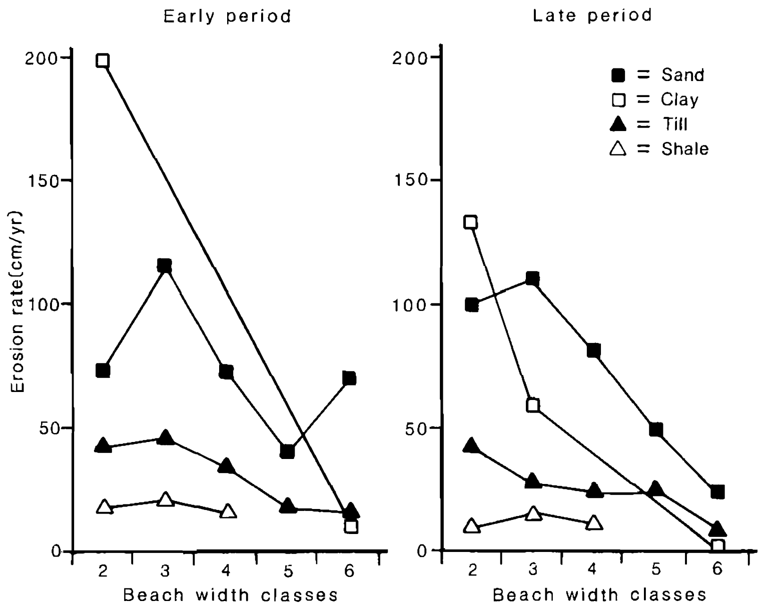

Figure 2. Erosion rates and beach widths. Beach width class 2 includes beaches from 0-6.0 m in width, class 3 from 6.1-12.1 m, class 4 from 12.2-18.2 m, class 5 from 18.3-24.3 m, and class 6 greater than 24.3 m.

shale show consistent decreases in erosion rates with increasing structure density, whereas the sand has one anomalous erosion rate. In summary, as beach width or structure density increases, the erosion rate usually decreases.

BEACH WIDTH, STRUCTURE DENSITY, AND EROSION RATE RELATIONSHIPS

Inconsistencies in the bivariate trends (Figures 2 and 3) probably result from the absence of the other significant variable, either beach width or structure density. To examine this hypothesis, both beach width and structure density were used to determine their combined effect on erosion rates. First, matrices of 25 possible beach width/structure density combinations were defined using the 5 structure density and 5 beach width classes for each deposit type, for both the early and late periods. Then, an average erosion rate was calculated for each combination that contained 10 or more observation points (Figure 4). Because of the uneven distribution of beach widths and structure densities, the number of cells filled in each matrix varied greatly, and ranged from 1 for the limestone/dolostone in the early period to 22 for the till in the late period.

In the early period, clay shows a consistent decrease in erosion rate as structure density increases, although the observations are limited to the narrowest beach width class; till and shale show inconsistent trends, yet overall decreases in erosion rates as structure density and beach width increase. Sand shows little, if any, trend as structure density and beach width increase. In the late period, clay again shows a consistent decrease in erosion rate as structure density increases; observations however are limited with one exception to the narrowest beach width class. Till shows a nearly consistent decrease in erosion rate with increases in beach width and structure density. Sand shows an inconsistent, yet overall decrease in erosion rate. Shale shows little trend at all.

In general, as beach width and structure density increase, erosion rates tend to decrease for the clay and till, and erosion rates fluctuate for the shale and sand. Overall, the trends are most apparent in the late period, particularly in the clay and till. The findings for the till are the most significant as this cohesive deposit fronts nearly half of the shore, and it is characterized by a much wider range of beach width and structure density combinations than the other deposits. The trends in the clay are the most

