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Beach Profiles and the Seaward Limit of Disturbance
Along the Ohio Lake Erie Shoreline

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Abstract

Beach profile measurements extending from the top of the bluff to greater than 5 m water depths were made along the Ohio Lake Erie shoreline in the fall of 2002 and spring of 2003. Nine shore-normal transects, from Wildwood State Park to Fairport Harbor (a 30 km reach to the east of Cleveland), were sampled with traditional differential GPS (DGPS) survey methods. Bluff and beach profiles were done with GPS antenna attached to walking and wading individuals, and on manually pushed vehicles. Submarine bathymetric surveys were conducted with a personal watercraft (PWC) equipped with a DGPS receiver, onboard navigation system, and dual-transducer 192 KHz frequency sonic altimeter. These data were compared with historical surveys conducted by the Army Corps of Engineers in 1876 and 1948, and by the Ohio Department of Natural Resources (ODNR) Division of Geological Survey in 1970 and 1994. All elevations were transformed to the International Great Lakes low-water Datum (IGLD 1985) for inter-comparison. The data show continuous bluff retreat in most locations, even during periods of low lake levels that occurred most recently in the past decade. The bathymetric surveys show a multiple barred profile, with bar-trough relief of up to 2 meters and cross-shore distances between sand bars ranging from 100-400 m. Comparisons spanning the 125 year period show that the sand bars at particular alongshore locations appear to retain their configuration and offshore position, suggesting a nearly stationary profile configuration. In contrast, the alongshore variation in profile configuration is, in comparison, rather large. The strong spatial but weak temporal variability in sand bar positions indicates that perhaps a strong geologic control of the large-scale sedimentary features is present. Although the strong alongshore variability in observed cliff and submarine profiles, the alongshore averaged sediment volume's show clear trends in the behavior of the above and below low-water datum sediment volume's. The data show that there has been nearly continuous cliff retreat since 1876. This trend has continued through the past decade despite rapidly declining water levels in the mid to late 1990's. In contrast, the alongshore-averaged submarine profiles show an inverse relationship to the gross water level changes, with increase sediment under declining water levels, and decreased sediment volume under rising water levels.

ACKOWLEDEMENTS

The following results were obtained by the principal investigator in collaboration with Mr. Jason Magalen, and undergraduate honors student at Ohio State University, and Mr. Don Guy, Jr., of the Ohio Department of Natural Resources (ODNR). Results from this work constituted Mr. Magalen's Honor's thesis (attached with this report), and were presented at the American Geophysical Union's Ocean Sciences meeting held in Portland, OR, in January of 2004 (Magalen, *et al.*, 2004). A manuscript is presently being drafted for submittal to the Journal of Great Lakes Research to be submitted by the end of this summer. All historical data extraction and datum adjustments were made by Don Guy, as well as identification, location, and coordinates for the historical range points used to define the transect lines. The waverunner survey system (CBASS) was developed under funding from the Office of Naval Research.

INTRODUCTION

The study area is located just to the east of Cleveland from Wildwood State Park in Euclid, OH, to Headlands Beach State Park abutting the west jetty at Fairport Harbor, an approximately 30 km stretch of coastline (Figure 1). According to historical accounts, this region has undergone significant change over the past century. Records indicate that the beach along the south-eastern shore was used as a road in the 1800's (Stout, 1993). Over the years the once vast sandy beaches have eroded back into just a few areas with significant sediment (such as at Headlands State Park). Primary cause for the considerable shoreline change is often attributed to the combination of the geological makeup of the beach and cliff material composed primarily of argillaceous clay-like shale (that is much more susceptible to erosion than, for example, limestone or dolomite found elsewhere in Lake Erie), and the meteorological conditions that cause wave attack and mean lake level variations (Carter and Guy, 1983).

The axial orientation of the lake is directed from the southwest to the northeast, and aligned with the dominant direction of local weather patterns. Data from NOAA National Data Center Buoy 45005, located just northwest of Cleveland, OH, indicate that although the dominant direction of the wind and wave propagation is along the long axis of the lake, significant wind and wave events occur in all directions. The apparent directional uniformity in storm events has led to speculation that the dominant cause for the dramatic beach change is associated with lake level fluctuations. As there are no tides in Lake Erie, lake levels fluctuate on time scales associated with weather patterns and climate changes that fluctuate on both short (order days-to-weeks) and longer (order annual-to-decadal) time scales. Lake levels are also influenced by human impacts associated with urban utilization and agricultural needs.

