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WINTER COASTAL OBSERVATIONS, LAKE ERIE, OHIO SHORE

Peter W. Barnes[1], Michael McCormick[1], and Donald Guy[2]

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[1] USGS, Menlo Park, California
[2] Ohio Geological Survey, Sandusky, Ohio

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"...the annual recurrence of ice on its (Lake Erie) *waters, requires consideration as one of the most important items of research in the program of shore and beach studies of Lake Erie"* Wm. H. Gould, 1943.

Introduction

As part of a multi-year effort to better understand the magnitude of coastal erosion problems and the processes driving coastal erosion on the Ohio shore of Lake Erie, the U.S. Geological Survey and the Ohio State Geological Survey have undertaken a program to provide a regional assessment of the Ohio coast and nearshore. As part of that assessment the influence of lake ice formation and lake ice presence is being studied. This report summarizes the first year of winter observations and provides preliminary interpretations of the influence of ice on coastal processes drawing upon knowledge gained during a three year study of coastal ice processes which addressed the role of the Nearshore Ice Complex (NIC) in southern Lake Michigan (Reimnitz et al., 1991, Kempema and Reimnitz, 1991, Barnes et al. 1992, Folger et al., 1992, Hayden et al., 1992, Barnes et al. in press). The Nearshore Ice Complex is a term used to define the more stable ice that is fast to the coast and often grounded on the nearshore lake bed - consisting primarily of the icefoot at the shoreline and ice ridges grounded on offshore bars.

The primary objective of the present study is to characterize the sediment load of the coastal lake ice and to identify possible coastal sediment transport scenarios involving the ice canopy in Lake Erie. More specifically the study proposes to:

- Study the extent, character, density, and volume of coastal ice.
- Determine the amount of sediment present in the winter ice canopy along the shore, and in the drifting and ridged ice offshore.
- Determine mechanisms of sediment entrainment and transport and estimate transport volumes and pathways for ice rafted sediment.
- Compare the Lake Erie ice regime and its sediment content with the well studied but different, winter ice regime in Lake Michigan.

Field and Laboratory Methods

The following section describes the field and laboratory methods used to obtain the data reported in the field notes, text, and tables that follow.

Profile observations and data

We used an electronic distance meter (EDM), which uses infra-red ranging to provide range, azimuth, and elevation information, to measure bathymetric and NIC profiles at Cedar Point, Heidelberg Beach and Geneva State Park (Fig. 1). These are established profile sites being monitored by the Ohio Geological Survey over a period of years. Profiles of the NIC at other sites were done using a thread and calibrated reel to provide distance, and a graduated stadia rod to determine ice thickness. In most cases, the outer edge of ice, which commonly stretched to the horizon, could only be estimated due to thin ice that prevented access for accurate measurements.

These data are used to calculate NIC volume, which when combined with sediment concentrations values (see below) are used to determine the sediment content of the NIC per kilometer of coast.

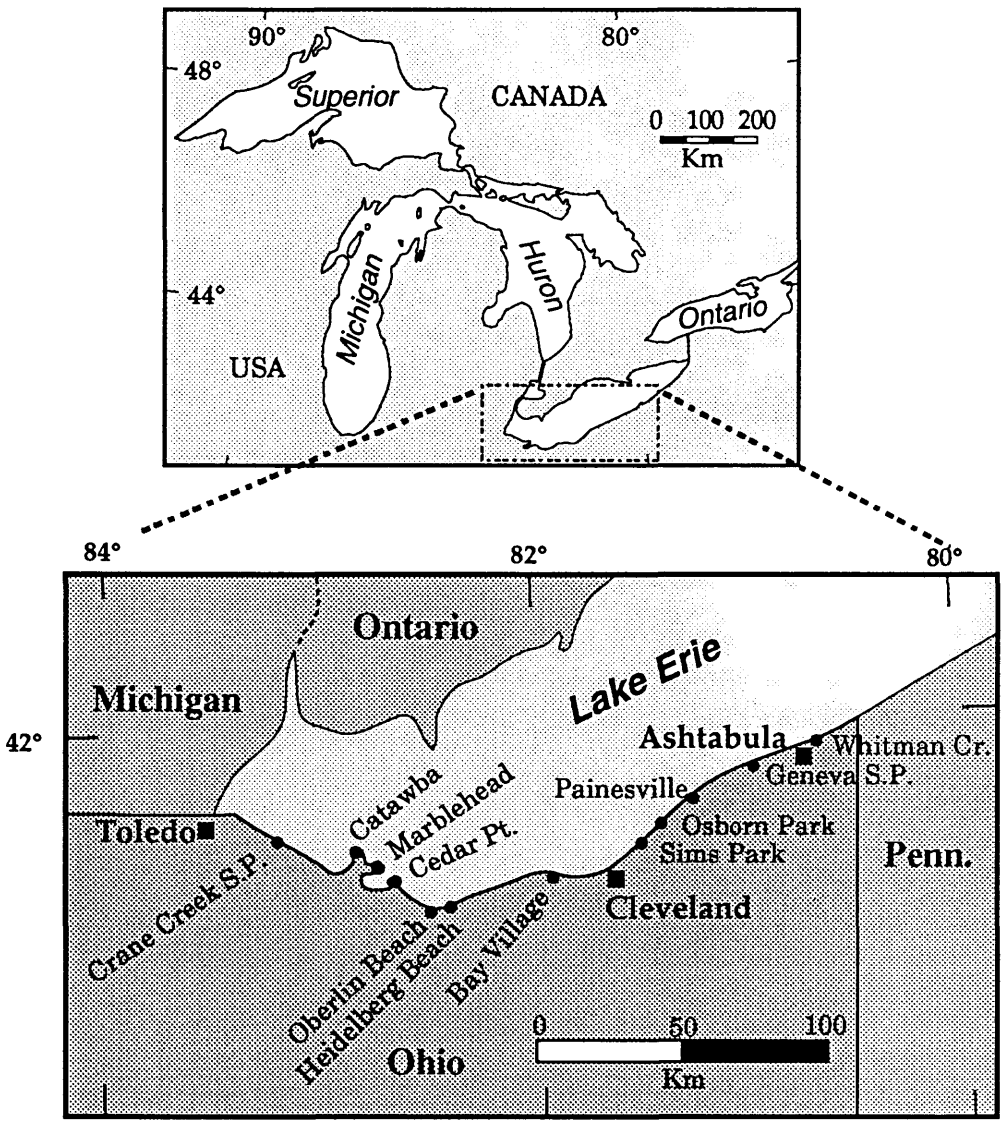

Figure 1 - Map of northern Ohio showing sample localities.

Sample analyses

All samples collected have a prefix of LE-93 (Lake Erie 1993) which precedes the sample number. This prefix may be dropped in this report.

Most samples were collected using an 11-cm-diameter ice corer which provided cores of a known volume. Ice density measurements were calculated by comparing ice volume to water volume after melting the sample. Sediments concentrated on the ice's surface by ablation were scraped off the tops of the cores before sampling. In rare cases, factors such as a lack of congelation freezing precluded obtaining solid cores and ice volumes could not be measured. In these cases, bulk

samples were scooped by hand; these samples can be recognized in Table 1 by their lack of density measurements. We collected cores from different sections of the NIC to provide a means of comparing the sediment concentration and grain size across these different sections.