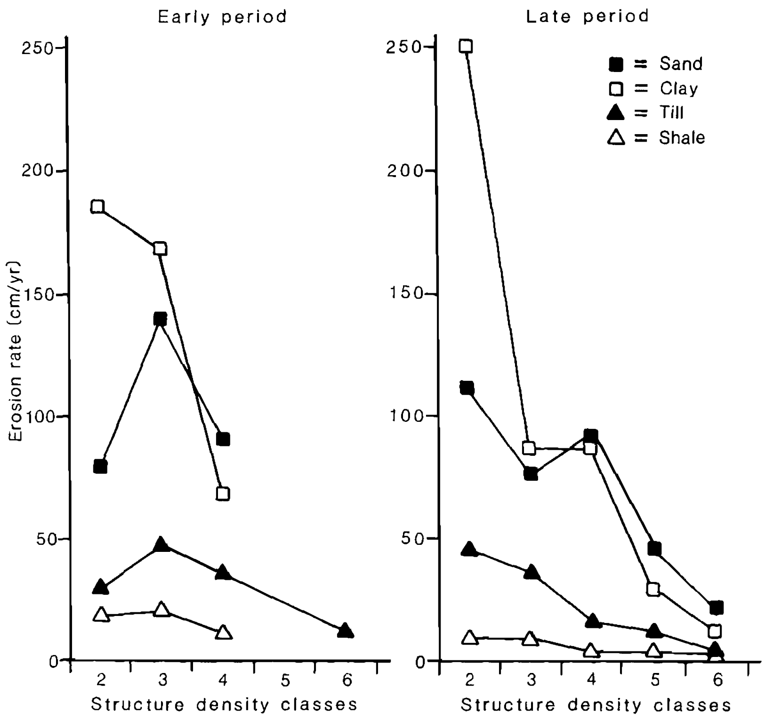

Figure 3. Erosion rates and shore protection structure densities. Structure densities were coded as: 1 = low (less than ⅓ of a stretch was protected by structures), 2 = moderate (⅓ to ⅔ of a stretch was protected by structures), and 3 = high (greater than ⅔ of a stretch was protected by structures). The individual classes represent the sum of the two structure density classes that bracket the period, thus a density of 6 represents high structural density at the beginning of the period as well as at the end of the period.

consistent; but because of the narrow beach widths that characterize this deposit, the trends reflect mostly differences in structure density. The anomalous trends in the sand probably reflect the unstable, noncohesive nature of this deposit, as it is the only deposit of the five that can build lakeward as well as erode landward. The inconsistent trends in the shale of increasing erosion rates with increasing beach widths we cannot explain.

Aside from the complex nature of coastal processes, the long time periods and lake level variations probably account for the inconsistent trends. The construction of shore protection structures greatly increased in the 1900's; thus much of the 1937-40 structure density represents shore protection for only the last 20 to 30 years of the 60-year period. In addition, the structures lose effectiveness when damaged by ice and waves. For example, shore protection structures along southwestern Lake Ontario are commonly damaged or destroyed in 10 to 20 years (DAVIDSON-ARNOTT and KEIZER, 1982) so even though they generally are repaired or replaced, there are intervening times when the shore is unprotected or poorly protected. Nonetheless, the more consistent trends between structure density and erosion rates in the late period appear to demonstrate the overall effectiveness of increased shore protection structures. In the late period, both the frequency and magnitude of high lake levels exceeded those of the early period. For example, lake level was greater in 1952, 1972, and 1973 than in any of the years in the early period, and the long-term mean was exceeded by 15 cm or more in 11 years in the early period and by 10 years in the much shorter late period (LAKE SURVEY CENTER, 1973). Because lake level, for a given physical setting, is the most important shore erosion variable, the abnormal levels in the late period undoubtedly have contributed to weaker trends in contrast to the early period between beach widths/structure densities and erosion rates.