Surprisingly, despite the long records of water level changes and historical surveys, not quantitative comparison between shoreline and bluff erosion with water levels fluctuations has been done. The purpose of this work, is to examine the changes beach profile from the cliff top to 5-10 m water depths, and compare them with concommittent water level changes over the past 125 years.

FIELD METHODS AND HISTORICAL DATA

Historical surveys have been conducted along this stretch of coast periodically since 1876 by the Army Corps of Engineers (in 1876 and 1948), by ODNR (in 1970 and 1994) and by the Ohio State University (in 2002 and 2003; work supported by the Lake Erie Protection Fund). The surveys was conducted be each group were along the same survey transects determined by survey benchmarks established in the mid 1800's. The benchmarks consisted of front and rear range pins. In some cases the location of the pins can not be found, and in others the front pin has been lost owing to the cliff retreat shoreward of the most seaward (front) pin. The latitude and longitude coordinates of the pin marks were surveyed in using modern GPS survey equipment. Horizontal distances along the transect lines were measured relative to the rear range pin location for all surveys. In cases where only the rear range pin exists, then direction of the survey was assumed to be normal to the shoreline.

A total of 11 survey lines were examined. Of those, two either did not contain complete historical surveys or the range pin locations were in doubt, leaving a total of 9 that are reported in this work. The location of the specific transects surveyed are shown in Figure 2, and labeled with their historical identification numbers.

The methods used in the surveys have varied over the years as improvements to survey technologies has occurred. Early, pre 1905 surveys were done with spooled lines leading to boats, emery boards, and lead drop-lines. These methods evolved into transits with wading profiles and fathometers in the 1970 and 1994 surveys. Finally, the recent surveys conducted by our team were done with GPS-based systems and sonic altimeters (describe in more detail later). Despite the variety of survey methods, in all cases, the surveys were related to the local measured water level at the time of the survey. From the well-established Lake Erie water level time series, the survey elevations can thus be placed at the same datum. All historical and modern surveys presented herein were referenced to IGLD 1985 (see Figure 3) and plotted relative to the known benchmark locations.

It should be noted that the expected accuracy of the measurements is not known for the early surveys. In order to ensure that the measurements from different time periods are comparable, the elevations and positions of the rear range pins were compared. We found that in general the historical surveys agreed to within about 1-2 m horizontally with our GPS surveys, and were typically within about 0.25-0.50 m vertically. Considering the significant changes in survey methods over the past 125 years, we were satisfied with these results. Changes in elevations or horizontal shifting by twice those amounts do not alter the results presented herein.

Historical water levels have been recorded (accurately) since the mid 1800's, and are shown relative to mean sea level in Figure 3. Also shown on the plot are the times when the surveys took place. Although lacking any tidal fluctuations, water levels in Lake Erie fluctuate monthly and on a slower multi-year to multi-decadal time scale. Recently in the late 1990's, Lake Erie water levels were at its lowest in about 4 decades. During this period, concern over beach erosion had significantly decreased from the previous 2 decades when relatively high water levels were attributed to severe beach erosion. However, as will be shown later, cliff retreat has not stopped, and appears to have continued since 1876 in a nearly linear fashion up through this past decade.

Our recent survey methods incorporated advancements in GPS technology. The cliffs and adjacent beaches were surveyed using GPS antenna attached to people wading and walking. These methods are accurate to about +/- 10-20 cm depending on beach and cliff material such as rocks and boulders. Submarine profiles were conducted with the Coastal Bathymetry Survey System (CBASS), a personal watercraft (Yamaha Waverunner GP1200) equipped with GPS antennae and receiver, dual-transducer 192 khz sonic altimeter, custom navigation system, and onboard PC computer (Figure 4). This unit allows us to make rapid and accurate (better than 10 cm) surveys of the nearshore from very near the shoreline out to 20+ m water depths.

RESULTS

Example surveys from the bluff edge to greater than 10 m water depths are shown in Figure 5 for two profile lines, XI-16 and IX-4, separated about 20 km alongshore. The surveys clearly define the cliff edge, beach foreshore, and any submarine features (such as sand bars) that exist. The profiles from the two locations show marked differences, with significantly more submarine sediment at the IX-4 (more eastern) location than at XI-16. This is perhaps not surprising since the general trend of the alongshore sediment drift is from west to east along that part of the Lake Erie shoreline, evidenced by the large accumulation of sand (making up Headlands Beach) that has built up to the west of the Fairport Harbor jetty since its construction in the early 1900's (Carter, 1977). The profiles also show multiple sand bars with up to 2 m of vertical crest-trough relief, fairly large features by even typical ocean beach standards. In the analysis that follows, we will separate the spatial and temporal changes that occur to the cliff and those that occur to the submarine beach profile, and examine their relationship to water level changes.