In samples which contained little if any fine material, as determined by the lack of suspended material after settling several minutes, sediment was concentrated by melting the ice and decanting the melt water . It is probable that small amounts of fine material were lost during decanting. We dried the samples and weighed the sediment to the nearest 0.0001g. Samples which exhibited indications of fine material were filtered through pre-weighed 4μm polycarbonate filter membranes, dried and reweighed to calculate concentrations. Ice volume, melt water volume and sediment weight were used to calculate the sediment concentrations in grams/liter of melt water, and per liter of ice.

After drying, we selected several samples representing different environments on which to run comprehensive grain size analyses. These samples were wet-sieved through 2mm and 63μm sieves to separate mud, sand and gravel fractions. Organic materials (leafs, wood, and shells) were removed and weighed before continuing with the analyses. The reported weight percentages of organic content are probably slightly low as some organic material inevitably remained. We further separated the sediments into standard grain size intervals by dry sieving the gravel, and by using a Rapid Sediment Analyzer (RSA) to measure settling velocies of the sands. Details of RSA methods can be found in Gibbs (1974). The lack of significant amounts of fine material prevented further breakdown of the mud fraction. Hence, all fine material is confined to a single grain size category (< 63μm) in the statistical analyses for mean diameter, sorting and skewness following Folk and Ward (1957). We calculated percentage grain size compositions of other bulk samples by dry-sieving through 63μm and 2mm screens after hand-picking out the organic material. We visually determined the dominant grain size of material on the filters. The separated organic material was weighed and its percentage calculated using the entire sample.

RESULTS

Preliminary summary of observations and interpretations from February, 1993 field work along the Ohio coast of Lake Erie at the sites shown on Figure 1 are outlined below. Where appropriate, comparisons have been made to studies in southern Lake Michigan (see references);

- The Lake Erie nearshore ice complex (NIC) is poorly developed compared to that observed on Lake Michigan in that multiple shore-parallel ridges were rare.
- The Lake Erie NIC may have all of the features observed in the Lake Michigan NIC but the brash component on Lake Erie typically consists of large ice plates or sheets of ice formed during calm conditions
- There is much more offshore ice in Lake Erie than in Lake Michigan.
- The icefoot is small and very poorly developed on the southern coast of the western basin of Lake Erie, but is higher and better developed on the coast of the central basin.
- A good percentage of this offshore ice is smooth and clear (skim ice) or only slightly rough (shale ice or brash).
- Sheets of clear or skim ice up to 5cm thick are a common constituent of the coastal ice and are mixed with varying amounts of slush to form brash.
- No large (multi-meter) offshore ice ridges were observed in 7-day-old ice but ice ridges a meter or more high were common nearshore and less than a meter high offshore.

• Ice features in Lake Erie are similar to, but much smaller than ice features in the Arctic where ice commonly pushes on and shears against itself. This contrasts to the common wave-formed ice features observed in Lake Michigan.
• Wave formed ice features are confined to the icefoot and occasionally to a nearshore ice ridge.
• The ice in the western basin seemed less deformed except at constrictions and at promontories than the ice to the east.
• Pancake ice was observed as a well developed feature at only a few locations.
• Pressure/shear ridging in the offshore ice near Painesville seemed to contain sediment discoloration.

ACKNOWLEDGMENTS

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REFERENCES

Barnes, P.W., Kempema, E.W., Reimnitz, Erk, McCormick, Michael, Weber, W.S., and Hayden, E.C., 1993, Beach profile modification and sediment transport by ice: An overlooked process on Lake Michigan: Journal of Coastal Research, v. 9. p. 65-86.

Barnes, P.W., Kempema, E.W., Reimnitz, Erk, and McCormick, Michael, in press, The influence of ice on Lake Michigan Coastal Erosion: Journal of Great Lakes Research, v. 20, n. 1.

Folger, D.W. Colman, S.M., and Barnes, P.W., (eds.), 1992, 4th Annual southern Lake Michigan Workshop: U.S. Geological Survey Open-File Report 92-324, 116 p.

Folk, R. L. and Ward, W. C., 1957, Brazos River bar, a study in the significance of grain size parameters: Journal of Sedimentary Petrology, v. 27, p. 3-26.

Gibbs, R. J., 1974, A settling tube system for sand-size analysis: Journal of Sedimentary Petrology, v. 44, p. 583-588.

Hayden, Eran, Barnes, P.W., McCormick, Michael, and Reimnitz, Erk, 1992, The effect of ice on coastal erosion in Southern Lake Michigan: U.S. Geological Survey Open-File Report 92-374, a video.

Kempema, E.W., and Reimnitz, Erk, 1991, Nearshore sediment transport by slush/brash ice in southern Lake Michigan, *in* N.C. Kraus , K.J. Gingerich, and D.L. Kriebel (eds.), Coastal Sediments '91: American Society of Civil Engineers, NY, p. 212-219.

Reimnitz, E., Hayden, E., McCormick, M., and Barnes, P.W., 1991, Preliminary observations on coastal sediment loss through ice rafting in Lake Michigan: Journal of Coastal Research, v. 7, p. 653-664.

TABLE 1: Sample analysis summary of grain size data, organic composition, ice densities and sediment concentrations in melt water and ice.

