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SOUTHERN LAKE MICHIGAN COASTAL EROSION STUDY WORKSHOP

February 5-6, 1991

Held at the

USGS Center for Coastal Geology

St. Petersburg, FL

Edited by

Folger, D. W., Colman S. M., and Barnes, P. W

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This report is preliminary and has not been reviewed for conformity with U. S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

April 1991

CONTENTS

FIGURES

APPENDIX

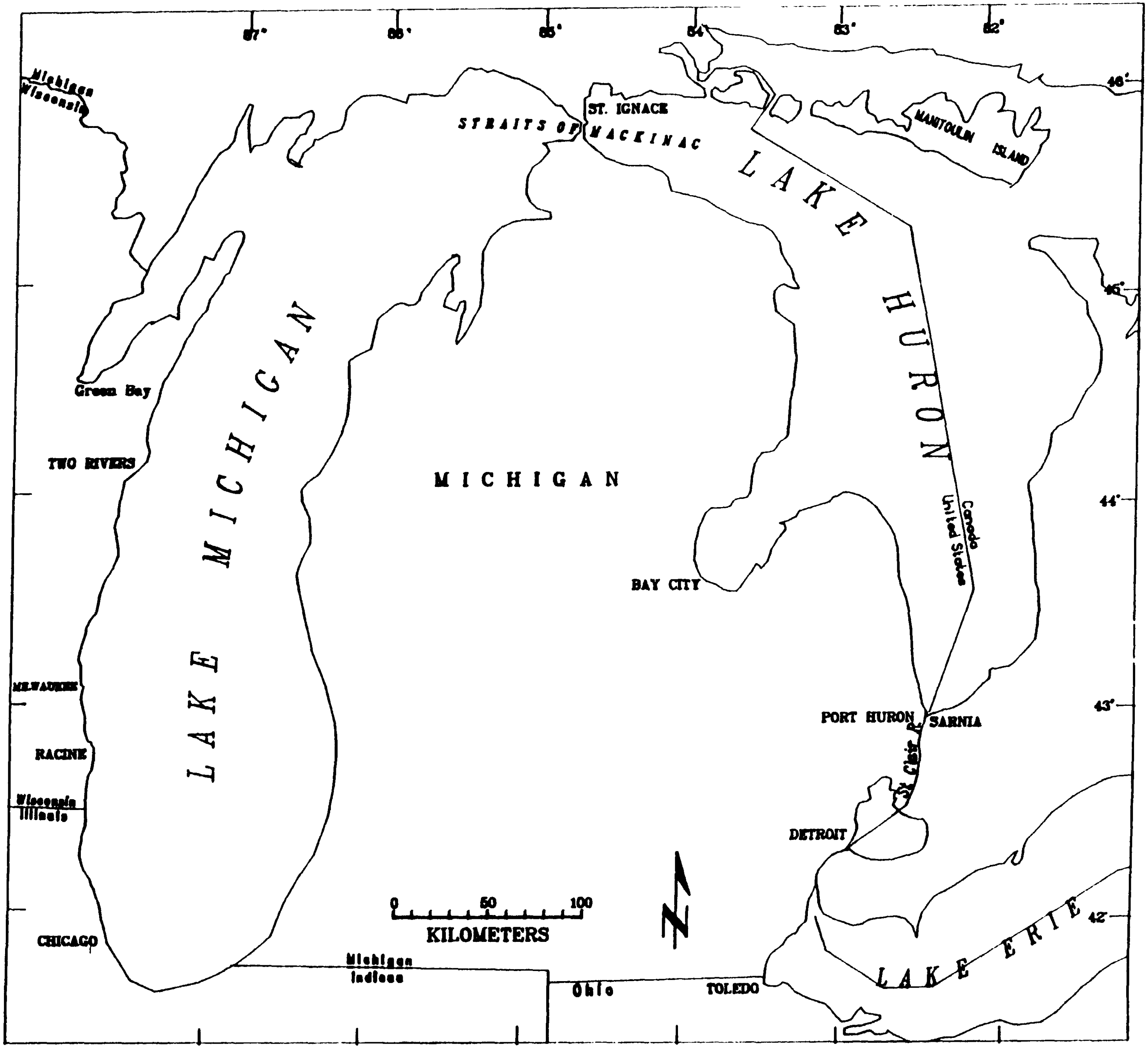

87°
86°
85°
84°
83°
82°
46°
45°
44°
43°
42°
Michigan
Wisconsin
STRAITS OF MACKINAC
ST. IGNACE
MANITOULIN ISLAND
LAKE HURON
LAKE MICHIGAN
MICHIGAN
Green Bay
TWO RIVERS
MILWAUKEE
RACINE
Wisconsin
Illinois
CHICAGO
Michigan
Indiana
Ohio
TOLEDO
BAY CITY
Canada
United States
PORT HURON
SARNIA
St. Clair R.
DETROIT
LAKE ERIE
0
50
100
KILOMETERS

Figure 1a.

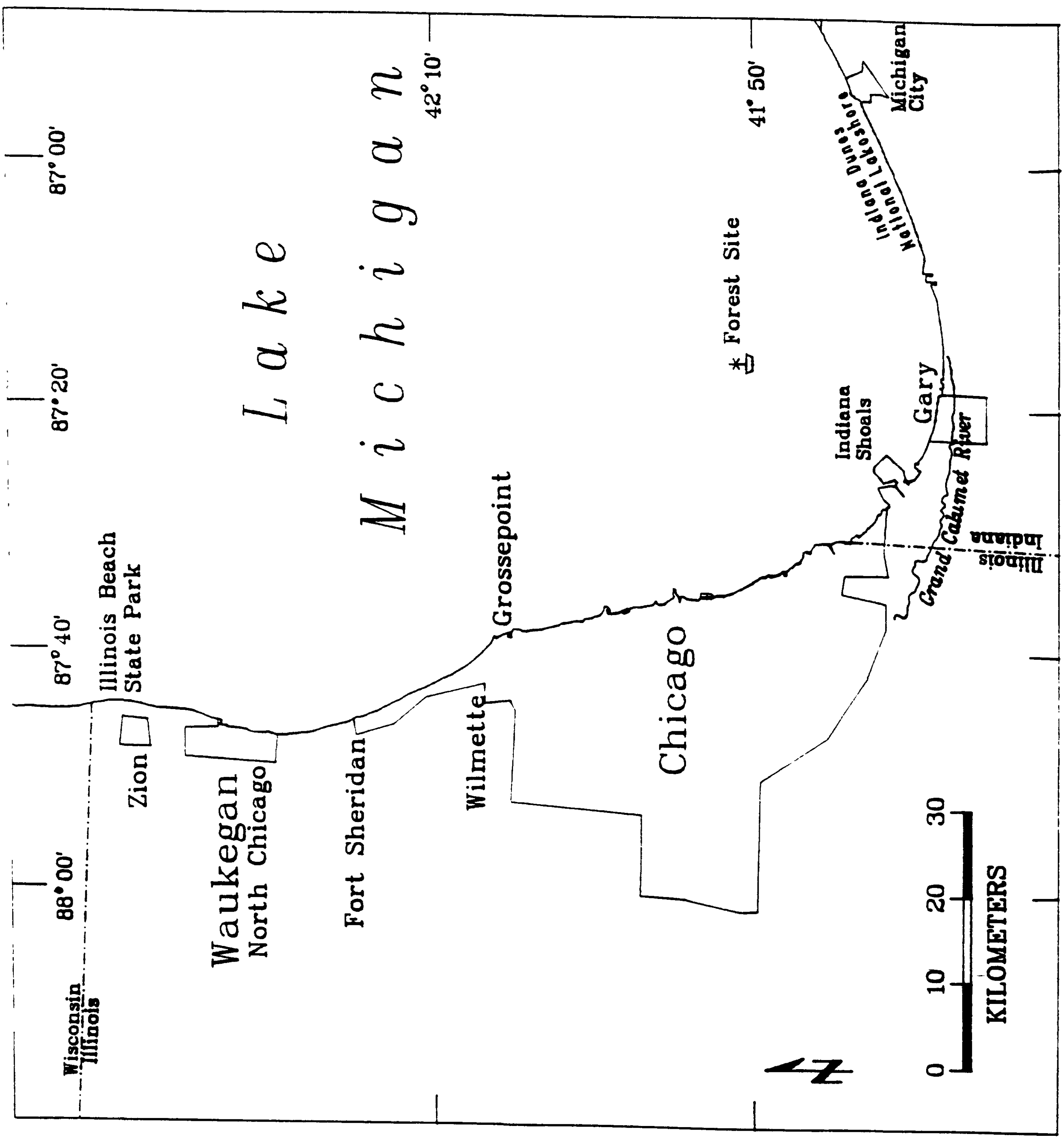

Lake Michigan
87° 00'
87° 20'
87° 40'
88° 00'
42° 10'
41° 50'
Wisconsin
Illinois
Illinois Beach
State Park
Zion
Waukegan
North Chicago
Fort Sheridan
Wilmette
Grossepoint
Chicago
Forest Site
Indiana
Shoals
Gary
Grand Calumet River
Illinois
Indiana
Indiana Dunes
National Lakeshore
Michigan
City
0
10
20
30
KILOMETERS
N

Figure 1b.

INTRODUCTION

The Southern Lake Michigan Coastal Erosion Study was initiated in 1988 in response to shoreline damage related to the high lake levels of 1985-86. The purpose of the study is to gain better understanding of the processes that cause erosion and flooding of the Illinois-Indiana shorelines, to document the mechanisms and frequency of lake level fluctuations, and to develop models to predict the extent and speed of coastal retreat.

The study consists of three parts that are scheduled to be completed on October 1, 1992. Of the first two parts, Framework and Lake-Level, only a survey of nearshore sand thickness is yet to be completed. All the rest of the data are in the compilation phase. Field work for the third part, Processes, is well underway and will continue through 1991. The study area is shown in Figures 1,a,b.