All the surveys for profile XI-14 are shown Figure 6. The upper panel shows 3 km of cross-shore profile, whereas the lower panel shows the cliff change and the nearshore profile shallower than 5 m water depths. The surveys show significant cliff retreat since

1876 continuing through the past decade. Submarine profile changes are less dramatic and seaward of about 5 m water depths have not changed in the past 10 years.

All of the surveys are shown in Figure 7. These plots are ordered sequentially as you move from east to west, down the left column first, then the right hand column. Only shown are the close-up views of the cliff areas. The most notable feature is the significant alongshore variability in profile behavior. The cliff retreat (except at the most western location, IX-1, where there is no cliff) is highly variable both temporally at a given transect, but also spatially along the coast.

In order to quantify the observed high alongshore variability in profile change, we averaged the sediment volume alongshore both above and below the low water datum. Figure 8 shows a schematic of our methods for computing the average volume above and below the datum. We summed the integrated volumes, normalized by the distance along the shoreline, and then plotted the alongshore averaged volume densities and compared them to the gross changes in the mean water level (Figure 9). What we found was that despite the highly variable alongshore profile characteristics and highly variable water level changes over the past 125 years, the retreat of the cliff material has remained nearly constant (upper panel, Figure 9), suggesting that the retreat of the cliffs is not tied to water level fluctuations, and thus wave activity at the base of the cliff.

We also found that the alongshore averaged submarine sediment volume varied inversely with gross water level changes, with increased sediment during lower stands of the lake, and higher sediment volume during periods of lower water levels. The nature and implication of this result is not known, and the subject of ongoing research.

Although this work is not explicitly shown in this report it is worth noting that, surprisingly, we found that the sand bars tended to occur in about the same locations and to retain nearly the same form over the 125 years of survey data. Considering the dynamic nature of typical sand bars found in most natural beach settings, we are rather surprised by this result, and at the onset of the study did not expect the historical profiles to necessarily look anything like the present day configurations. The strong temporal and weak spatial variability in profile characteristics suggests that the profiles may have strong geologic control.

SUMMARY

Recent and historical beach profile surveys, extending from the cliff top to about 5 m water depths, at 9 locations along a 30 km stretch of coast to the east of Cleveland, OH, reveal continuous bluff retreat in most locations, even during periods of low lake levels that occurred most recently in the past decade. The bathymetric surveys show a multiple barred profile, with bar-trough relief of up to 2 meters and cross-shore distances between sand bars ranging from 100-400 m. Comparisons spanning the 125 year period show that the sand bars at particular alongshore locations appear to retain their configuration and offshore position, suggesting a nearly stationary profile configuration. In contrast, the alongshore variation in profile configuration is, in comparison, rather large. The strong spatial but weak temporal variability in sand bar positions indicates that perhaps a strong geologic control of the large-scale sedimentary features is present. Although the strong alongshore variability in observed cliff and submarine profiles, the alongshore averaged sediment volume's show clear trends in the behavior of the above and below low-water datum sediment volume's. The data show that there has been nearly continuous cliff retreat since 1876. This trend has continued through the past decade despite rapidly declining water levels in the mid to late 1990's. In contrast, the alongshore-averaged submarine profiles show an inverse relationship to the gross water level changes, with increase sediment under declining water levels, and decreased sediment volume under rising water levels