Sample	Gravel (%)	Sand (%)	Mud (%)	Mean grain size (mm)	Sorting (ø)	Skew.	Organic (%)	Ice density	Sed. conc. (water) g/L	Sed. conc. (ice) g/L
LE-93-1T •	5.5	93.4	1.1				0	0.64	6.60	4.22
LE-93-1B x	1.0	98.7	0.3	0.47	0.87	-0.36	0	0.72	7.26	5.23
LE-93-2 •	0	97.3	2.7				0	0.88	0.17	0.15
LE-93-3 •	0	69.0	31.0				0	1.06	0.06	0.06
LE-93-4 •	0	85.3	14.7				0	0.74	0.12	0.09
LE-93-5 •	0	18.8	81.2				0	0.88	0.04	0.04
LE-93-6 •	0	0	100.0				0		0.0019	0.0017
LE-93-7 •	0	88.0	12.0				0	0.89	0.03	0.03
LE-93-8 x	17.0	83.0	0	0.76	1.04	-0.48	5.60	0.60	8.19	4.89
LE-93-9 o	None	Rare	Comm.					0.50	0.00	0.00
LE-93-10 x	0	87.5	12.5	0.26	1.32	0.22	0		0.20	
LE-93-11 x	0	92.6	7.4	0.17	1.14	0.71	5.37	0.63	1.20	0.76
LE-93-12 •	0	87.4	12.6				0	0.57	1.05	0.59
LE-93-13 •	1.8	97.7	0.5				1.29	0.47	3.88	1.82
LE-93-14 o	None	Rare	Comm.						0.40	
LE-93-15 •	0	50.4	49.6				0	0.80	0.02	0.02
LE-93-16 •	0	31.2	68.8				0	0.83	0.13	0.11
LE-93-17 •	0	29.8	70.2				0	0.71	0.21	0.15
LE-93-18 •	0	85.9	14.1				0	0.67	0.54	0.36
LE-93-19 x	0	88.7	11.3	0.21	0.92	0.11	0	0.53	0.87	0.46
LE-93-20 x	82.7	17.3 *	0	4.41	1.92	0.78	7.18	0.50	43.70	21.83
LE-93-21 •	0	90.5 *	9.5				28.99	0.72	0.50	0.36
LE-93-22 o	None	Rare	Comm.					0.75	0.02	0.01
LE-93-23 •	9.5	87.8	2.7				0	0.44	1.37	0.60
LE-93-24 •	0	89.7	10.3				0	0.67	0.76	0.50
LE-93-25 •	0	44.6	55.4				0	0.72	0.33	0.23
LE-93-26 o	None	None	Abund.					0.68	0.01	0.00
LE-93-27 •	0	50.1	49.9				0	0.64	1.54	0.98
LE-93-28 •	7.0	90.7 *	2.3				0	0.55	7.74	4.26
LE-93-29 •	0	98.5	1.5				0	0.47	1.56	0.73
LE-93-30 •	0	80.6	19.4				0	0.72	0.62	0.44
LE-93-31 •	0	68.5	31.5				0		0.12	
LE-93-32 •	0	63.0	37.0				24.23	0.47	0.95	0.45
LE-93-33 •	0	48.3	51.7				0	0.86	0.04	0.04
LE-93-34 •	0	62.8	37.2				0	0.67	0.01	0.01
LE-93-35 •	0	25.6	74.4				0	0.81	0.45	0.36
LE-93-36 x	11.7	88.3	0	0.6	0.94	-0.09	0	0.61	2.89	1.75
LE-93-37 x	0	100.0	0	0.36	0.44	-0.17	0	0.51	2.20	1.13
LE-93-38 •	0	84.4	15.6				0		0.20	

x - Complete grain size analysis using sieves and RSA.
• - Gravel/sand/mud analysis using 2mm and 63µm screen.
o - Visual estimation of filter membranes.
* - The sand component of these samples contained some fine shell debris, and thus the sand percentage is a little high.

Field Notes and Observations, February 1993

The following field notes and observations are reported in chronological order so that the sample numbers remain in chronological order. At each locale the field notes are presented followed by a short field description of the samples taken at that location. This is followed by a table where the sediment concentrations in the ice have been combined with profile data to estimate the sediment content (from Table 1) of a hypothetical 1 meter wide section of the NIC and offshore ice out to 200m distance from shore. Where profile data were collected using the EDM, profiles of the NIC and lake bed are included.

February 15, 1993

Cedar Point - 1100hrs
Lat. 41° 28.03' N, Long. 82° 39.82' W
Ohio State Geological Survey, Erie County range #50

A very narrow (10m) beach backed by a 2m high ridge protected by rock rubble (Figure 2A). The EDM was located on the southwestern edge of a concrete 'patio' atop a ridge. Ice extended nearly to the horizon where a thin dark band of water was visible. The inner 26.5m of ice was typical of what we saw in Michigan with an icefoot extending out 10-20m from shoreline and a nearshore ice ridge between 20-40m from shoreline (Figure 2B), but the NIC was not well developed. The icefoot and ice ridges were grounded in less than a meter of water and were 1-2m high. Lakeward the ice consisted of pressured and rafted ice sheets (skim ice) and areas of refrozen slush and brash. The ice ridges seemed to be composed of ridged slabs that were pushed on top of each other rather than built by wave overwash as observed in Lake Michigan. Offshore profile stopped at 276m by the hip chain where the water was 360cm deep. Along the outer portion of the transect (from 26-276m) there were two or three areas of 'pressure' ridging of ice slabs with 30-50cm ridges. Ice thickness was 20-30cm where poked with rod but up to 120cm thick in rafted slabs forming the ridges. The slab ice must come from offshore.

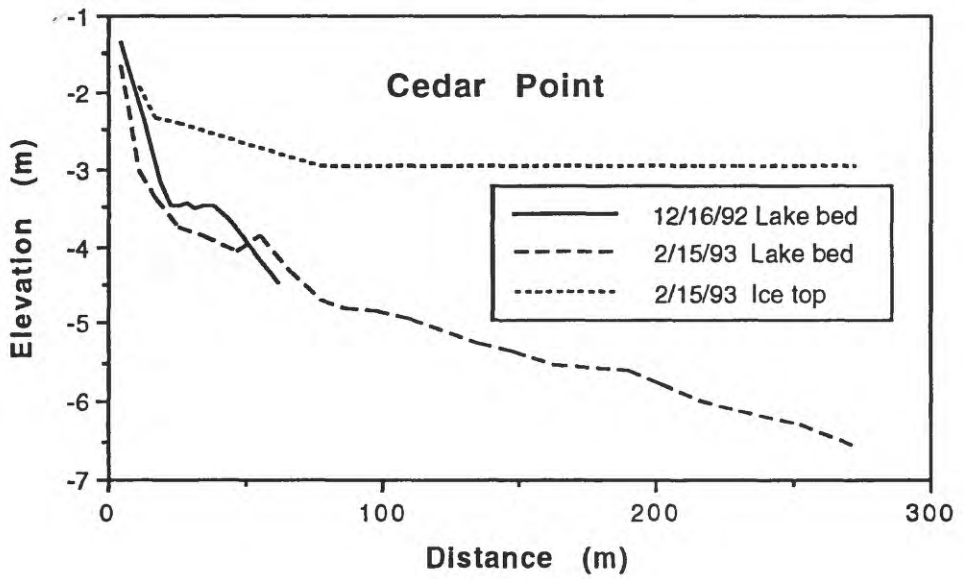
Samples

1-T 24x7cm ice core - top 24cm of icefoot, 12m from EDM.
1-B 26x7cm ice core - bottom (62-90cm) of same core.
2 35x7cm ice core from nearshore ice ridge, 17.4 m from EDM.
3 28x7cm ice core of outer edge of NIC ice, 26.5 m from EDM.
4 22x7cm ice core - Entire core of ice offshore of nearshore ridges. Smoother and harder than shoreward ice. Taken 2m lakeward of nearshore ridges.
5 30x7cm ice core taken about 100m offshore of icefoot.- Entire core of rough ice forming offshore ice ridges. Ridged slabs of skim ice about 7 cm thick, then a slushy layer with visible sediment.
6 Sample from 276m in 50cm high ice ridge of 1 to 10cm thick slabs of non-granular skim ice.