FRAMEWORK

Studies of sediment texture reveal that most of the lake bottom between Waukegan, IL, and Michigan City, IN, from about 2 km to 15 km offshore, is covered by gravel, cobbles, or till, with a patchy veneer of thin sand. Thus, most of the area is non-depositional. To the north of Waukegan and east of Michigan City, finer-textured material (mainly silty sand) is common on the lake floor. In addition to reconnaissance bottom-sediment maps, detailed maps were constructed in areas at Wilmette, Fort Sheridan, Michigan City, and Indiana Shoals, where sidescan sonar imagery has been mosaicked.

About 50% of the Indiana Shoals lake bed is characterized by high acoustic reflectivity to sidescan sonar signals due to gravel, cobbly sand, or sandy gravel. The coarse-textured material is oriented in east-west trending megaripples with wave lengths of 0.75-1.0 m. Areas with low acoustic reflectivity comprise fine to medium sand in small ripples a few cm in wavelength. The finer material apparently moves in response to moderate waves and currents during all seasons, covering and uncovering the coarse-textured material, which probably moves only in response to large waves generated during major storms.

Beach and nearshore sand deposits apparently have become significantly thinner since 1975 along the Illinois shore of Lake Michigan. Whereas more than 6 million cubic meters of sand lie between Waukegan and the Wisconsin border, to the south, the sand wedge has decreased in thickness, in some areas to zero. During the summer of 1991, more data will be collected with a hydraulic probe to assess the extent and thickness of the nearshore sand deposits. Measurements of nearshore sand thickness made with ground-penetrating radar (GPR) during the summer of 1990 are still being evaluated.

Based in part on the data acquired in this study, a reconstruction of the geologic history of southern Lake Michigan, reveals that during the late Pleistocene and Holocene the nearshore area was supplied with abundant sand by longshore currents along the eastern margin of the lake. However, longshore sand movement on the western side of the basin was trapped by an embayment at Chicago and did not reach the southern shore until about 3,500 yrs BP. After this time, sand from both margins rapidly filled the embayment in the western part of the Calumet Lacustrine Plain.

LAKE LEVEL

Seismic-reflection profiles, collected in the southern two-thirds of Lake Michigan, show a prominent basin-wide seismic reflector which is time-transgressive. It marks the extreme low lake level of the Chippewa phase (beginning about 10 ka) and the subsequent Chippewa-Nipissing transgression (ending about 5 ka). Most relict strandline nearshore features were destroyed by the rapid transgression during which lake level rose between 70 and 120 m..

As much as 15 m of glacial-lacustrine sediment were deposited in the southern basin between 13 and 10 ka. Succeeding Holocene rates were considerably less, about 0.3 mm/yr between 10 and 5 ka; however, much of the lower part of the thick lobes of post-glacial sediment on the eastern side of the basin appear to have been deposited at higher rates between 9 and 10 ka. Most of the southern Lake Michigan basin only contains 2-4 m of sediment deposited in the last 9 ka and thus has been sediment-starved during the Holocene. A dramatic decrease in sedimentation rates took place about 5 ka on the western side of the southern basin.

A variety of sedimentologic, paleontologic, isotopic, magnetic, and geochemical analyses have been used to study the relationships among lake level, climate, and the sediments. Many of the properties of the sediments, such as grain-size, show clear correlations with known lake-level changes. Ostracode assemblages show that the lake varied in volume, total dissolved solids, and temperature. These variations are related both to climate and to changes in lake inflow and outflow. Magnetic properties of the sediment, including magnetic susceptibility and the concentrations and grain size of magnetite, correlate with other sediment properties and with changes in lake level. The magnetic properties seem to reflect variations in depositional energy and sediment sources. Variations in stable isotope contents of carbonate shells in the sediments are related to external climatic changes, as well as to sources of discharge into the lake.

PROCESSES

The nearshore ice complex (NIC) was studied to determine the role of ice in coastal erosion. Ice formation and loss were monitored with a video camera to augment direct observations and repetitive profiles. Ridges of ice, as high as 7 m, were found in the NIC. The NIC, itself, commonly develops and decays several times during winter, incorporating, transporting, and depositing sediment in each cycle. Ice-rafted sediments including cobbles were found as far as 8 km from shore. Measured alongshore rates of sediment transport by ice rafting appear to be sufficient to account for the removal of coarse sediment eroded from Illinois bluffs and for the coarse detritus observed in deep Holocene lake basin sediments.

Bluff retreat along 30 km of Lake Michigan shoreline from Wilmette to Waukegan was measured from aerial photographs and maps over two time periods, 1872-1937 and 1937-1987. The data show that retreat rates vary widely in local areas from 10 and 75 cm/yr for short periods but that the average rate for the entire area is similar for the two periods.

The dunes at Indiana National Lakeshore represent a major sediment sink for sand along the southern Lake Michigan shoreline. Experiments have been initiated to monitor eolian sand transport from the coast to the dunes. Wind speeds were sufficient to move sand on 63 days between 17 July and 12 December, 1990, equally divided between onshore (north) and offshore (south). However, during the time that wind blew onto the beach (north) the winds were stronger. The result was a net loss of sand from the beach to the onshore of about 14,900 kg/m (8.6 m^3 /m), which represents about 21 cm of backshore surface lowering.

In sharp contrast to the sediment sink in the southernmost part of the study area, rapid erosion is occurring at one site along the shoreline near the Wisconsin border. During 9 months in 1989, more than 60 m of shoreline recession occurred on the shore near North Point Marina in the northern reach of Illinois Beach State Park. The rapid erosion developed a log-spiral shoreline in a partially protected area where 1.3 million m^3 of dredge spoil had been deposited. The study demonstrated that a developing log-spiral form is in a state of dynamic equilibrium as it expands landward and downcoast.

Modeling studies of beach-profile time series indicate that the equilibrium beach concept should not be used to predict nearshore response to short term water level changes on the Great Lakes. However, the equilibrium profile may be appropriate for prediction of changes in the nearshore due to changes in water level that occur over a relatively long time. In keeping with previous work, the lag between profile response and water level change is on the order of a few years.

PRODUCTS

In addition to reports and scientific journal articles, data from all aspects of the study will be used to construct a sediment budget for the southern Lake Michigan area.

The southern Lake Michigan Coastal Erosion Study dataset is an ideal candidate for publication on a CD ROM. Most of the data are digital or in some graphic form that can be scanned. Data are being staged in ARC/INFO, MAPGEN, ISM, and MIPS.

A summary volume based on the research results will be submitted to a publisher in October, 1992. It will include sections on all three parts of the study and will focus on applications of results to coastal management problems. The tentative schedule for the compilation of the volume that synthesizes the results of the study is as follows: 1) preparation of expanded outlines of Framework and Lake Level papers (due October, 1991); 2) preparation of expanded outlines of Processes papers (due January, 1992); 3) completion and submission of papers for review (due July, 1992); and 4) submission of revised papers for publication (due October, 1992).

After all the data have been assembled for scientific purposes, non-technical articles will be published in newspapers and magazines for southern Lake Michigan users and visitors.

AGENDA

3RD ANNUAL WORKSHOP

SOUTHERN LAKE MICHIGAN COASTAL EROSION STUDY

USGS CENTER FOR COASTAL GEOLOGY

St. Petersburg, FL

February 5-6, 1991

Purpose: To review work accomplished and develop a plan and timetable for integration, synthesis, and presentation of all aspects of the study.

TUESDAY

February 5,1991

Introductory Comments

0830	Coastal studies overview	Abby Sallenger
0840	Status of the southern Lake Michigan project	Dave Folger

Review of Work Accomplished

GEOLOGIC FRAMEWORK

0900	Completed bedrock and isopach maps Lakeward boundary of the sand wedge	Dave Foster
0915	Completed sidescan images of Indiana Shoals and Bottom sediment texture off Illinois	

	and Indiana	Dave Folger
0930	Preliminary survey of littoral drift sand deposits along the Illinois shore of Lake Michigan from Waukegan to Evanston	Charlie Shabica
0945	Discussion	
1000	Coffee Break	

LAKE LEVEL CHANGE

1020	Introduction-status and products to date	Steve Colman
1030	The Chippewa unconformity and the preservation of low lake-level features; observations from high-resolution seismic-reflection profiles	Dave Foster
1045	Sedimentation rates, lake levels, and paleoclimate	Steve Colman
1100	Geochemical, paleomagnetic, and magnetic-petrologic studies of Holocene sediments in southern Lake Michigan	Rich Reynolds
1120	Ostracode biostatigraphy and isotope geochemistry	Rick Forester
1135	Discussion	
1200	Lunch at the Studebaker Building	
1300	Isostatic uplift	Curt Larsen
1315	Indiana Dunes	Todd Thompson
1330	Storm deposits	Ralph Hunter

1345	Discussion	

PROCESSES

1400	Introduction	Peter Barnes
1410	Lake ice influences on the coastal profile and sediment transport, and overlooked processes in southern Lake Michigan	Ed Kempema
1425	Possible wave-induced changes in Lake Michigan nearshore lakebed properties, Illinois Beach State Park	Jim Booth
1440	Winter ice, waves, and currents	John Haines
1500	Coffee break	
1515	Littoral transport processes	Mike Chrzastowski
1530	The Lake Forest Proposal	Mike Chrzastowski
1545	A 115-year record of bluff recession along the Lake Michigan shoreline in Illinois	Randy Jibson
1600	Modeling beach and nearshore profile response to lake level change and storm wave forcing	Bill Wood
1615	Eolian sand transport in the backshore-foredune portion of the Lake Michigan shoreline, Indiana	Greg Olyphant
1630	Summary discussion	
1730	Adjourn	

WEDNESDAY

February 6, 1991

Data Integration, Synthesis, and Presentation

0830	Examples of and models for products What questions should we be answering?	Abby Sallenger
0900	**Introduction to Data Integration**	Steve Colman
0910	Vehicles for data integration	Chris Polloni
0925	Discussion	
1000	Coffee break	
1015	IAGLR Symposium 1991	Mike Chrzastowski
1020	Discussion- IAGLR Symposium Volume? USGS Professional Paper(s)?, Bulletin(s)?	
1100	**Introduction to Summary and Outreach Products**	Peter Barnes
1110	Preparation of coastal studies pamphlet	Jeff Williams
1120	Discussion-slick publication, videos, Circulars, contract?	
1200	Lunch at the Studebaker Building	
1300	**Design and Schedule for Final Product Assembly and Presentation**	Dave Folger
1430	Coffee break	
1445	Complete discussion	

1500 Delegation of Product Working Groups

Data
Research
Summary/Outreach

ABSTRACTS

Lake Ice Influence On the Coastal Profile and Sediment Transport, and Overlooked Processes in Southern Lake Michigan.