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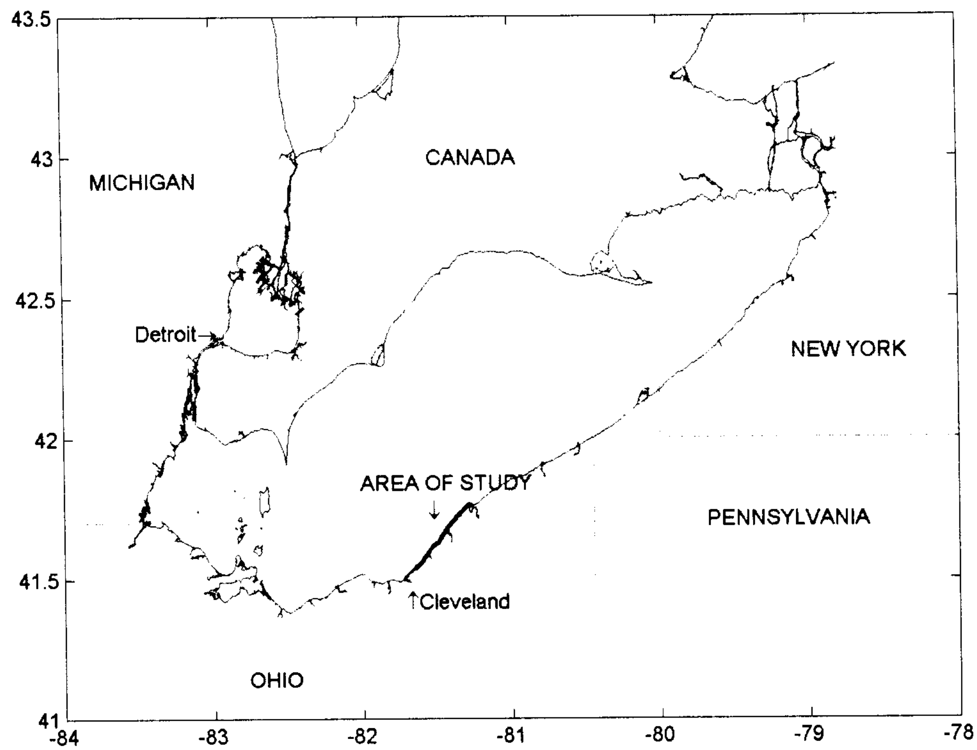

Figure 1. Map of the study area, located along a 30 km stretch of coast just to the east of Cleveland on the south-eastern Lake Erie shore.

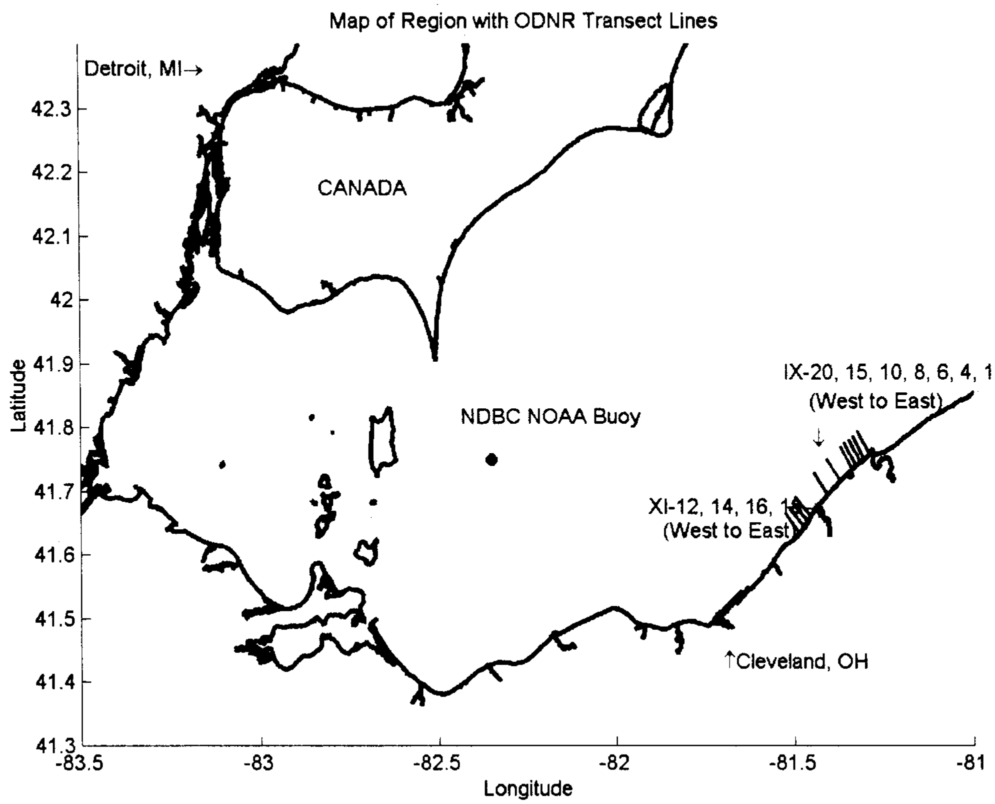

Figure 2. The location of the individual survey transect lines with identification numbers.