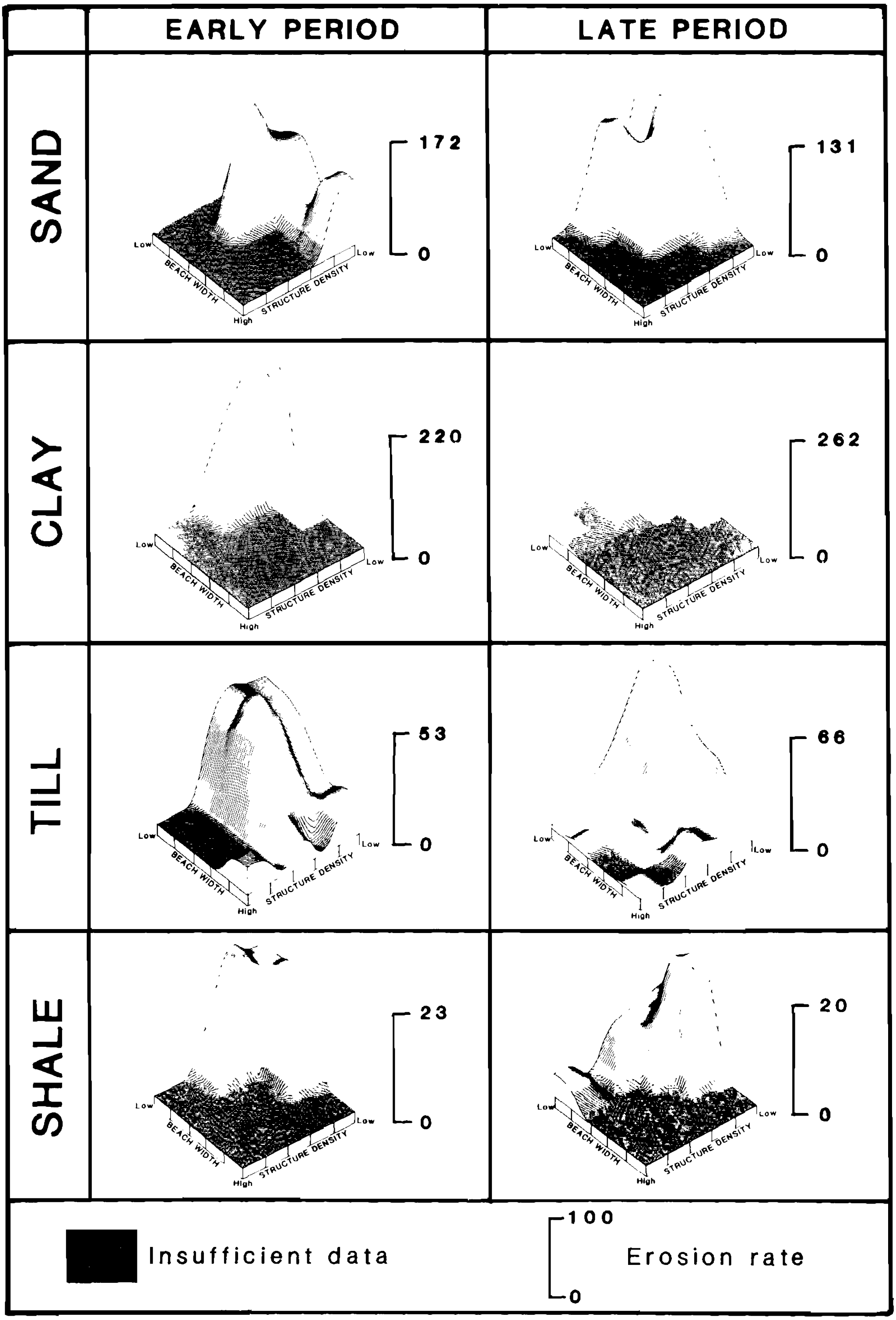
EARLY PERIOD
LATE PERIOD
SAND
CLAY
TILL
SHALE
172
131
220
262
53
66
23
20
0
Low
High
BEACH WIDTH
STRUCTURE DENSITY
Insufficient data
100
0
Erosion rate

Figure 4. (Facing page) Erosion rates, beach widths, and structure densities. The vertical dimension of each surface depicts the erosion rate represented by the vertical scale in cm/yr. Vertical divisions above beach width and structure density axes define class boundaries as explained in the caption for Figure 3. The gently dipping slope of the surfaces toward the bottom of the page (particularly in the late period) shows the inverse relationship between erosion rates and beach widths/shore protection structure densities. Insufficient data are combinations of beach width and structure density classes that have 9 or less cases.

CONCLUSIONS

Erosion rates (particularly along the till and glaciolacustrine clay bound shores) in general decrease as beach widths and/or shore protection structure density increase. The argument of a wide beach as the best natural form of shore protection has been widely accepted, and is consistent with our empirical results. On the other hand, the argument of shore protection structures as a beneficial form of shore protection has been widely debated. Our results, which show decreased erosion rates with increased shore protection, seem to indicate the usefulness of the structures as a form of shore protection. Moreover, this decrease in erosion has occurred in spite of an extremely nonuniform approach to the construction of shore protection structure along the Lake Erie shore. However, structures have not led to more uniform erosion rates, and thus the shape of the shore is becoming more irregular as the unprotected stretches are eroding more rapidly than the protected ones. Because the shore is the source of most of the beach sand, increased protection will lead to narrower beaches and thus to an increase in the amount of wave energy reaching the shore. This may necessitate larger, more massive structures, and perhaps imaginative coastal management solutions if erosion is to be held in check and the shore is to be fronted with beaches.