Peter W. Barnes, Edward W. Kempema, Erk Reimnitz, and Michael McCormick, USGS, Menlo Park, CA.

Winter field work, undertaken in 1989, 1990, and 1991 at more than 20 locations along the coast of western and southern Lake Michigan, examined the role of lake ice on coastal erosion and sediment transport. This examination includes studies of ice zonation, ice sediment content, sediment entrainment by ice, and potential for, and rates of, ice rafting.

During the formation of coastal ice a nearshore ice complex (NIC), develops in stages, consisting of an ice foot along the shoreline, and a lakeward sequence of wave-generated ice ridges with intervening shore-parallel lagoons. A ubiquitous belt of mobile brash and slush ice precedes and accompanies each stage supplying the ice for construction. The NIC is best developed on coasts with beaches and poorly developed along steep, engineered coasts. During a single winter the NIC develops and partially or completely decays several times. Ice ridges were typically 1-2 m high but reach a maximum of 7 meters and are commonly located on offshore bars. Coastal profiles illustrate both erosion and deposition, plus the consistent development of an erosional trough along the outer edge of the ice ridges. These bathymetric changes and the ice ridge construction reflect the offshore displacement of wave energy from the summer shore face by the ice ridge.

Sediment recovered from the NIC was primarily sand and was concentrated in the ice foot and in ice ridges. Lower concentrations were found in the lagoonal ice and the drifting ice offshore. Values ranged from less than 0.1 g/liter to 866 g/liter of melt water; the latter obtained from an ice and sediment mass rolling along the lake bed. High sediment concentrations are also associated with anchor ice masses nearshore. Averaged values indicate the static NIC contains 180 to 280 tons (290 to 450 m^3) of sand per kilometer of coast, much of which is rafted during decay of the NIC. The NIC sediment load is roughly equivalent to the average amount of sand eroded from the bluffs and to the amount supplied to the deep Lake Michigan Basin by ice rafting each year. In addition to the static sediment load, southward alongshore ice rafting by brash and slush was common at rates of 10-30 cm/sec. Applying conservative sediment concentrations for the drifting ice suggests that 0.35 to 2.75 x 10^3 tons of sediment per day may be transported along shore. Ice rafting can result in long transport trajectories as ice rafted sediments including cobbles were recovered up to 8 km offshore. We conclude that the NIC influences coastal erosion by displacing wave energy lakeward and by modifying the coastal profile. Coastal erosion is also enhanced by ice entrainment and transport of sediment along- and off-shore at magnitudes sufficient to remove sand supplied by bluff erosion and to supply the ice rafted component in deep basin sediments.

1991 studies focus on mechanisms of sediment entrainment during early phases of freeze-up and on quantifying the longshore and offshore transport rates. Time-lapse observations on ice and wave interaction, along with field measurements of the wave interaction with the NIC, provide tools to study the interaction between coastal hydraulic and ice regimes.

Analysis of Possible Effects of Summer Storm Waves on Lake Michigan Lakebed Properties in the Illinois Beach State Park Nearshore Zone

James S. Booth and William J. Winters

Branch of Atlantic Marine Geology, U.S. Geological Survey

The fortuitous interruption of sampling activity by a summer storm provided an opportunity to examine the effects of storm waves on lakebed morphology, near-surface sediment density, and penetration resistance in a nearshore zone off Illinois Beach State Park. Special sampling equipment and methods to measure in-situ density and an in-situ penetrometer were used by SCUBA divers on two, shore-normal sampling transects consisting of stations at 4, 6, 8, and 10 m water depths. The transects were spaced about 200 m apart. Within the study area, the bathymetric contours are generally smooth, shore-parallel, and progressively wider apart, whereas the sediment grain size gradually decreases offshore from fine sand at 4 m water depth to very fine sand at a depth of 10 m. Collection of the data from the three shallower stations of each transect was separated by the storm, which generated waves having heights up to 2 m and periods of about 7 s. Accordingly, if inherent differences between the two transects within this area were insignificant prior to the storm (i.e., little local variability over a 200 m interval), we may assume that the observed, significant changes are due to the storm.

Ripples were not present in the sand at the first three stations during the pre-storm sampling and were present on the post-storm lakebed at the last three sites. Moreover, preliminary results suggest that the thickness of the sand lens in the innermost part of the study area may have been slightly reduced: the in-situ penetrometer encountered a much more resistant lakebed beneath the shallower two stations after the storm as compared to the pre-storm two shallow stations. The relative density of the uppermost sediment at the 4-m station was considerably reduced after the storm, suggesting that wave-generated oscillatory currents (bottom velocities > 100 cm/sec) may have, whether or not there was net erosion, entrained or otherwise reworked the sand to a depth of 10 cm or more. This looser, more porous lakebed may be more susceptible to erosion than the pre-storm bed. Experimental studies using an oscillatory water tunnel are underway to determine if the density of the sand influences its susceptibility to changes by wave-induced currents.

Late Holocene Coastal Evolution of the Central Chicago Lakeshore and Model for Related Evolution of the Chicago River

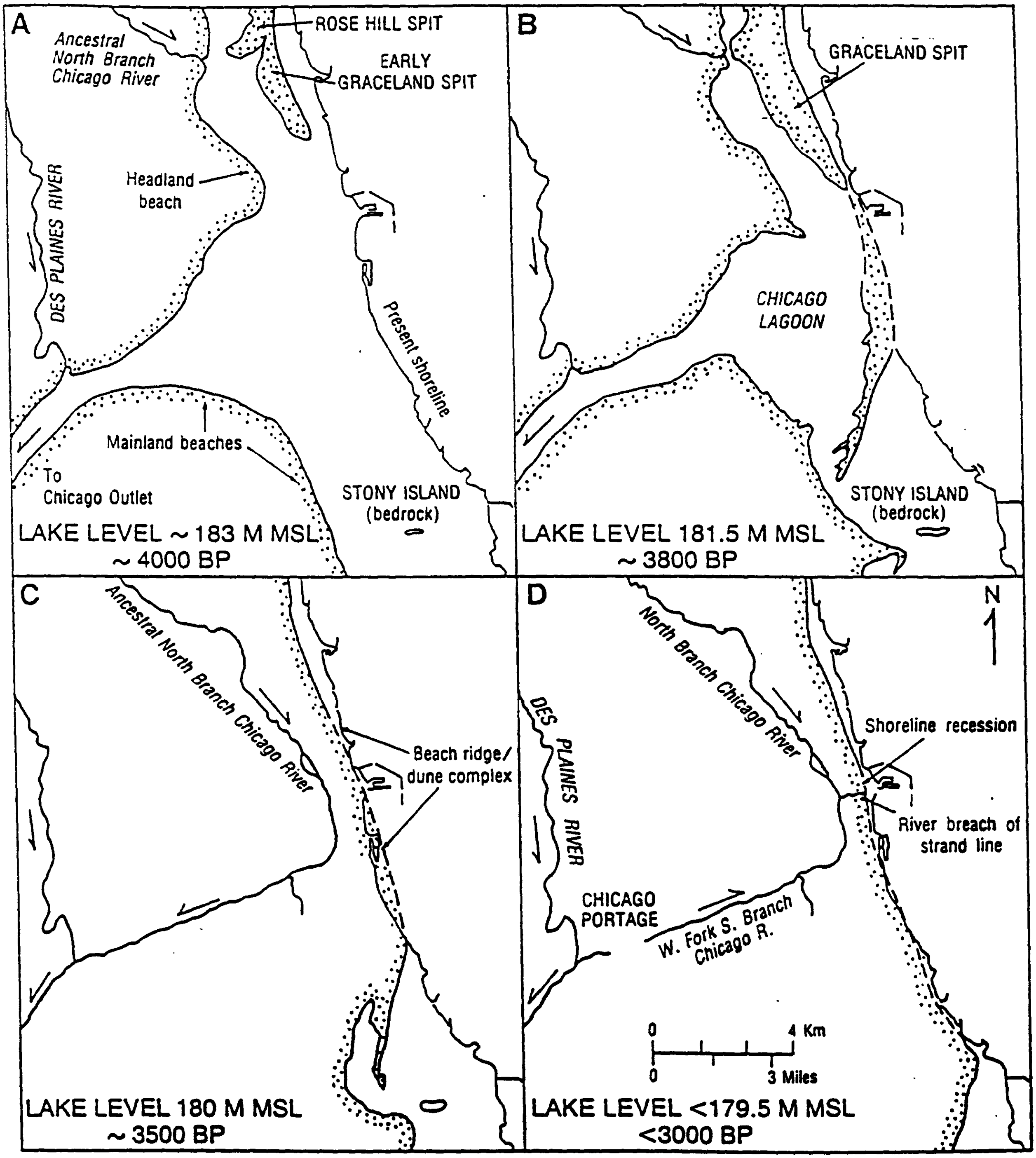
Chrzastowski, M. J., Illinois State Geological Survey, 615 E. Peabody Drive, Champaign, IL 61820

Geomorphology of relict spits and beach ridges adjacent to the Chicago lakeshore indicates a coastal evolution from the mid-Nipissing phase (approx. 4700 BP) to present. Coastal accretion was followed by coastal erosion along a 6-km reach of the central Chicago lakeshore. The erosion apparently contributed to the development of the unusual drainage pattern of the Chicago River with its long (58 km) North Branch, short (17 km) South Branch, and shorter (2 Km) main branch that links the river to Lake Michigan.