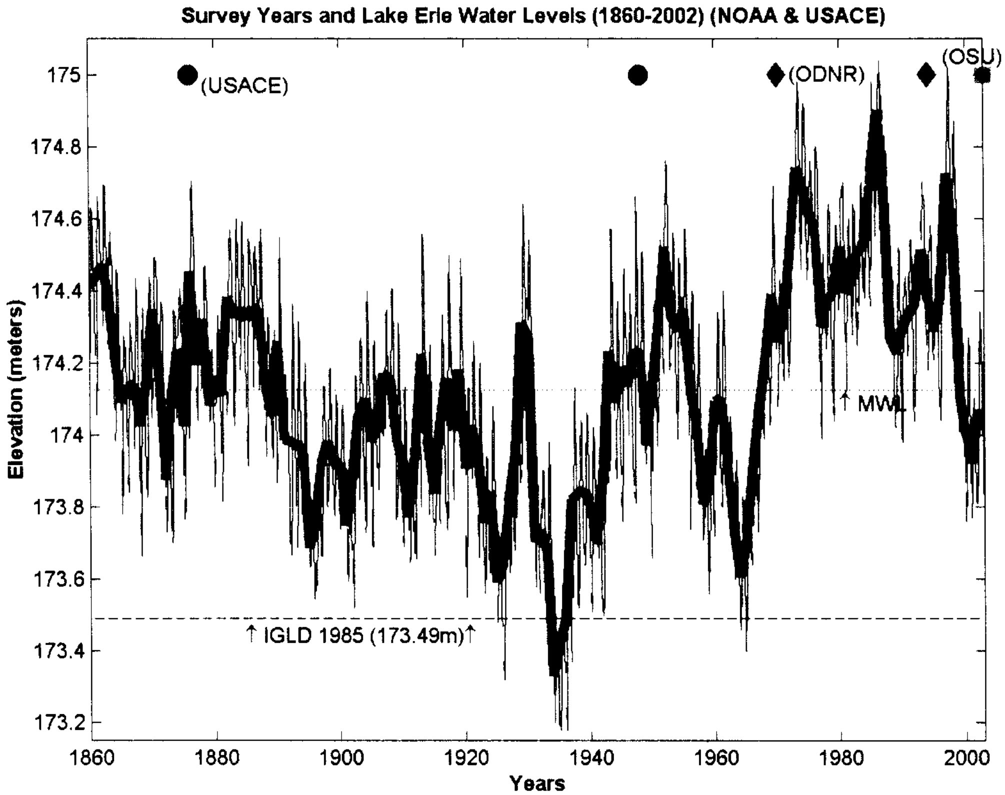

Figure 3. Time series of Lake Erie Water Levels from 1860 to 2002. The vertical axis is in meters above mean sea level. The IGLD 1985 datum is shown for reference. The monthly water level is shown in thin black line, while the annual is shown in thick red lines. The time of the surveys is shown by the symbols along the top edge of the plot. Also indicated are the agency that conducted the surveys.

Figure 4. Figure showing the CBASS survey system used to make the submarine profile measurements, and during survey on Lake Erie.