ACKNOWLEDGEMENTS

The authors thank H.R. Collins, State Geologist, for releasing the Ohio Survey data used in this paper. We acknowledge Beth Vesley for help with the erosion rate measurements, Carl Hopfinger and Dale Liebenthal for help with the beach width measurements, and Gary Isbell for help in putting the data on computer tape. Helpful reviews were made by Jim Harrell, Dag Nummedal, Maury Schwartz, and John Szabo.

LITERATURE CITED

BENSON, D.J., 1978. Lake Erie shore erosion and flooding, Lucas County, Ohio. *Ohio Geological Survey Report 107*, 99p.

CARTER, C.H., 1976. Recession rates of rock, till, and glaciolacustrine clay along the U.S. shore of Lake Erie. Abstract. *North-Central Section Geological Society America Meeting*, Kalamazoo, Michigan, p. 470.

CARTER, C.H.; BENSON, D.J., and GUY, D.E., Jr., 1981. Shore protection structures: effects on recession rates and beaches from the 1870's to the 1970's along the Ohio shore of Lake Erie. *Environmental Geology*, 3, 353-362.

CARTER, C.H. and GUY, D.E., Jr., 1981. Erosion rates in the wave erosion zone along the Ohio shore of Lake Erie. Abstract. *Geological Society America Annual Meeting*, Cincinnati, p. 423.

CARTER, C.H. and GUY, D.E., Jr., 1983. Lake Erie shore erosion, Ashtabula County, Ohio: setting, processes, and recession rates from 1876 to 1973. *Ohio Geological Survey Report 122*, 107p.

DAVIDSON-ARNOTT, R.G.D. and KEIZER, H.I., 1982. Shore protection in the town of Stoney Creek, southwest Lake Ontario, 1934-1979: historical changes and durability of structures. *Journal Great Lakes Research*, 8(4), 635-647.

ENVIRONMENT CANADA — Ontario Ministry of Natural Resources, 1975. Canada/Ontario Great Lakes Shore Damage Survey. *Technical Report, Environment Canada — Ontario Ministry of Natural Resources*, 97p.

KUHN, G.G. and SHEPARD, F.P., 1983. Beach processes and sea cliff erosion in San Diego County, California. *In:* P.D. Komar (ed.), *CRC Handbook of Coastal Processes and Erosion.* Boca Raton, Florida: CRC Press, 267-284.

LAKE SURVEY CENTER, 1973. Monthly bulletin of lake levels. *U.S. Department of Commerce, NOAA — National Ocean Survey*, one sheet.

SHUISKY, Y.D. and SCHWARTZ, M.L., 1980. Influence of beaches on development of coastal erosion slopes in the northwestern part of the Black Sea. *Shore and Beach*, 48(4), 30-34.

SUNAMURA, T., 1973. Coastal cliff erosion due to waves: field investigations and laboratory experiments. *Journal Faculty of Engineering*, University of Tokyo (B), 31(1), 86p.

SUNAMURA, T. and HORIKAWA, K., 1972. A study using aerial photographs of the effect of protective structures on coastal cliff erosion. *Coastal Engineering in Japan*, 15, 105-111.

U.S. ARMY CORPS OF ENGINEERS (North Central Division), 1973. National shoreline study. Great Lakes region inventory report. *House Document 93-121*, 221p.

VALENTIN, W., 1971. Land loss at Holderness. *In: J.A. Steers (ed.), Applied Coastal Geomorphology.* Cambridge, Massachusetts: M.I.T. Press, 116-137.

WOOD, A., 1978. Coast erosion at Aberystwyth; the geological and human factors involved.*Geological Journal*, 13, 61-72.

YATSU, E., 1966. *Rock Control in Geomorphology.* Sozosha, Toyko, 135p.

ZABAWA, C.F.; KERHIN, R.T., and BAYLEY, S., 1981. Effects of erosion control structures along a portion of the northern Chesapeake Bay shoreline. *Environmental Geology*, 3(4), 201-211.