On Chicago's far north lakeshore, the Graceland spit and adjacent younger beach ridges commonly have a north-south orientation. However, in their southern reach, between 1 to 9 km north of the Chicago River, both the spit and beach ridges rotate south-southeasterly such that their termini point lakeward across the historical shoreline. Relict spits and beach ridges resume about 5 km south of the Chicago River. These begin at the pre-lakefill shoreline and extend south-southwesterly as much as 6.5 km landward close to the mainland shore of the mid- to late-Nipissing phase. Construction and maintenance of these shoreline features would require continuity of a net southerly littoral transport, and the strandlines north and south of the Chicago River must have been

originally connected. Thus, these strandlines indicate that an arcuate shoreline formerly extended across what has historically been an open-water area of the central Chicago lakeshore.

At its maximum extent, possibly about 3800 BP, this arcuate barrier spit/beach-ridge system formed a lagoon that occupied the central Chicago area and drained westward through the Des Plaines channel to the Chicago outlet. Lake-level decline lowered water level in the outlet and reduced the areal extent of the lagoon. This allowed the ancestral North Branch Chicago River to flow farther southward and westward across the exposed lagoon floor, ultimately to become a tributary to the Des Plaines River. Within the past 2-3000 years, coastal erosion removed the arcuate protrusion of the coast opposite the central Chicago lakeshore. At the northern (updrift) end of this coastal erosional zone, the ancestral North Branch, possibly during flood stage, apparently breached the narrow divide between the river and the lake to form the lakeward-flowing Chicago River main branch. This breach resulted in reversed flow in what became the south Branch Chicago River and formed the Chicago Portage between the head of the South Branch and a westward-flowing tributary to the Des Plaines River.



A
Ancestral North Branch Chicago River
ROSE HILL SPIT
EARLY GRACELAND SPIT
Headland beach
DES PLAINES RIVER
Present shoreline
Mainland beaches
To Chicago Outlet
STONY ISLAND (bedrock)
LAKE LEVEL ~ 183 M MSL
~ 4000 BP
B
GRACELAND SPIT
CHICAGO LAGOON
STONY ISLAND (bedrock)
LAKE LEVEL 181.5 M MSL
~ 3800 BP
C
Ancestral North Branch Chicago River
Beach ridge/ dune complex
LAKE LEVEL 180 M MSL
~ 3500 BP
D
N
North Branch Chicago River
DES PLAINES RIVER
Shoreline recession
River breach of strand line
CHICAGO PORTAGE
W. Fork S. Branch Chicago R.
0
4 Km
0
3 Miles
LAKE LEVEL <179.5 M MSL
<3000 BP

RATES OF SEDIMENTATION IN SOUTHERN LAKE MICHIGAN AND THEIR RELATION TO CHANGING LAKE LEVELS

COLMAN, S.M., U.S. Geological Survey, Woods Hole, MA 02543

New accelerator-mass spectrometer (AMS) radiocarbon ages, together with lithologic and seismic-stratigraphic correlations, suggest that sedimentation rates in southern Lake Michigan have varied considerably during late Pleistocene and Holocene time. Although late-glacial rates of lacustrine sedimentation in Lake Michigan are relatively low compared to other glacial-lacustrine settings, as much as 15 m of sediment were deposited during an interval of a few thousand years, between about 13 and 10 ka. Holocene sedimentation rates are considerably less than late Pleistocene rates of proglacial lacustrine sedimentation. Changes in lake level appear to have a major influence on sedimentation rates in the basin, during both late-glacial and Holocene times.

The approximate end of glacial-lacustrine sedimentation is marked by a distinct unconformity and overlying sandy zone, which are associated with a major fall in lake level to the low Chippewa stage and the subsequent transgression. In much of the southern basin of Lake Michigan, AMS radiocarbon ages suggest that sedimentation rates were relatively uniform, about 0.3 to 0.4 mm/yr, between 10 and 5 ka. However, much of the thick lobes of Holocene sediment (as much as 18 m thick) on the east side of the southern basin appears to have been deposited very rapidly between about 9 and 10 ka, during the early part of the Chippewa low stage. Thereafter, sedimentation rates were lower on the eastern side of the basin, comparable to those in the central and western parts. Consequently, most of the southern basin appears to contain similar amounts (2 to 3 m) of sediment deposited in the last 9 ka. These low amounts of sediment suggest that southern Lake Michigan has been essentially a sediment-starved basin during the Holocene.

Radiocarbon and sedimentological data available to this point suggest that a dramatic decrease in sedimentation rates occurred about 5 ka, at least in parts of the southern basin. This decrease amounted to a factor of 5 or more (to 0.057 mm/yr in one core) and approximately coincided with the Nippissing high stage, or the fall therefrom.

Modern sedimentation rates as measured by ^{210}Pb, ^{137}Cs, or the influx of weed pollen, range from about 0.3 to 2.0 mm/yr. These rates are accompanied by a coarsening of the sediment in most of the basin and indicate increases in sedimentation rates and changes in sediment sources in the last 100 years, presumably associated with human activities.

INDIANA SHOALS : A DYNAMIC SEDIMENTARY ENVIRONMENT

Folger, D. W. [1], Schlee, J. S.[1], Foster, D. S.[1], Polloni, C. F.[1], Seekins, B. A.[1], Brown, C. L. [1], and Olson, A. C.[2]

[1]U. S. Geological Survey, Woods Hole, MA 02543, [2]A & T Recovery Inc., 7109 W. 34th St. Brwyn, IL 60402

A sidescan sonar mosaic, single-channel seismic profiles, bottom samples, and direct observations reveal that bottom sediment movement on this shallow (<10 m deep) shoal is common and vigorous.

About 50% of the bottom is characterized by areas of high acoustic reflectivity. These areas, sampled from a surface vessel and by scuba divers, comprise mostly gravel and cobbly sand or sandy gravel. This coarse material is most often oriented in east-west trending megaripples with wave lengths of 0.75-1.0 m and wave heights of about 0.3 m.

Comparison of bathymetric profiles collected in 1964-1968 with those collected during this study in 1989, show that large ridges and swales in the area have not moved during the past 25 years; however, some accretion and erosion have taken place. There appears to be no correlation with these areas and the distribution of the highly reflective coarse-textured material.

Areas where little acoustic energy is reflected are characterized by fine to medium sand in small ripples a few centimeters in wavelength. This finer material probably moves in response to moderate waves and currents covering and uncovering the coarse-textured material which, in contrast, moves mainly in response to oscillatory currents associated with large waves generated during major storms.

Holocene History of Lake Michigan

The Ostracode Record

Richard M. Forester

U. S. Geological Survey

Denver, CO

Four ostracode assemblages, identified from about 250 core samples, indicate that Lake Michigan varied in volume, conductivity, and temperature during the Holocene. These environmental changes were caused by climatic and geomorphic controls of lake volume. When lake volume is reduced, climatic and geomorphic processes can be separated with internal records, because conductivity will either increase due to evaporation or remain about the same due to drainage. Conversely, a gain in volume requires an external climate record to separate climatic from geomorphic drivers.

The oldest ostracode assemblage (>10.5 Ka) reveals a lake composed of cold (about $4^{\circ}C$), dilute (conductivity <150 uS/cm) water, forming glacial Lake Michigan. That assemblage was replaced (10.5-9.5 Ka) by taxa indicating that lake volume decreased, conductivity increased somewhat, and temperature rose seasonally in shallow water (10° to $15^{\circ}C$). Small lakes and bays having seasonally variable termperature and conductivity were common on the margin of the large lake. Lake water loss was primarily due to drainage at North Bay, but with secondary climate control. A third ostracode assemblage indicates that from 9.5 to 8 Ka lake volume increased, conductivity fell, and temperature remained cold (< about $8^{o}C$). Cold, dilute water probably draining from Lake Agassiz, produced this change. The youngest ostracode assemblage suggests that about 8 Ka lake volume decreased, conductivity rose (>400 uS/cm), and temperature remained cold (<10^{o} to $12^{o}C$). Lake level, however, was higher than during the episode from 10.5 to 9.5 Ka. The volume change was a response to a relatively dry mid-Holocene climate. Ostracodes were not preserved after 6 Ka, because a lower sediment accumulation rate left shells in contact with water unsaturated in calcite. Calcite saturation occurs around 400 uS/cm implying that conductivity decreased after 6 Ka.

The Chippewa Unconformity and the Preservation of Low Lake-Level Features: Observations From High-resolution Seismic-reflection Profiles

Foster, D.S., and Colman, S.M., U.S. Geological Survey, Woods Hole, MA 02543.

Seismic-reflection profiles collected in the southern two-thirds of Lake Michigan show a basin-wide seismic reflector within lacustrine sediments. This reflector is time-transgressive and represents the extreme low lake level of the Chippewa phase (10 ka) and the subsequent Chippewa-Nipissing transgression (10-5 ka). A conformable horizon in the deep basins, which correlates with a gradational change from red glaciolacustrine to gray postglacial clay, is equivalent to the erosional surface of the Chippewa unconformity. The planar character of the reflector and the absence of erosional channels at the unconformity suggest that erosion occurred subaqueously during the Chippewa-Nipissing transgression. Most strandline and relict nearshore features, as well as pre-existing regressive and subaerial features, were apparently destroyed during the transgression. Local occurrences of paleochannels, beach deposits, wave-cut scarps, and other relict nearshore features occur at a variety of depths and cannot be mapped at the spacing of our seismic profiles. Strandline deposits of the maximum Chippewa lowstand are generally not preserved. Instead, cores show that a sand, pebble, and shell layer only a few centimeters thick occurs immediately above the Chippewa unconformity.