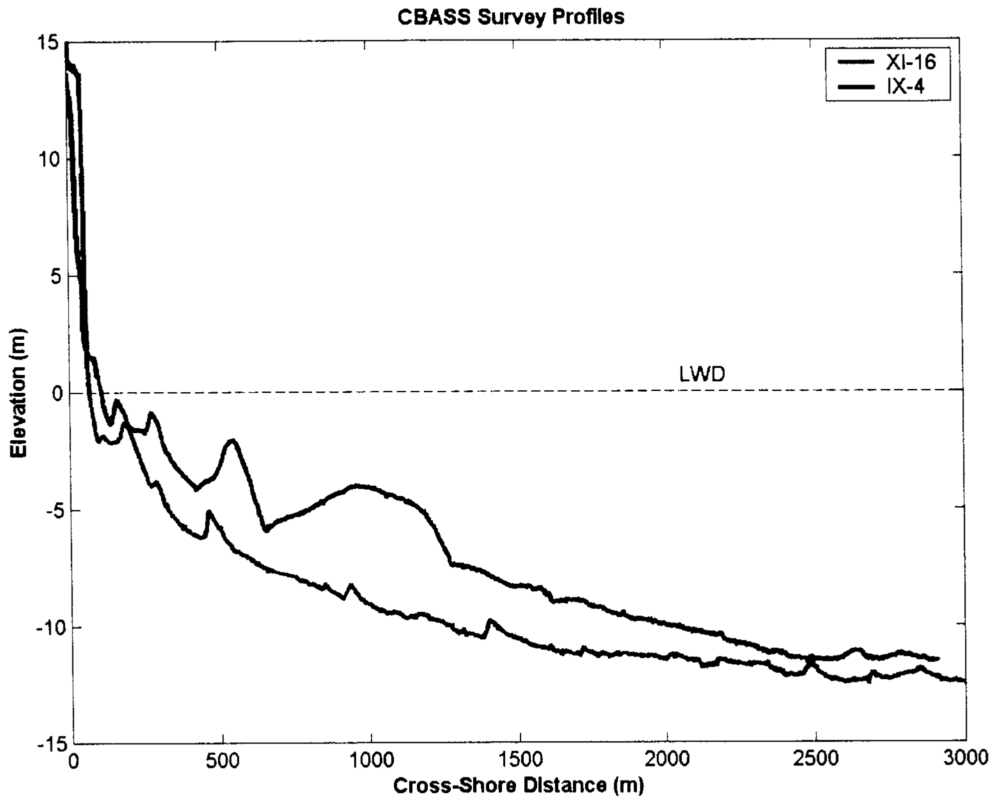

Figure 5. Example profiles extending from the bluff top to greater than 10 m water depths obtained with the CBASS survey system and walking/wading beach and bluff surveys. The two profile shown are from two transects separated by about 15 km alongshore. Clearly observed are significant alongshore variations in the volume of sediment and the number and relief of the submarine sand bars. The origin for each of the surveys is determined from the historical benchmarks at each line.

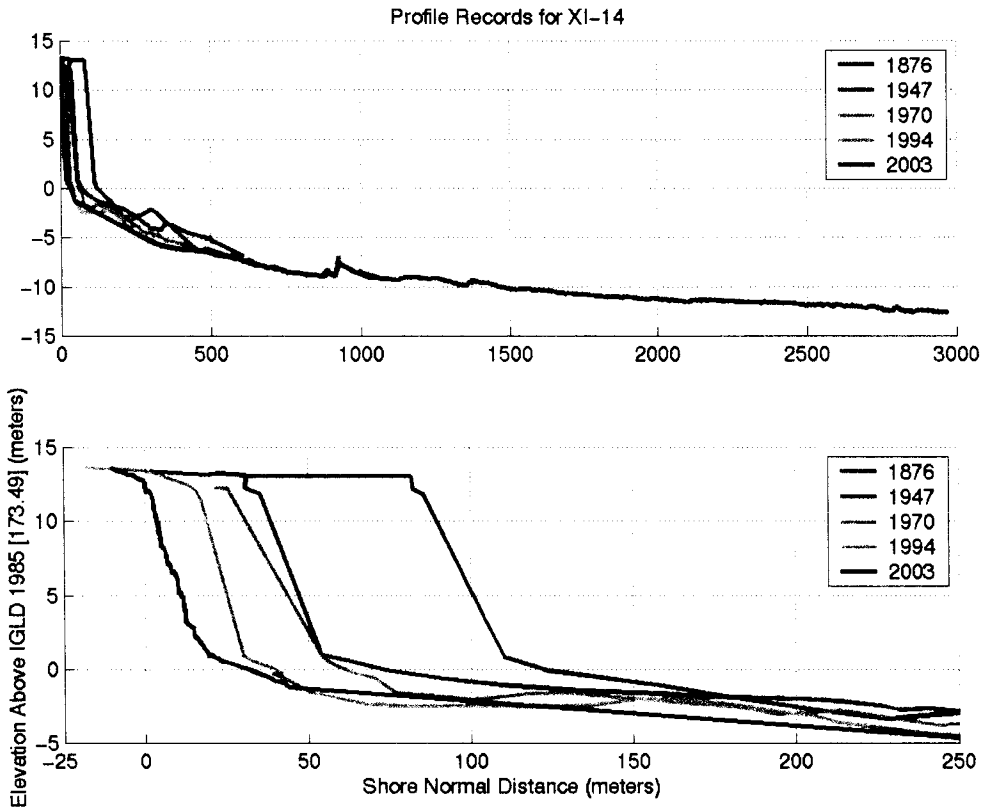

Figure 6. (upper panel) All surveys for profile line XI-14 dating back to 1876 and including our recent 2003 surveys, extending from the top of the bluff to well offshore (depth dependent on the survey method of each particular era). (lower panel) Expanded view of the nearshore and cliff areas showing the significant cliff retreat that has continued up to the present time.