Cedar Point 2/15/93	Icefoot	Nearshore ice ridge	Offshore ice ridges	Offshore ice
Width x Thickness (m)	10 x 1.5	20 x 1.5	30 x 1.2	>200 x 0.25
Ice volume (m^3)	15	30.0	36.0	>50
Sed. concentration of ice (g/l)	4.73	0.11	0.018	0.09
Sediment content (kg/m/coast)	70.95	3.3	0.648	4.5
Total sed. content (kg/m/coast)	79.40			

Notes: Icefoot concentration averaged from 2 samples (1T & 1B).
Offshore ridges' concentration averaged from two samples (4 & 6).

NIC/Lake Bed Profile



A

B

Figure 2 - A) View of NIC at Cedar Point on February 15; **B)** Aerial view on February 19 showing NIC, offshore ice, and frozen lagoonal ice.

Heidelberg Beach - 1400hrs
Lat. 41° 23.33' N, Long. 82° 27.26' W
Indiana Street groin profile location
Narrow, 20m wide beach backed by steep slope to 10m height. Profile taken off groin at end of Indiana Street (Figure 3A). The icefoot, which averaged 5m wide, appeared to be composed of the remnants of ice volcanoes, judging from their conical nature and 'craters'. The sediment on these cones was coarser than sediment concentrated in the rest of the NIC, and had a lot of organic matter. The coarseness may result from the increased wave energy at the entrants to the craters. Samples were taken of the icefoot and of a nearshore ice ridge formed of rafted, shingled, clean-appearing slabs of thin ice about 30m offshore. From here inshore the ice was grounded. Five-cm thick ice lakeward of ridge forced a detour to get onto rafted ice (Figure 3B). No evidence of anchor ice on the lake bed was felt out to 175cm depth (the maximum depth of the traverse) where there were 1-5cm slabs, and thicker 10cm slabs and brash making up the ice. At several places, walking on the flat ice caused cracking. In areas of rafting offshore, there was evidence of sediment in the ice, primarily in the thicker slabs. The ice lakeward of the grounded ridges had an estimated average thickness of 10cm and was composed of the rafted and brash pieces. Areas of ridging had thicknesses up to 50 cm. Ice appeared hard on top and at bottom with a soft zone in between.
Distances from EDM setup (= 0.0m)

End of groin- 9.7m
Start of icefoot- 13.4m
End of icefoot- 15.0m
Start of shingling ice- 22.2m
Start of highly ridged shingles- 30.9m
End of ridge/start of offshore ice- 42.2 m

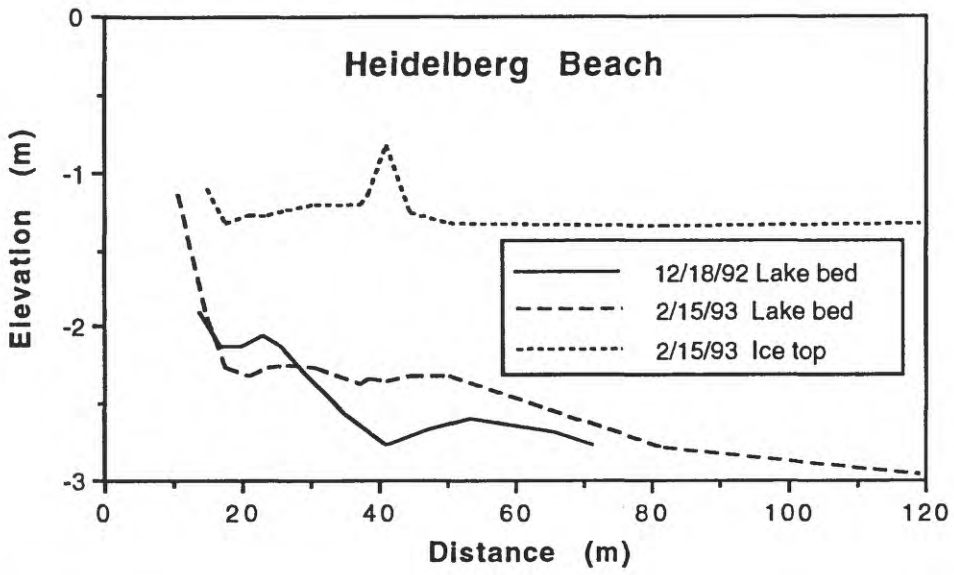
Samples

7 31x7cm ice core from top of icefoot about 14m from EDM location on groin.
8 20x7cm ice core. Sample from inactive volcano cone comprising icefoot. Taken about 15m west of profile line. Abundant pebbles and organic matter covered the cone.
9 40x7cm ice core from top of ice ridge on profile line about 40m from EDM.
10 Various pieces of ice collected from rubbled ice field offshore of nearshore ridges.

Heidelberg Beach 2/15/93	Icefoot	Frozen brash & slush	Offshore ice ridge	Offshore ice
Width x Thickness (m)	2 x 0.8	7 x 1	20 x 1	>200 x 0.1
Ice volume (m^3)	1.6	7	20	>20
Sed. concentration of ice (g/l)	2.46	0.23	0.002	0.184
Sediment content (kg/m/coast)	3.94	1.61	0.04	3.68
Total sed. content (kg/m/coast)	9.27			

Notes: Calculation of sediment concentration in offshore ice uses density of offshore ice at Cedar Point (0.9).

NIC/Lake Bed Profile



A

Figure 3 - A) View of Heidelberg Beach's NIC showing sediment covered ice volcano on February 15.

B

Figure 3 - B) Aerial view offshore ice and lead on February 19.

Oberlin Beach - 1600hrs
Lat. 41° 22.95' N, Long. 82° 30.16' W
The most southern coastline in the Great Lakes and eroding further south. The narrow, 10m wide beach is backed by 15m high slope and sheer bluff in glacial lacustrine mud. There was lots of turbid ice at this location extending as far offshore as could be seen. Samples taken of icefoot (from 0 to 5.5m from shore line averaging 30cm high/thick), nearshore ice ridge (from 5.5 to 11m - averaging 60cm high/thick) and frozen brash that extended to 42m from the shoreline (Figure 4A) composed of 10-20cm thick slabs and blocks that were formed into raised-rim pancake ice 1 to 2 m in diameter and an estimated 50cm in thickness - this is the first place we have seen well developed pancakes. Lakeward of the brash skim ice mixed with brash extends to the horizon (Figures 4A & B). We estimate that 60% of the ice offshore is composed of turbid brash about 50cm thick.

Poking through the thin ice between ridges exposed an ice structure which looked to be much more turbid than the upper layers. Much of the upper, clean skim ice was thin (1-7cm) and was underlain by some slushier ice, which was then underlain by dirty ice layers up to 15 cm thick. The dirty underlying ice looked like anchor ice. The sediment was evenly disseminated, and the ice crystal growth showed a random orientation. It seemed that the anchor ice formed while the upper surface of the lake was frozen already, and then became detached and floated up towards the surface where it got caught under the new lake ice. Could this be the source of the pancaked/layered dirty ice reported by Reimnitz et al. (1991) from Lake Michigan? This ice seems more prevalent in areas where the upper surface is large pancakes. Perhaps these are large enough in diameter to stop wave action from disrupting the underlying anchor ice layers once breakup occurs.

Samples

11 55x11cm ice core of sediment-rich ice from NIC ice ridge: abundant organics.