Seismic profiles show a lens-like unit locally within postglacial deposits, between 42 and 94 m below present lake level, just above the Chippewa unconformity. The upper surface of the unit appears to mark a facies change from relatively high energy to low energy deposition, which occurred as lake level rose to the Nipissing high stage. Sand and gravel deposits, which veneer till in the south western corner of the lake may be equivalent to this lens-like unit.

The maximum lowstand of the Chippewa low stage may be derived from the maximum depth of the Chippewa unconformity and an assumed depth of wave-base erosion, but the latter assumption creates large uncertainties. We have been unable to map the shorelines of the Chippewa and later lake stages because of the poorly preserved strandline features and subsequent isostatic deformation.

Defining the Chippewa unconformity and equivalent conformity from the seismic profiles and using the available core data has made it possible to map the thickness and distribution of postglacial deposits. Postglacial lacustrine deposits have an asymmetric distribution; as much as 18 m of postglacial deposits lie beneath the slope along the eastern side of the lake, whereas the western slope of the basin is underlain by deposits 4 m or less thick. Postglacial sediment is generally 2-4 m thick in the deep basins. Only thin patches of postglacial sediment and lag deposits veneer till beneath the southwestern end of the lake and mid-lake bathymetric highs, suggesting these are regions of erosion and nondeposition.

Nearshore Dynamics, Ice Formation, and Sediment Transport

John W. Haines, USGS, St. Petersburg, FL 33701

The presence of ice along the shoreline greatly modifies the dynamics of the nearshore. Observations clearly show that bands of nearshore slush may attenuate waves -- limiting or even prohibiting wave breaking. In the absence of slush the nearshore ice complex may limit breaking by creating an ice shoreline in substantial water depths. Under such conditions waves may reflect strongly from the ice face, resulting in energetic cross-shore standing waves. These modifications of the energy and momentum distributions across the nearshore modify the nearshore currents and sediment transport patterns. These, in turn, result in changing bathymetry which impacts both wave and ice development.

A winter field experiment was designed to investigate the dynamics of this system. The experiment consisted of measurement of surface elevation and currents across the nearshore at Gillson Beach, Illinois. Over the month-long experiment, meteorological and video observations were also made to document the evolving ice complex. Periodic bathymetric surveys, surveys of the ice complex, and observations of sediment entrainment by ice were also made. A wide range of ice, wind, and wave conditions were encompassed by the study.

The ice environment proved to be dynamic and energetic. However, because offshore data collection was only marginally successful, our ability to describe the hydrodynamics of the system is limited. The data collected will allow us to document the conditions under which the ice complex grows and decays. Continuous video monitoring (see Holman, this volume) provides us with information on the transport rates of drifting ice under a variety of conditions. This, coupled with observations by Barnes and others (this volume), will provide a first quantitative estimate of the rates of sediment transport associated with drifting ice.

Video Monitoring of Ice Processes

Rob Holman, Oregon State University

The incorporation of sediment into shorefast ice and its subsequent loss by offshore or longshore ice rafting may represent an important component of the nearshore sediment budget. To help monitor ice formation and loss, a video camera was installed at the top of a 10-m tower overlooking the Gillson Beach field site. Images were recorded using a Sony time lapse VCR running at 4 frames per second continuously during daylight hours. Approximately two weeks of data were collected, from mid to late January. The objectives of the observations were:

- to measure the temporal and (to some degree) longshore spatial variability of shorefast ice complex,
- to estimate the extent of frazil or slush ice,
- to estimate trajectories and velocities of broken ice advection

Quantification of the video imagery will be carried out using image processing hardware at Oregon State University. Broken ice drift estimates should not be difficult to measure. However, the width of the shorefast ice complex is difficult to determine at times due to shadowing by the 3-m-high ice ridge. Some estimates of spray processes may be possible.

A 115-year record of bluff recession along the Lake Michigan shoreline in Illinois

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Using airphotos and maps, we measured amounts and rates of bluff retreat at 300 locations along 30 km of the Lake Michigan shoreline from Wilmette to Waukegan, Illinois, over two time periods: 1872 to 1937 and 1937 to 1987. Results show that the rates of bluff retreat in these two periods vary locally between 10 and 75 cm/yr but that the average rate for the entire area is similar for the two periods. Retreat rates showed no correlation with lake-level fluctuations or changes in average amounts of rainfall, neither of which varied significantly between the two periods. Beach-width and groin construction likewise showed no effect on retreat rates. Local variations in rates of retreat do correlate closely with variations in lithology of materials exposed in the bluff. However, the temporally constant regional retreat rates throughout the area and the regular shape of the southern Lake Michigan shoreline both indicate that a uniform rate of retreat, about 20 to 25 cm/yr, prevails and that local variations in retreat rates balance out through time to produce long-term parallel slope retreat in the area.

RELATIVE LAKE LEVEL CHANGES IN THE UPPER GREAT LAKES—RECONSTRUCTING THE PATTERN OF POSTGLACIAL WARPING WITH ACCURACY. Curtis E. Larsen, U.S. Geological Survey, 954 National Center, Reston, VA 22092.

The evidence for Holocene Lake level change in the Upper Great Lakes is complicated by the superimposed history of postglacial isostatic warping of the region. Existing models of both the short-term lake level fluctuations and the regional postglacial uplift are not linked and are neither precise nor complete. The underlying theory and data of both types of models, however, may be combined to construct a more accurate and internally consistent model for understanding lake level changes.

The data on dated lake shore terraces and the historic record of lake level fluctuations in the Great Lakes region can be deconvoluted to identify both the regional pattern of postglacial crustal warping and the scale of climate-related hydrologic episodes. Relative changes in the altitude of lake terrace data for a fixed time and a given lake are independent of the hydrologic cycle and have been used to constrain the regional crustal warping model. Once this isostatic uplift base has been established, the data deviations of the shoreline elevations from the uplift datum can be used to measure the climate-related hydrologic cycle.

Existing models of Holocene lake level change in the Upper Great Lakes provide neither precise nor complete models of postglacial isostatic warping of the region. The short term historic record of lake level fluctuations, measured at lake level gage sites around the lake shores, have been used to reconstruct steady-state models. While accurate within the range of data, these models cannot be accurately extrapolated into the distant past or future. Geophysical models formulated on the basis of assumed mantle viscosities and approximately dated positions of former glacial ice margins are imprecise, but indicate that the uplift history is non-linear over time (i.e. not steady-state). Both types of models rely on the relative position of former water planes in their fundamental development, but when used independently furnish incompatible results. The underlying theory and data of both types of models, however, may be combined to construct a more accurate method for reconstructing differential crustal movement in the region. The geomorphic record of uplifted and deformed former water planes together with the contemporaneous outlets to the lakes links both models. Former Late Holocene water planes of the Nipissing- and Algoma-phase Great Lakes join the three upper lakes and their controlling spillways

The Nipissing and Algoma phases of the Upper Great Lakes represent a close analog to the modern hydrological system. Lakes Superior, Michigan, and Huron became a confluent lake about 6000 years ago due to rapid uplift of a single controlling outlet at North Bay, Ontario. As that outlet was uplifted, a low level of Lake Huron rose in concert to overflow into the Lake Michigan basin at the Mackinac Straits, Lake Superior at the Sault Ste. Marie. The system finally overflowed to the south as a single lake at Port Huron, MI and Chicago, IL. By 5000 yrs B.P., the confluent lake contained four linked lake spillways, each rising at different rates that increased with distance to the north. Three of the four spillways were bedrock-floored outlets that operated as fixed controls. The fourth, the present Port Huron outlet, is floored by glacial deposits and was subject to deepening by erosion.

Evidence of the differential movement of the former water planes associated with the four outlet systems is preserved by the Nipissing I

(5,000 BP), Nipissing II (4,400 BP), and Algoma (3,600 BP) shorelines. The altitude and slope of each shoreline records the cumulative vertical movement of the crust since the shoreline was formed by a single horizontal water plane. The present-day altitude of each shoreline is described best by an exponential curve that rises northward with distance from an asymptotic limit defined by the altitude of the present lake surface (ca. 177 m). This exponential relationship is also compatible with the relative movement recorded from historic lake-level gage data. Thus the geologic and engineering data sets are both consistent and comparable.

The exponential model for the deformed shorelines allows a unique uplift curve to be constructed for any point along the axis of the shoreline profiles. The cumulative uplift due to crustal warping for any position in the area is described by a model equation of the form:

$$\text{Cumulative uplift} = b \cdot 10^{(-mt)}$$

where t is time, m is a rate constant that is defined for the region, and b is a coefficient calibrated for each locality. One well studied site, Port Huron, MI (PH), is evaluated to determine the "m" constant. Historic vertical movement determined from lake level gages for each locality is used to define a site-specific value for "b". The deviation of measured lake terrace surfaces from the Cumulative Uplift datum are subsequently used to determine the Holocene record of lake level fluctuations relative to present day levels.

Along with the underlying crust, each controlling outlet moves relative to sea level, however, differential movement of water planes in the lake system must be reckoned relative to an assumed stable reference. The south shore of Lake Michigan is that reference point. It is the least mobile area in the system and marks the position of the southernmost of the bedrock-floored former outlet channels to the upper lakes. In addition, the shoreline features near the two southern outlets are the most reliably dated. Thus, differences in altitude between shoreline features of similar age at the Chicago and Port Huron outlets measure contemporaneous vertical movement. The Nipissing II terraces show 2.5 m of differential movement. Approximately 1.5 m separate the Algoma features and 0.09 m of historic movement is recorded over the past century between lake level gages at the two sites. The three data points of contemporaneous vertical movement define a cumulative uplift curve for the Port Huron outlet relative to Chicago,

$$CU = -1.0746 \cdot 10^{(-0.00034\ t)},$$

but independent of potential erosional changes in the channel (Figure 1).