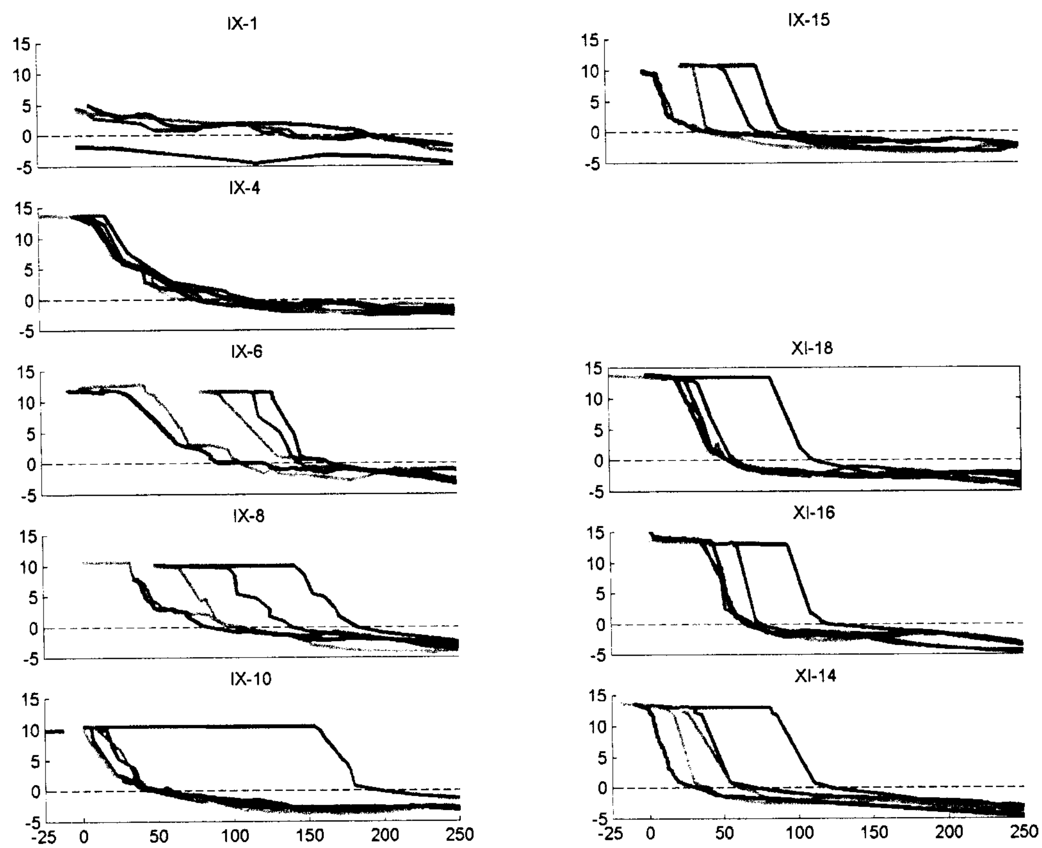

Figure 7. Expanded view of the nearshore and cliff areas for all 9 transects, ordered from west to east down first the left column, then the right column. The figures show significant cliff retreat, but with marked alongshore variability.