12 60x11cm ice core from frozen brash adjacent to NIC - taken through a large pancake. Representative sample of brash from 11-42m off the beach (60cm thick).

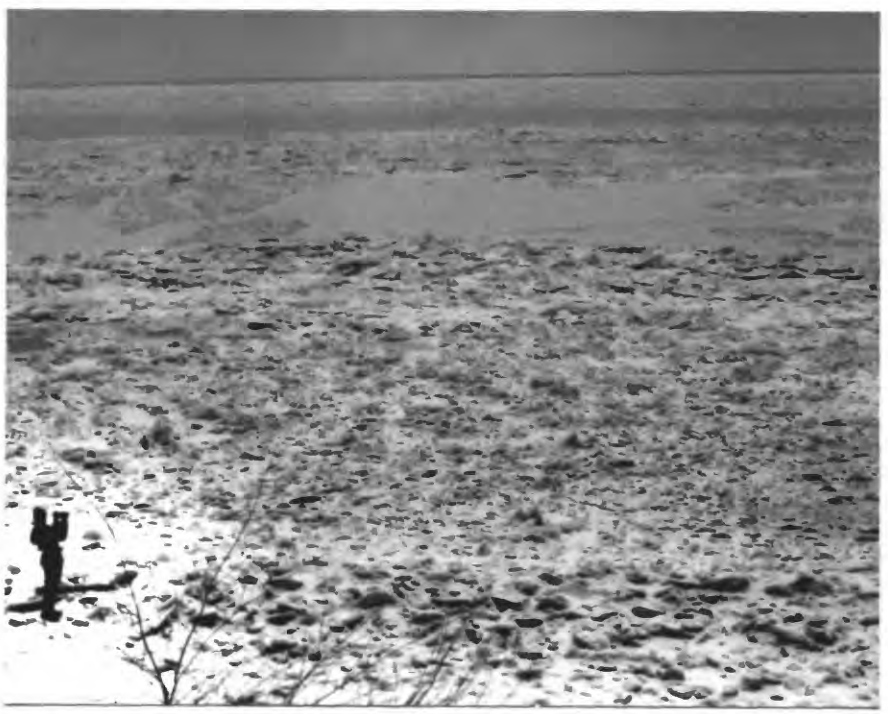
13 11x11cm ice core from upper section of 75cm high icefoot. 11cm segment comes from 15-26cm depth in core

14 Anchor ice collected from submerged floe. Surface ice was removed to allow the anchor ice to float to surface. No ice volume measurement was taken.

Oberlin Beach 2/15/93	Icefoot	Ice ridge	Frozen brash & slush	Offshore ice
Width x Thickness (m)	5.5 x 0.3	5.5 x 0.6	31 x 0.65	>200 x 0.5
Ice volume (m^3)	1.65	3.3	20.15	>100
Sed. concentration of ice (g/l)	1.82	0.76	0.59 (0.24*)	0.35
Sediment content (kg/m/coast)	3.00	2.51	10.26	35
Total sed. content (kg/m/coast)	50.77			

* Sediment concentration in anchor ice uses density of 0.6.

Notes: Sediment concentration in offshore ice uses visual estimate of brash offshore and measured sediment concentration in frozen brash and slush.
Thickness of frozen brash & slush includes 15cm anchor ice.



A

Figure 4A - View of NIC and rubbled offshore ice at Oberlin Beach on February 15.

B

Figure 4B - Aerial view of offshore ice at Oberlin Beach on February 19.

February 16, 1993

10cm of new snow overnight with easterly winds. Examination of Ohio Geological Survey files of coastal photos indicates that ice conditions and nearshore ice complex are not that different from Lake Michigan in some years. The difference that did stand out was the lack of multiple parallel ridges in Lake Erie in most places and times. A good icefoot and adjacent first ridge up to 2m in thickness are common in Lake Erie but lakeward from there, the ridging and rafting seem poorly organized. Some photos showed a very dirty icefoot.

Crane Creek State Park - 1400hrs
Lat. 41° 37.78' N, Long. 83°11.27' W
Wind from N and NE varies in intensity, and snow is drifting. Drive to Crane Creek State Park and sample nearshore ice where 20knt wind was blowing directly onshore. Ice extends as far offshore as we can see in blowing snow (at least 500m). There are patches of bare ice lakeward of groins that are spaced about every 100m and extend 50m lakeward of shoreline. Started at lakeward end of a line 70m offshore, beyond the groins in an area of snow-free ice that may represent much of the offshore ice at this end of the lake (Figure 5). Ice core (15) determined ice thickness of 14.5cm. After coring, water started flowing up through the hole indicating that lake level was rising due to NE winds. Other cores were taken inshore of a shore parallel 20cm high ridge just lakeward of the groins. The ridge was composed of rafted 3cm thick ice slabs. Ice inshore, between the groins, consisted of rubbled brash ice 10cm high, and a nearshore ridge and icefoot complex of overlapping volcanoes 70-100cm high within about 20m of the shoreline.

NIC dimensions

Icefoot	(0-2m - distance from shore)
Small nearshore ridge	(2-10m)
Flat ice	(10-20m)
Low ridged area	(20-60m)
Offshore ice ridge with flat areas	(60-70m)
Low offshore ridge	(70-75m)
Flat ice to horizon	(>75m)

Samples

15 14.5x11cm ice core. Taken 67.5m lakeward of shoreward edge of icefoot, 5m lakeward of small ridge. Ice appears clean and hard.

16 14.5x11cm ice core taken of hard, clean ice 20m shoreward of sample 15. 170cm water depth.

17 12x11cm ice core taken in middle of rubble field 40m shoreward of sample 15. Water depth is 110cm. Core appears more turbid than first 2 samples with a coarse layer at the bottom.

18 12x11cm - Sections of ice core taken from 6-12cm and 18-24cm depths in a core whose total length was 34cm. Core composed of slushy turbid ice taken in rubbled area 57.5 m shoreward of sample 15, and 10m lakeward of inner edge of icefoot Water depth is 85cm.

19 65x11cm ice core of granular ice speckled with sediment throughout. Taken in nearshore ice ridge 67.5m shoreward of sample 15.

20 12x11cm sections of ice core whose total length was 28 cm. Sections taken from 0-6 and 16-22cm in core. Core becomes more turbid towards the base. Pebbles and shells 1.5cm from bottom of core. Taken 78m from sample 15 in the icefoot.

Crane Creek State Park 2/16/93	Icefoot	Nearshore ice ridge	Offshore ice ridges	Offshore ice
Width x Thickness (m)	2 x 0.3	8 x 0.65	65 x 0.20	>200 x 0.15
Ice volume (m^3)	0.60	5.2	13.0	>30
Sed. concentration of ice (g/l)	21.83	0.46	0.21	0.02
Sediment content (kg/m/coast)	13.10	2.39	2.73	0.6
Total sed. content (kg/m/coast)	18.82			

Notes: Thickness/sediment concentrations of offshore ice ridges averaged from three cores (samples 16, 17, & 18)

Figure 5 - Aerial view of NIC at Crane Creek State Park on February 19.