Consistent with the determined constant m = - 0.00034, cumulative uplift curves are constructed to intersect the documented amount of historic vertical movement (Figure 2). Each site-specific curve is part of a family of curves in ratio with the slope of the calculated uplift curve for Port Huron (m=-0.00034). A curve for the North Bay region, no longer linked to the Lake Huron basin with a continuous water plane, is extrapolated beyond the Lake Huron basin by projecting historic uplift along its unique exponential uplift-distance curve to find the comparable historic movement. A curve of similar slope to the those on the lake shores is constructed.

As an independent check on the accuracy of the constructed curves, the elevation of Nipissing and Algoma terraces, relative to the Port Huron uplift curve, were plotted. These former lake level stands represent climate-related events superimposed on the uplift of the region. Therefore their elevations relative to background uplift is important.

The Nipissing I terrace was found to lie 5.2 m above the background uplift. The Nipissing II and Algoma surfaces are 3.0 m and 1.7 m, respectively, above background. When adjusted by deducting these amounts from the observed present elevations of terraces, the terrace altitudes plot as points on the Port Huron curve. To test the relative position of contemporaneous terraces at each of the other outlet locations to their calculated uplift curve, the altitudes of dated terraces at each of the constructed sites were reduced by the above amounts and plotted relative to the calculated curve. The adjusted terrace locations relative to constructed uplift curves at the Straits of Mackinac and the Sault Ste. Marie are shown in Figure 2. At North Bay, the present surface of Trout Lake (201.5 m) was contemporaneous with the final northward overflow of the Nipissing II water plane. That relative elevation plots directly on the North Bay curve. Hence, the family of curves accurately reconstructs vertical movement of the region relative to the Chicago.

The same data are plotted arithmetically and relative to a pre-1900 historic mean for Lake Michigan and Lake Huron in Figure 3. The uplift curves for North Bay, the Sault Ste. Marie, the Straits of Mackinac, and Port Huron show the relationship of superimposed climate-related high lake-level episodes relative to cumulative uplift and the present altitudes of bedrock-controlled spillways. The presentation shows the Nipissing II level to be the final flow through the Chicago outlet at 180 m.
In the North Bay region, the simultaneous spillway through Trout Lake was raised above the water plane of the confluent Upper Great Lakes. Thus, the continuous water plane draining at Chicago with North Bay was terminated at about 4400 BP. In Lake Superior, the Algoma level shows as the last episode in the confluent lake system to occur above the threshold

of the Saint Mary's River as uplift separated that upper lake at about 3300 BP.

A contemporaneous comparison of lake-level episodes superimposed on the uplift of each outlet (Figure 4) corroborates the reconstruction. The present altitudes of the Nipissing and Algoma beach features at Chicago (C) are fixed reference points. The uplift of North Bay relative to its unique outlet threshold shows the superimposed Nipissing II episode (C+NB) to coincide in time and space with its counterpart at Chicago. Similarly, uplift relative to the St. Mary's River rapids demonstrates simultaneous coincidence of the Algoma episodes (C+S) at Chicago and Lake Superior.

Because of continued downcutting of the Port Huron outlet, episodes superimposed on that curve do not correspond with the bedrock outlets. Rather, they track the erosion rate at that outlet. For the Nipissing I episode to coincide with that at Chicago, the comparable reference mean level of the lakes draining through Port Huron was at 181.7 m (5000 BP). Subsequent coincidence of the Nipissing II episode (4400 BP) between Port Huron, Chicago, and North Bay requires a reference mean level at 179.7 m. At the time of final confluence with Lake Superior at the Algoma episode (3600 BP), the required coincidence of Port Huron with Sault Ste. Marie and Chicago, places the reference mean at 178.2 m.

The incision of the St. Clair River at the Port Huron outlet kept pace with the vertical movement of the region as beach terraces formed at the contemporaneous head of the river are now raised above the modern threshold of the river. This erosion is illustrated in Figure 3 by the relationship between superimposed climate-related lake level episodes at both Port Huron and Chicago with the uplift curve for Port Huron. The Nipissing I, II, and Algoma terraces at Port Huron lie 5.2, 3.0, and

1.7 m above the calculated uplift curve. At Chicago, on the other hand, the Port Huron cumulative uplift curve corresponds with the peaks of the same lake-level episodes. As the "fixed" point in the system, Chicago records simultaneous events at Port Huron as that area was uplifted. The Chicago record shows the lake-level events at their contemporaneous position with the eroding head of the St. Clair River. At Port Huron, the deepening of the river channel in concert with uplift are preserved. Consequently, there is an increased difference in altitude between the modern head of the river and the same superimposed high lake-level events at Port Huron.

The fall in altitude of the Nipissing and Algoma levels as recorded at Chicago (Figures 3 and 4) directly reflects the differential uplift rate at Port Huron. The relationship of the same erosional surfaces at Port Huron, however, shows a composite of uplift of that region combined with incision of the outlet channel. As important, the comparison shows that the upper range of the Nipissing and Algoma levels were less than 1 m above the background uplift, suggesting that the rate of uplift tended to overwhelm the climate-driven processes in the system. As the uplift rate slowed, the climate variable began to play a major role as illustrated by an approximate 2 m upper range documented for the region 400 years ago.

The consistency of the uplift model with the geomorphic evidence in the Upper Great Lakes basin indicates greater accuracy than has heretofore been demonstrated for the region. It integrates geologic and engineering data into a coherent structure that can be used to deduct the uplift component, as well as the erosion rate at Port Huron, from geologic studies of former lake level stands. As a result we can now use geologic information with confidence to reconstruct a paleohydrologic record for the Upper Great Lakes that will link the present with the past.