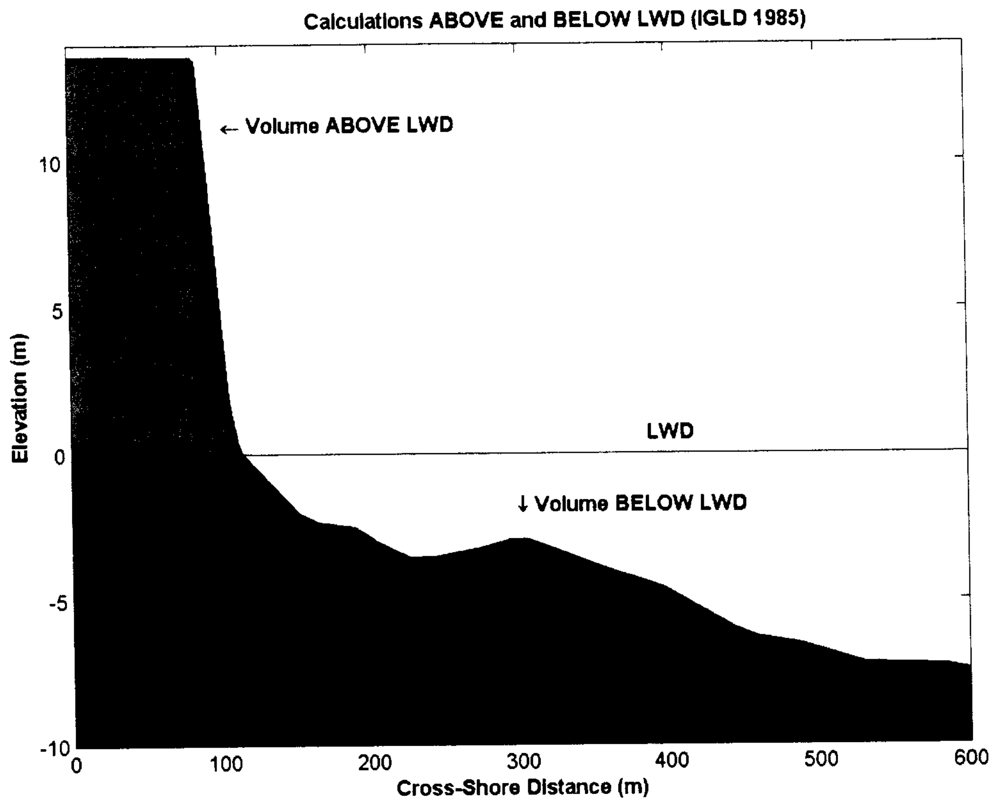

Figure 8. Schematic that describes how we compute volumes above and below the low-water datum (LWD; equal to IGLD 1985).

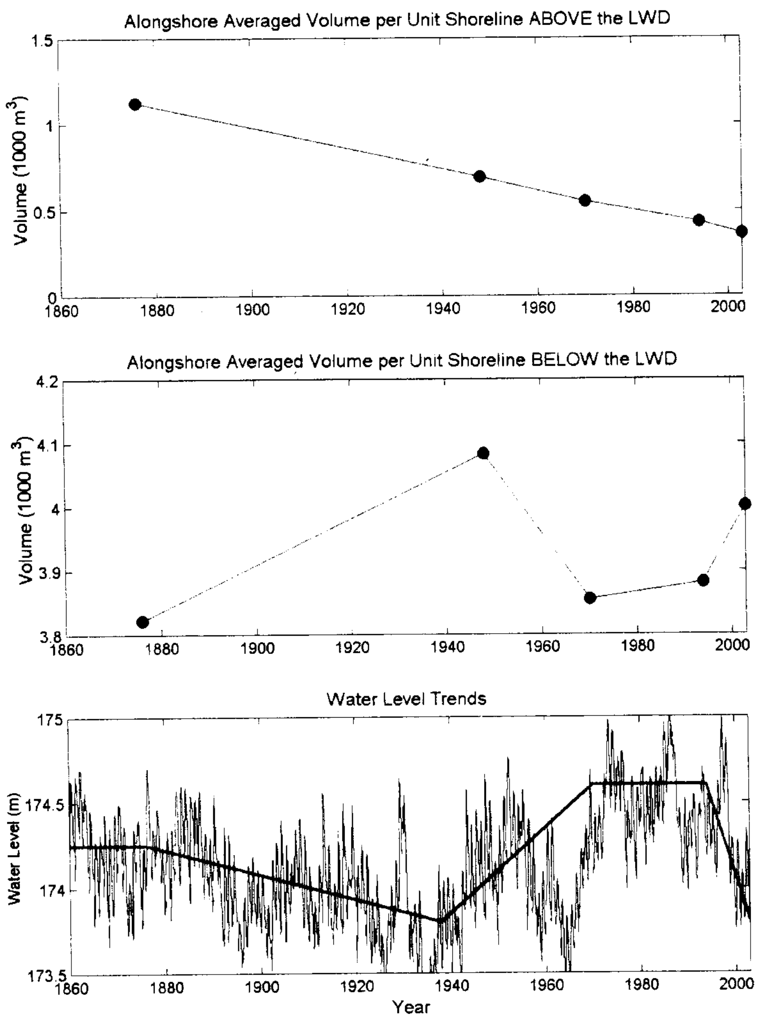

Figure 9. (upper panel) Alongshore averaged volume per unit shoreline above the low-water datum. The figure indicates a nearly constant gross retreat of cliff material continuing through the past decade despite declining water levels. (middle panel) Alongshore averaged volume per unit shoreline below the low-water datum. The figure indicates an inverse relationship between total sediment volume with gross water level changes. Surprisingly, when water levels are decreasing, the total submarine nearshore sediment volume increases; and when water levels are increasing the total sediment volume decreases. (lower panel). Time series of water levels. Gross trends between surveys are indicated by the thick red lines.

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