Catawba - 1600hrs
West facing State Beach at Catawba had open water and almost no ice along this lee shore from previous northeasterly storms.

Marblehead - 1630hrs
Lat. 41° 31.784' N, Long. 82° 42.730' W
East facing shore south of Marblehead lighthouse had a pocket beach with a large NIC with ice volcanoes (Figures 6A & B). These features were 2 to 20 m wide and at least 2m high, with an estimated 3m thickness over a 150m section of the coast. These large coastal ice features were observed in pockets elsewhere along the northeast facing coast. Core of the ice showed turbid ice intermixed with 5-10cm blocks of clear skim ice that constituted about 30% of the core (Figure 6C). We also took a core of the 10 to 20cm high, granular brash and slush ice offshore of the ridge. The offshore ice morphology was caused by ice push rather than wave overwash processes.

Samples
21 12x11cm ice core from icefoot - Sections taken from a core whose total length was 129cm (Figure 6C). Sections taken from 0-6cm and 89-95cm (top 1cm of core was covered with zebra mussels and was scraped off before measuring and sampling. Melted sample seemed to contain mostly organics.
22 5x11cm core of the rough (10-20cm relief) granular brash ice adjacent to the icefoot. Volume measurement is +/- 20%. Ice thickness greater than 50cm.

Marblehead 2/16/93	Icefoot/Ice ridge	Offshore ice
Width x Thickness (m)	15 x 3	>200 x >0.5
Ice volume (m^3)	45	100
Sed. concentration of ice (g/l)	0.36	0.01
Sediment content (kg/m/coast)	16.2	1
Total sed. content (kg/m/coast)	17.2	

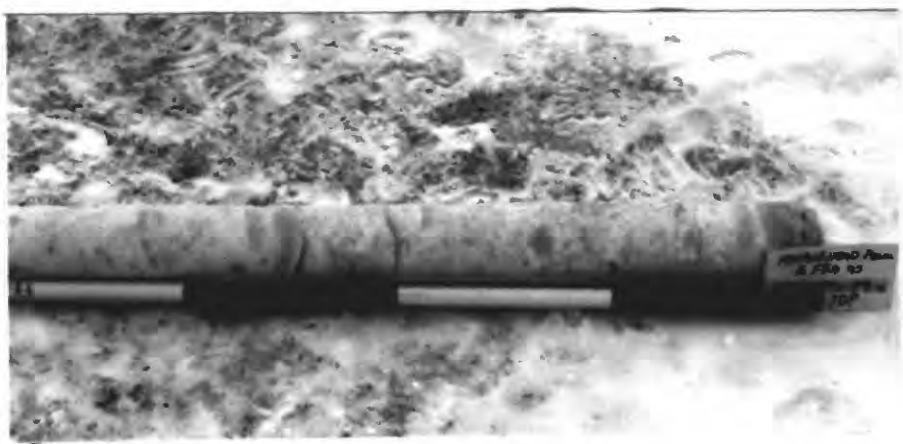
Notes: Width of icefoot/ice ridge varied from 2-20m with wider NIC more common. Offshore ice's width and thickness estimated from field observations.

A

Figure 6A - View of sediment laden icefoot at Marblehead on February 16.

B

Figure 6 B - Aerial view of NIC and offshore ice at Marblehead on February 19.



C

Figure 6 C - Core of icefoot at Marblehead showing large brash chips.

February 17, 1993

Bay Boat Club, Bay Village - 1000hrs
Lat. 41° 29.481' N, Long. 81° 55.454' W
Calm winds and sunny skies at this location; temperature just below freezing. Shore ice at this site consisted of a1 to 2m-high, 10m-wide icefoot and ice ridge at the shore (Figure 7A). Lakeward of the icefoot was a rubbled brash ice region with 20cm surface relief, which was difficult to walk on. Lakeward of the rubbled brash was a second ridged area 15m wide, 50cm high and up to a meter thick. About 50m offshore, ice was sampled that can be considered representative of the offshore ice located lakeward of the outer ice ridge. This offshore ice consisted of 20 to 40cm-high ridges of pressured skim and slush ice that extended to the horizon with an estimated average thickness of 40-50cm in the offshore area of the lake. The stream entering the lake at this location carried small quantities of anchor ice and frazil ice which may influence the local ice regime.
NIC -dimensions 0m- Beach
0-10m - icefoot, 1-2m thick

10-27m - rubbled brash area, 30-50cm thick
27-43m - ice ridge, 50 to 100cm thick
43m-horizon - skim and brash ice, 40-50cm thick

Samples

23 12cm section of 59x11cm core of icefoot which hit rock at the bottom. Granular ice throughout with sand evenly disseminated. Sample composed of core sections 0-6cm and 24-30cm. Location of sample in middle of icefoot.

24 12x11cm section of 95 cm core from ice ridge. Core was solid to 50cm and then slushy with brash chips below. Sampled 14-20cm and 86-92cm sections.

25 12x11cm section of 87cm +/- 5cm core from brash ice lakeward of ice ridge. Ridges are 20-40cm high. Core composed of 0-14cm solid ice (sampled 0-6cm) and 14-87cm slush and brash with sediment throughout. Individual brash pieces up to 20cm (sampled 34-40 cm).

Bay Village 2/17/93	Icefoot	Frozen brash & slush	Ice ridge	Offshore ice
Width x Thickness (m)	10 x 2	17 x 0.4	16 x 0.75	>200 x 0.45
Ice volume (m^3)	20	6.8	12	>90
Sed. concentration of ice (g/l)	0.60	0.24	0.5	0.23
Sediment content (kg/m/coast)	12.00	1.63	6.0	20.7
Total sed. content (kg/m/coast)	40.33			

Notes: Sediment concentration of brash/slush taken from offshore ice.

A

Figure 7 A - View of icefoot and bluffs at Bay Village on February 17.

B

Figure 7 B) Aerial view of Bay Village showing NIC, offshore ice and open water (upper right).

Whitman Creek - 1300hrs (east of Ashtabula)
Lat. 41° 55.289' N, Long. 80° 42.879' W
The bluff here is 10m to 15m high and the beach only a few meters wide (Figure 8A). The icefoot at this location is about 2m above the lake level which is the highest yet seen and consists of two ice ledges of different elevations, possibly the product of two different wave regimes. The NIC is formed into long tongues of poorly defined ridges, a meter or more in thickness, with an offshore area of rubbled brash, skim, and slush ice less than a meter thick except where ridged (Figure 8B). The NIC tongues extend up to 25m offshore but probably average slightly less at this location. Ice core of NIC is composed of frozen granular slush with less than 10% inclusion of clean skim ice (Figure 8C). Between snow squalls ice can be seen extending well offshore as mostly thin (~10cm) rubbled ice with small 20-40cm-high ridges, with an average thickness estimated to be between 15 and 20cm. A core taken here had a thickness of 50cm but this is in an area of thicker ice than the average. The ice lakeward of the NIC is a larger volume of ice than the NIC and estimating the sediment load relies on uncertain estimations of the ice volume for the vast areas offshore.