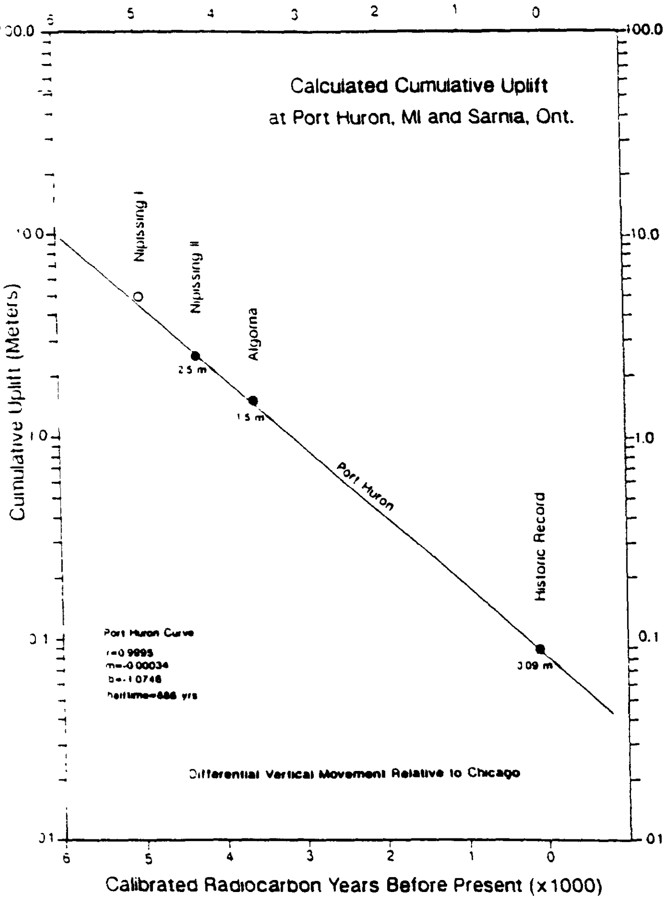

Figure 1

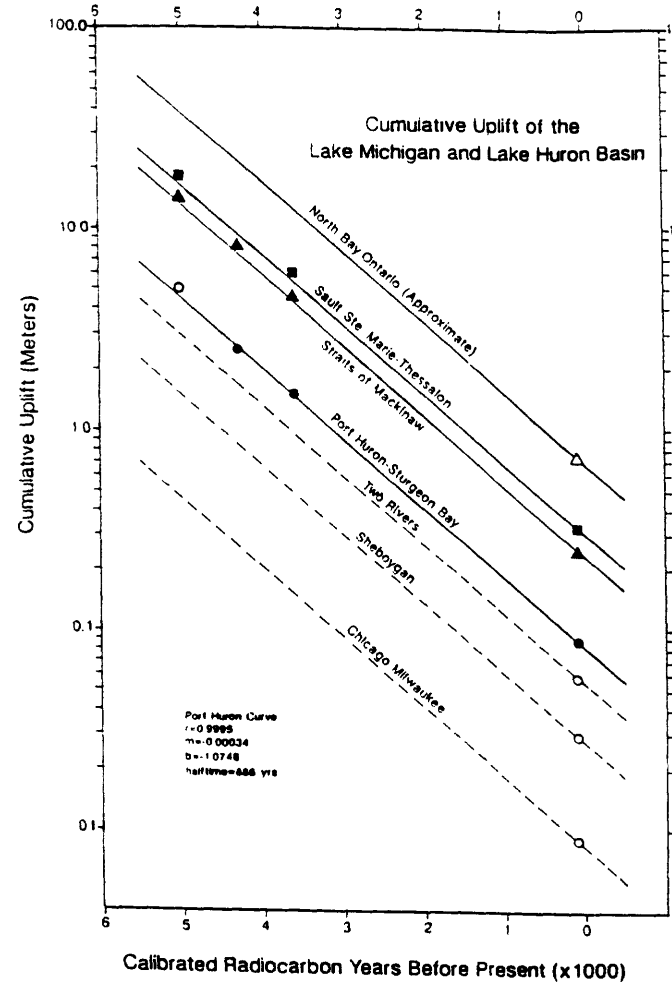

Figure 2

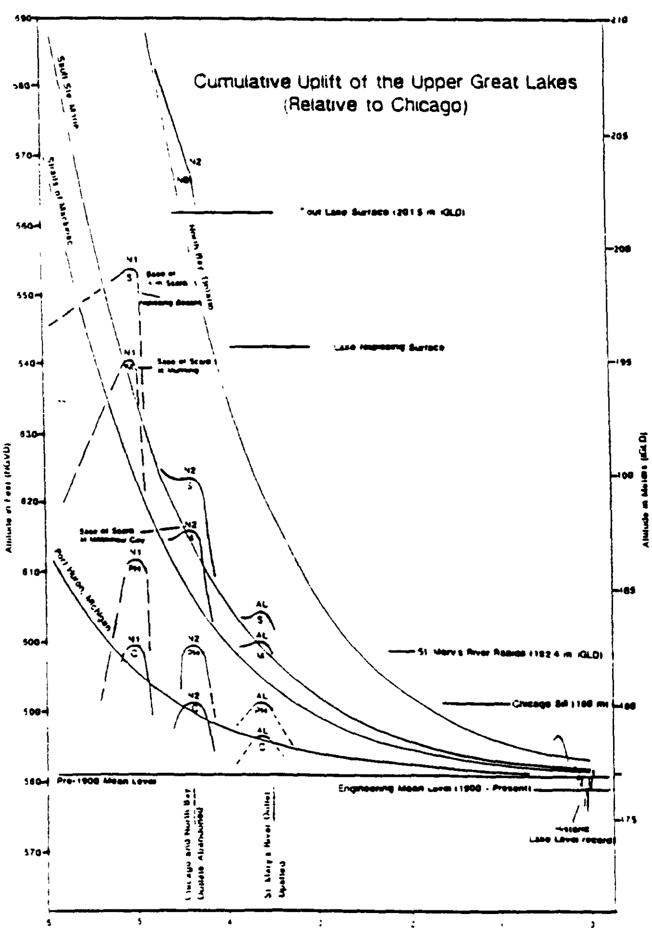

Figure 3

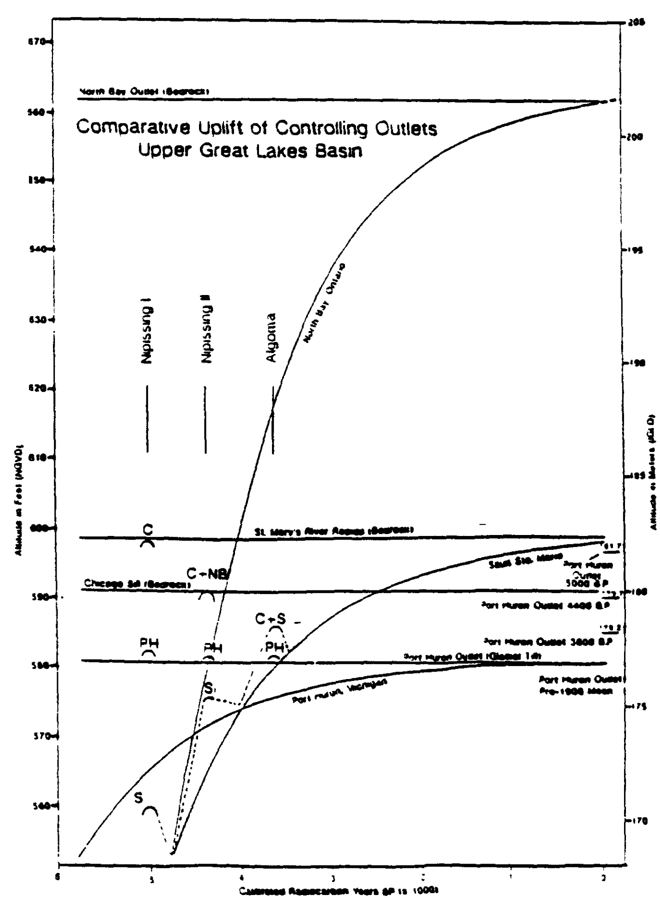

Figure 4

EOLIAN SAND TRANSPORT IN THE BACKSHORE - FOREDUNE PORTION OF THE LAKE MICHIGAN SHORELINE, INDIANA

Olyphant, G.A.[1], Bennett, S.W.[1], Fraser, G.S.[2], and Thompson, T.A.[2], [1]Department of Geological Sciences, Indiana University, Bloomington IN 47405, [2]Indiana Geological Survey, 611 North Walnut Grove, Bloomington IN 47405

A program of field monitoring has been initiated to study relationships between prevailing wind, boundary-layer wind shear, and resulting sand transport at West Beach on the Indiana National Lakeshore. Wind speed and direction are continuously monitored on the crest of the foredune ridge and vertical sand traps have been emplaced on the foredune ridge and in an adjacent blowout. Topographic surveys have been conducted four times and detailed measurements of wind profile characteristics and sand transport rates (when sand was moving) have been achieved on eight occasions.

Our records indicate that wind speeds were above the threshold for sand movement (ca. 5 m s^{-1}) at the field site on a total of 63 days between July 17 and December 12, 1990. The transport of sand was onto the beach (southerly wind) on 32 of the days and off the beach (northerly wind) on 31 of the days. The northerly winds were stronger so rates of sand transport were greatest during periods of onshore wind. Our calculations indicate that since mid-August, about 16,800 kg m^{-1} of sand have been transported off the backshore by onshore winds while 1,900 kg m^{-1} of sand have been transported onto the beach by offshore winds. The net loss of sand for the four-month period is about 14,900 kg m^{-1} (8.6 m^3 m^{-1}) which represents about 21 cm of backshore surface lowering.

CD ROM Archive and Atlas production: Vehicles for Data Integration

Chris Polloni, U.S. Geological Survey, Woods Hole, MA 02543

We are prepared to use CD ROM technology for archive and distribution of seismic profile and sidescan sonar data as well as vector and other raster imagery such as photographs. Sidescan mosaics are being used as base maps for other data sets such as bathymetry, dredge sites, sample locations, geomorphology, and other information that is spatialy relevant.

We have proposed to use the CD ROM as a media for data compilation, archiving and publication. This procedure requires that the data be formally released, reviewed for conformity, and having passed the review process, released for publication. All of the above will be accomplished with the CD ROM release. The most difficult part of publishing the CD ROM is finishing the readme file which resides in the root directory of the CD ROM and describes the data that is included.

The Southern Lake Michigan Coastal Erosion data set is an ideal candidate for publication by CD ROM. Most of the data are digital or in some form of graphic that can be scanned. Other data such as seismic lines and sidescan sonar records that are not digital will be summarized and the interpreted results published. The data are being staged in Arc/Info, MAPGEN, ISM, and MIPS. We have experience in combining data from these sources and displaying them on a PC using the DOS operating system and USGS software. The software is coded in the "C" language and is easily modified. Data is retrievable from CD ROM and can be restored to any system for reprocessing if desired. Our plan includes developing tools to provide easy access to the CD ROM from Arc/Info.

GEOCHEMICAL, PALEOMAGNETIC, AND MAGNETIC-PETROLOGIC STUDIES OF HOLOCENE SEDIMENTS IN SOUTHERN LAKE MICHIGAN: RECORDS OF DEPOSITIONAL CONDITIONS

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Integrated geochemical, mineralogical, paleomagnetic, and rock magnetic studies of Holocene sediments from Lake Michigan bear on many aspects of their history. The results delimit iron-sulfide authigenesis, contribute to intra- and inter-basin correlations, constrain sedimentation rates, and describe variations in the concentration and character of detrital magnetic particles that reflect depositional environments and changes in lake levels.

The distributions of sulfur species, organic and mineral carbon, and phosphate identify intervals in which authigenic magnetic iron sulfide minerals (such as the monosulfide greigite, Fe_3S_4) may have formed or in which detrital magnetic oxides may have been replaced by pyrite or vivianite. The geochemical and mineralogic results indicate that the magnetic record can be interpreted in terms of a magnetization acquired during or shortly after deposition that is carried by detrital grains. The geochemical signatures, although unrelated to magnetic

properties, may reflect interrelated changes in sediment chemistry, water chemistry, and sedimentation rates.

Paleomagnetic measurements, using a whole-core pass-through cryogenic magnetometer at the University of Rhode Island, have been completed on 12 cores. After alternating-field demagnetization, paleomagnetic-field secular variation records were obtained from most cores. These records resemble those in radiocarbon-dated sediments from Lake St. Croix, Minnesota, thereby permitting tentative age assignments and correlations.

Variations in the type, amount, and grain size of detrital magnetic minerals, determined from measurements of magnetic susceptibility (MS) and of artificial remanences acquired in the laboratory, record variable depositional conditions before human settlement. For example, a high content of coarse-grained magnetite is indicated by elevated values of MS combined with low ratios of anhysteretic remanent magnetization to MS. Such a relation may develop in a high-energy depositional environment, which in some settings reflects relatively low lake levels.

Results from 88 specimens from gravity core 4, in the southeastern part of the lake at a water depth of 80 m, register long-term (~1000-2000 yrs) and short-term (~200-500 yrs) changes in depositional conditions since 8.6 ka, the AMS ^{14}C age from the base of the core at 260 cm. From 240 to 160 cm, representing ~8 to 6 ka, the content and grain size of magnetite decreased; we attribute these changes to rising lake levels during the Chippewa phase. Abrupt and large changes in the character of magnetic mineralogy occur from 160 to about 120 cm (~5 ka); overall, the content of magnetite increases greatly, both in an absolute sense and relative to hematite. This trend, which apparently corresponds to the transition from the late Chippewa phase to the Nipissing phase, may reflect an increase in depositional energy at the site related to submergence of the mid-lake high and to resultant increased fetch of the larger lake. The magnetic-petrologic record from 160 to 15 cm is characterized by short-wavelength (10-25 cm) variations in magnetite abundance and grain size (high abundance corresponding to coarse grain size and low abundance to fine grain size), which may record fluctuations in lake level. A dramatic increase in magnetite abundance above 15 cm demarcates the onset of agriculture and industry in the catchment. This conclusion is supported by identification of spherical magnetite particles from industrial sources that comprise about half of the magnetic particles from depths of 5-8 cm.