Samples

26 13x11cm core of offshore ice. Total ice thickness is ~50cm for this core, but only the top part is solid. Sampled 0-13cm.

27 12x11cm sample taken from 93cm core of ice ridge. Sample taken from 63-75cm in core. Core as a whole was solid granular ice to 75cm, then granular ice to the bottom (Figure 8C). Dense dirty bands could be seen at 46-48cm and 72-75cm. Total ice thickness is about 157cm at core site.

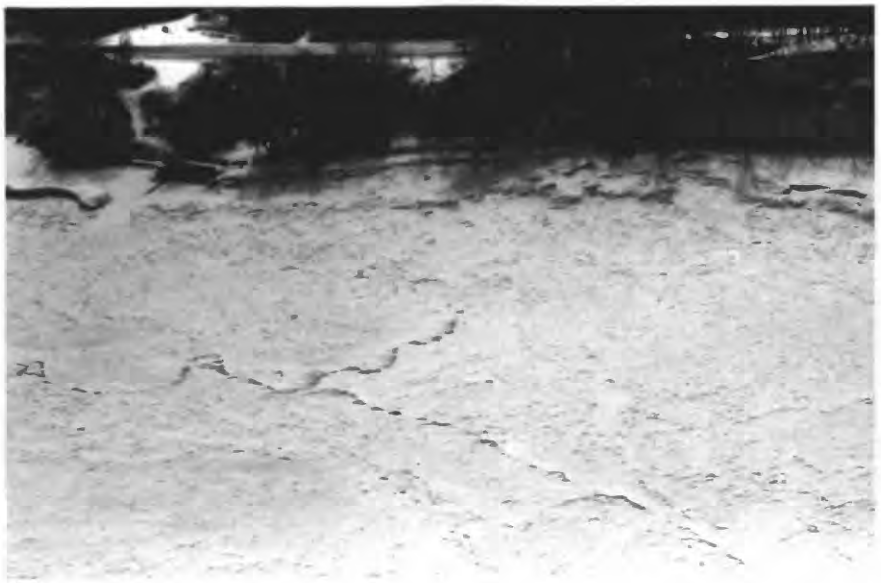
28 12x11cm ice core taken from same core as sample 27. Sampled 0-12cm.

Whitman Creek 2/17/93	Icefoot/ridge	Offshore ice
Width x Thickness (m)	20 x 1	>200 x 0.17
Ice volume (m^3)	20	34
Sed. concentration of ice (g/l)	2.62	0.003
Sediment content (m/coast)	52.40	0.10
Total sed. content (kg/m/coast)	52.50	

Notes: Sediment concentration in icefoot averaged from samples 27 & 28.

A

Figure 8 A - Rubbled offshore ice and NIC at Whitman Creek on February 17.



B

C

Figure 8 B) Aerial view of rubbled ice and NIC on February 19; **C** - Core of icefoot at Whitman Creek.

Geneva State Park - 1500hrs (Ohio Geological Survey profile location)
Lat. 41° 51.563' N, Long. 80° 57.997' W
Profile location of State Geological Survey has undergone erosion (15m) in the 7 years following the 1987 installation of a marina breakwater to the west. A foot path and bridge have been damaged (Figure 9). The till bluffs are about 10m high above a 2-3m wide beach. Winds at this location were building from the west. When we arrived there was no open water but an hour later two coast-parallel but irregular leads were opening an estimated 500m and 1000m offshore. There was an icefoot raised more than a meter above lake level, similar to Whitman Creek. The large icefoot ridges and volcanoes formed on Feb. 12, 1993 according to the park ranger. The 40m of NIC ended in water depths of 1.5m (Figure 8). The offshore ice was composed of 80% snow-covered brash and 20% pancakes with raised rims. Snow 15-20cm deep was underlain by unconsolidated slush - treacherous walking - except on exposed ice ridges and hummocks 10cm high, and on the new 50cm high ridge piled against the NIC. The offshore ice was not as dirty as at Whitman Creek. The lake bed was solid bedrock at all but one location offshore of the NIC.

NIC dimensions at Geneva Beach State Park: from inshore to offshore:

Low icefoot- 27m wide, 2.20m thick.
Higher icefoot/ridge - crenulated 4-7m wide, 3.60m thick.
Rubbled brash area - 12m wide, 1.20m thick, 30-50cm high rubble.
Flat offshore ice with rubble and pressured areas 15cm high to the horizon; thickness estimated to average 20-30cm

Samples

29 6x11 and 6x9cm sections of 50cm core of icefoot. Granular throughout. Sampled 0-6 and 20-26cm. Slushy ice below which was easily penetrated with stadia rod. Total ice thickness of 220cm.

30 12x11cm section of 27cm core from brash lakeward of icefoot. Ice was soft and granular from 0-17cm and hard, more crystalline from 17-27cm. Sample taken from 11-23cm.

31 Surface sample (no density) of offshore ice.

Geneva State Park 2/17/93	Icefoot	Ice ridge	Frozen brash & slush	Offshore ice
Width x Thickness (m)	27 x 2.2	5.5 x 3.6	12 x 1.2	>200 x 0.25
Ice volume (m^3)	59.4	19.8	14.4	>50
Sed. concentration of ice (g/l)	0.73	0.73	0.44	0.08
Sediment content (kg/m/coast)	43.36	14.45	6.34	4.00
Total sed. content (kg/m/coast)	68.15			

Notes: Sediment concentration in offshore ice calculated using 0.70 as density of offshore ice. Sediment concentration in icefoot was used in calculations for ice ridge.

NIC and Lake Bed Profile

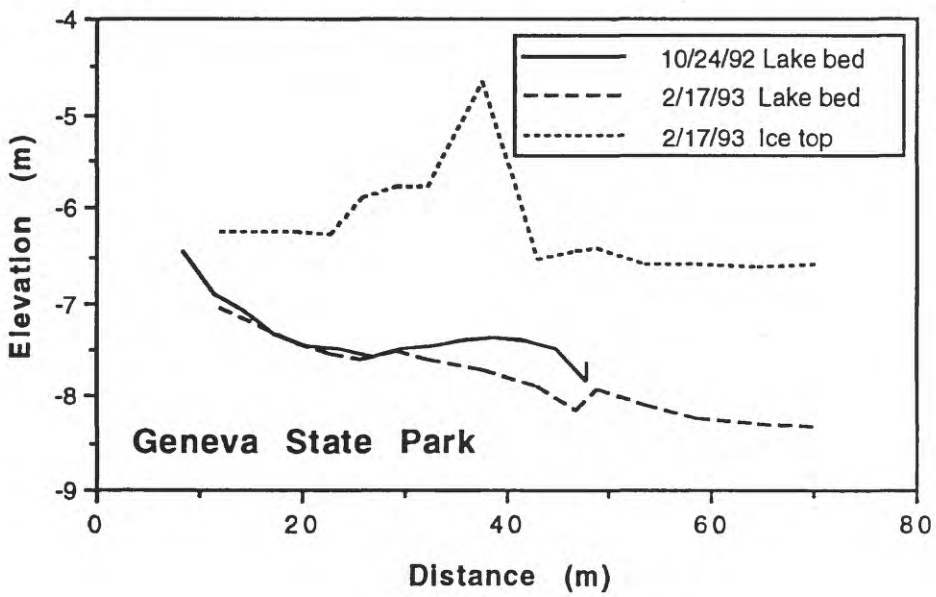


Figure 9 - Aerial view of offshore ice and open water at Geneva State Park on February 19.

February 18, 1993,

Painesville-on-the-Lake - 1000hr
Lat. 41° 45.082' N, Long. 81° 13.689' W
Wind from the west @15knts, Temp. -5 to -10°C.
Along this stretch of embayed coast there is almost no beach, and the eroding 20-m-high, nearly vertical bluff is receding into a small community (Figure 10A). In the summer of 1993, a video system will be installed to monitor coastal processes in this embayment (Figure 10B).

In the embayment, the 2m-thick, 5-10m wide icefoot/ridge had about a meter of freeboard and was composed of granular ice. The average width was 8m. Offshore of the icefoot was unfrozen slush and brash a meter thick which had sand distributed throughout. This ice filled the embayment. Immediately outside the embayment, solid brash and slush was 14cm thick where cored, but thicker elsewhere being underlain by slush. This ice extended to the horizon. A darkened horizon suggests that there might be open leads offshore, but snow showers make observations difficult.

Samples

32 12x11cm section from 82cm core of icefoot. Granular throughout with pieces of brash over 10cm in diameter containing sediment. Sampled 0-6cm and 24-30cm.

33 6x11 cm core of solid surface of brash ice just offshore of icefoot. Slush ice extended to the lake bed (~100cm) but could not be cored.

34 12x11 cm section from16cm core of offshore brash ice. Sampled 2-14cm. Slush to bottom at 30cm not cored.

Painesville-on-the-Lake 2/18/93	Icefoot	Brash & slush	Offshore brash
Width x Thickness (m)	8 x 2	100 x 1	>200 x 0.3
Ice volume (m^3)	16.0	100	>60
Sed. concentration of ice (g/l)	0.45	0.04	0.01
Sediment content (kg/m/coast)	7.2	4	0.6
Total sed. content (kg/m/coast)	11.8		

A

Figure 10 A - View of NIC, rubbled offshore ice and bluffs at Painesville on February 18.

B

Figure 10 - Aerial view of offshore ice at Painesville-on-the-Lake on February 19.

Osborn Park (Willoughby Municipal Park) - 1200hrs
Lat. 41° 42.137' N, Long. 81° 23.765' W
A ten-meter high, steep, eroding till bluff fronted at lake level by concrete blocks at western end, along with other manmade debris and a narrow sand beach. The icefoot here is primarily composed of brash ice, and a frozen mixture of 1-3cm thick slabs of skim ice and granular ice; elsewhere we have observed the icefoot ridge composed mostly or entirely of granular ice. The NIC contained coarse sand and pebbles. Offshore of a 5 to 10m wide NIC, brash with skim ice occurs to the horizon (Figure 11). This ice is 50 to 100cm thick with 20cm of relief. The average thickness of this offshore ice is estimated based upon the nearshore ice measurements . It may be thicker in areas of ridging. Ten meters offshore, at the lakeward edge of the icefoot, water depth was 140cm and ice extended to 130cm. During the aerial observation on the following day (Feb. 19th), a band of discolored, newly broken and ridged ice occurred 500-1000m offshore where shear developed between stationary ice inshore and moving ice offshore (Figure 11).

Samples
35 12x11cm section from 23cm core of brash that extends offshore to the horizon. Ice is hard and granular with a break at 10 cm. Sediment flakes can be seen at this break. Sampled 4-16cm.
36 12x11cm section from a 42cm core of icefoot. 20-42cm has more sediment in the form of sand and pebbles. Core composed of 20% slush and 80% brash. Sampled 6-12cm and 30-36cm.

Osborn Park 2/18/93	Icefoot/ridge	Offshore ice
Width x Thickness (m)	8 x 1.3	>200 x 0.75
Ice volume (m^3)	10.4	150
Sed. concentration of ice (g/l)	1.75	0.36
Sediment content (kg/m/coast)	18.2	54.0
Total sed. content (kg/m/coast)	72.2	

Figure 11 - Aerial view of offshore ice at Osborn Park on February 18.

John Sims Park, Euclid - 1430hrs
Lat. 41° 37.044' N, Long. 81° 31.334' W
Below-freezing wind and blowing snow at beach protected by shore-parallel breakwater. Bluff is composed of 3m of shale overlain by 7m of till. A large (>3m) ice ridge, is built on a segmented breakwater and extends lakeward. The ridge is mostly composed of irregular 20-40cm thick, solid skim ice slabs that must have formed offshore during calm lake conditions. For 16m lakeward of the breakwater, the ice ridge is 300-400cm thick (Figure 12). Offshore of the ridge, the ice is a 50cm thick rubble of skim ice, brash, and slush that is incompletely frozen. The rough area of the NIC inshore of the ridges and breakwater includes 5 to 20cm-thick skim ice which is very pronounced compared to the smoother slush ice surfaces typical of Lake Michigan. The solid ice and decimeter roughness makes this NIC slick and difficult to walk on. The 30cm-thick icefoot furthest up the beach is only composed of granular ice and sediment suggesting that the icefoot formed early when waves and frazil ice was present.

Samples
37 12x11cm section of 45cm ice core of ice ridge. Turbid with sediment throughout. Brash of skim ice with granular matrix. Sampled 15-27cm.

38 Sample of offshore ice which has a hard crust but is soft underneath. Freezing in core tube made extraction difficult and prevented an accurate core length measurement for density calculations.

Sims Beach 2/18/93	Icefoot/ridge	Offshore brash/slush
Width x Thickness (m)	16 x 3.5	>200 x 0.5
Ice volume (m^3)	56	100
Sed. concentration of ice (g/l)	1.13	0.14
Sediment content (kg/m/coast)	63.28	14.0
Total sed. content (kg/m/coast)	77.28	

Notes: Sediment concentration of offshore ice taken from concentration of water (0.2) x the average density of such ice (0.7)

Figure 12 - View of NIC at Sims Park on February 18 showing rubbled offshore ice, ice ridge and icefoot (from left to right).

February 19,1993

Cedar Point - 0915hrs

At Cedar Point profile site we noted that the offshore part of the profile where the previous traverse was made (February 15) had changed. The rubble of granular ice had been replaced by skim ice that is more crystalline as opposed to the typically granular brash or slush.

Coastal aerial observations 1030-1200, 1340-1430

Flew east to Ashtabula and back to Sandusky at noon. Then at 1340, flew west to Crane Creek area before returning to Sandusky at 1430. The flight was at 500 ft over the lake flying eastward and about 600 ft over the coast flying westward. The flight observations are contained on 8mm video tape and 35mm color slides.