Preliminary Survey of Littoral Drift Sand Deposits Along The Illinois Shore of Lake Michigan from Waukegan to Evanston

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Profiles of beach and lake bottom sand deposits were measured in 1989 and 1990 with a hydraulic probe at over 100 locations on the Illinois shore of Lake Michigan from Waukegan to Evanston. These data were compared to data collected by the Illinois State Geological Survey in 1975. Results show greatly depleted deposits of very fine sand veneering glacial clay tills. In many areas the sand veneer has been lost entirely, exposing the underlying clay to the erosive forces of storm waves. Profiles were also run adjacent to littoral barriers including harbor entrances and lakefills. Preliminary calculations show that the sand fillet north of Waukegan Harbor contains more than 6,000,000 cubic yards of sand. Substantially lesser amounts were found at the remaining barriers, all of which are downdrift from Waukegan Harbor.

MATHEMATICAL TRENDS IN THE EROSIONAL EVOLUTION OF A LOGARITHMIC-SPIRAL BAY ON THE ILLINOIS SHORE

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During nine months in 1989 (Feb.-Oct.), more than 60 meters of shoreline recession occurred on the Illinois Lake Michigan shore near North Point Marina in the northern reach of Illinois Beach State Park. Monitoring indicated the rapid erosional development of a log-spiral shoreline, an arcuate planform that approximates a curve defined by the equation for a logarithmic spiral. The equation, given in polar coordinates, is

$$r = r_0 e^{\theta \cot \alpha}$$

where r is the radius from the spiral center to the curve at any point, r_0 is the radius from the spiral center to the spiral origin (the headland where the spiral planform begins), θ is the angle between r_0 and r, and α is the constant angle between a tangent to the curve at any point and the radius vector at that point.

This type of coastal geometry has typically been studied only in its equilibrium stage. Thus, this monitoring program provided a unique opportunity to mathematically assess the planform evolution. For each of nine measured beach scarp positions between May 1 and October 19, linear regression was used to find the best-fitting, logarithmic-spiral curve, and the results were analyzed for chronological trends. All curves matched the measured data well, with correlation coefficients ranging from .9988 to .9998. A difference was seen, however, in the areal extent of the match. With time, the logarithmic-spiral erosion advanced farther down the coast, from a spiral

angle of 145 degrees on May 1 to a spiral angle of 195 degrees on October 19. Other trends observed during this down-coast advance were a decrease in the distance between the spiral origin and the spiral center, and a decrease in α.

A final log-spiral form is in steady-state equilibrium. This study demonstrates that a developing log-spiral form is in a state of dynamic equilibrium through its evolution as the form expands landward and downcoast. These observed trends have potential implications in predicting rates and geometry of shoreline recession behind and downdrift from the terminus of shore-parallel defense structures.

.PRESERVATION OF PATTERNS OF SHORELINE BEHAVIOR IN THE SOUTHERN PART OF THE LAKE MICHIGAN BASIN

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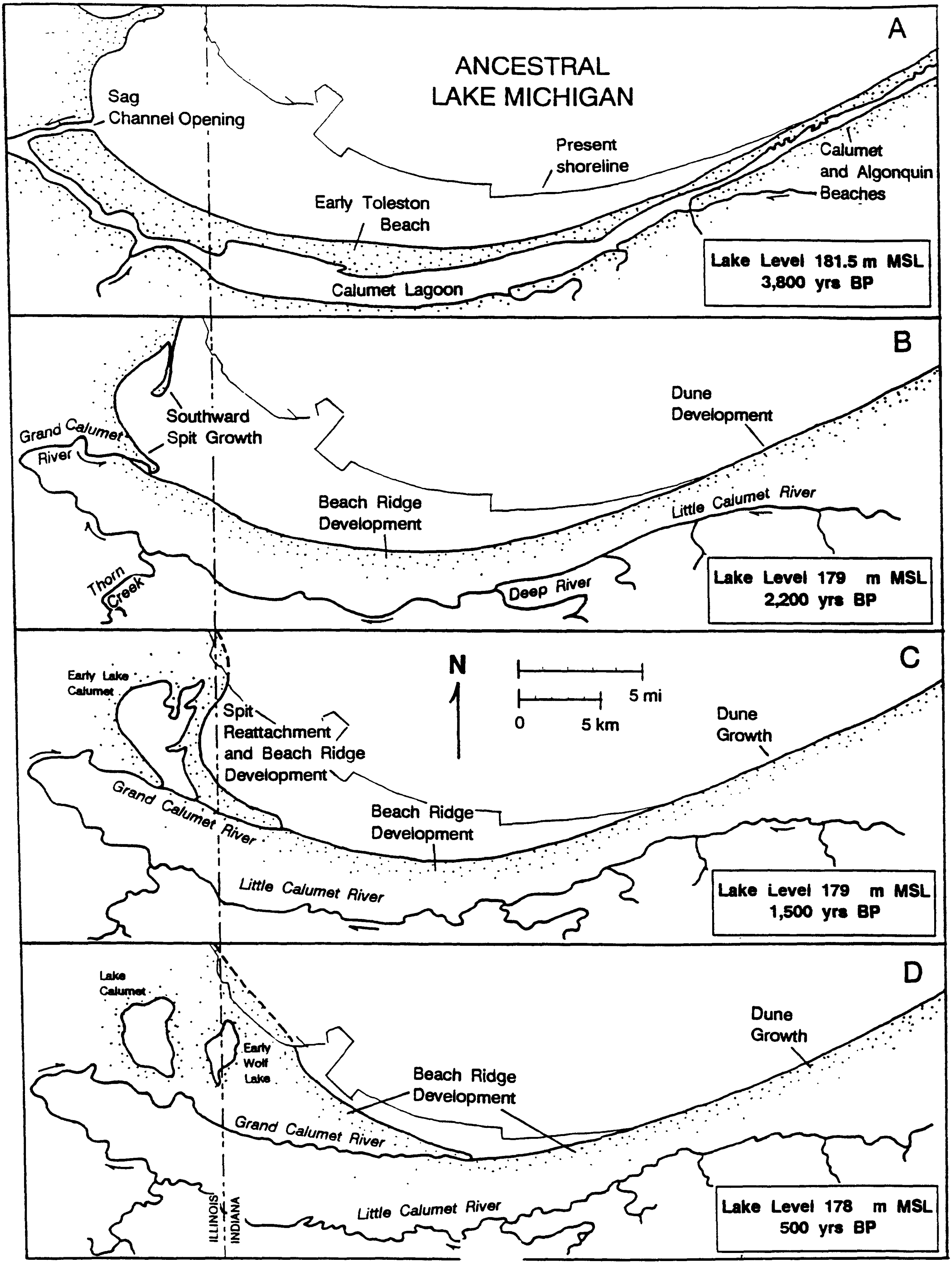
Throughout the late Pleistocene and Holocene, the southern part of the Lake Michigan basin was a sediment-rich system, receiving drift derived only from the eastern margin of the lake. Sediment from the western part of the lake did not reach the southern shore until after 3,500 yrs B. P., when the southern extension of the Graceland spit filled in an embayment in the western shore of Lake Michigan north of a headland at Stoney Island. At this time, sediment from both margins of the lake joined to rapidly fill the last vestiges of the embayment in the western part of the Calumet Lacustrine Plain.

The sediment accumulated in a series of spits that prograded from the Stoney Island headland to join shore-normal progradation in northwestern Indiana. The progradation in northwestern Indiana formed more than 150 beach ridges that arc across the Calumet Lacustrine Plain. Study of the timing of the beach ridge development suggests that lake level during the late Holocene may have been quasi-periodic at several time scales. The periods are 27 ± 6 years and 156 ± 13 years with a possible long-term fluctuation at approximately 600 years.


A
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Sag
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Present
shoreline
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Lake Level 181.5 m MSL
3,800 yrs BP
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Southward
Spit Growth
Grand Calumet
River
Dune
Development
Beach Ridge
Development
Little Calumet River
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Creek
Deep River
Lake Level 179 m MSL
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INDIANA
Lake Level 178 m MSL
500 yrs BP

MODELING BEACH AND NEARSHORE PROFILE RESPONSE TO LAKE LEVEL CHANGE AND STORM WAVE FORCING

William L. Wood
Great Lakes Coastal Research Laboratory
School of Civil Engineering, Purdue University

The equilibrium beach concept is based essentially on two premises. The first is that the form or shape of the nearshore profile is known, the second is that the nearshore profile responds on a time scale similar to that of water level change. The results of this study have shown that the nearshore profile form found by Dean (1977), $h(x) = Ax^{2/3}$, is appropriate for use in describing the "average" or characteristic nearshore profile found on the Great Lakes. However, the results have also shown that nearshore profiles respond on a much longer time scale than that of mean annual water level change. These results indicate that the equilibrium beach concept should not be used to predict nearshore response to short term water level changes on the Great Lakes. However, use of this concept may be appropriate for prediction of changes in the nearshore due to changes in water level which occur over a relatively long period of time (order of years). These results are similar to those found by Hands (1980). Hands concluded that response of nearshore profiles on the Great Lakes appeared to be "out-of-phase" or lagging behind that of water level change. In addition, Hands concluded that the lag between profile response and water level change was on the order of a few years.

The effect of falling water level on the nearshore profiles could not be determined due to the slower than expected response of the profiles to water level change. Since questions still exist as to the applicability of the equilibrium beach concept to falling water level, it is strongly suggested that this concept not be applied under conditions of falling water level.

Results of this investigation fail to support the argument that the shape factor A is dependent on mean sediment size. Although some paired data grouped around the curves developed by Moore (1982), there were not significant relationships supported by statistical analysis. This result is contrary to the findings of Dean (1977), Hughes (1978), and Moore (1982).

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PRODUCTS

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USGS Circular (Public Issues in Earth Science)

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DRAFT OUTLINE FOR SYMPOSIUM VOLUME

I. Introduction

A. Foreword — Sallenger, Williams

B. History of the Great Lakes — Larsen, Hansel, Colman

C. Coastal evolution of southern Lake Michigan — Chrzastowski, Todd

II. Framework

A. Introduction-Folger, Foster

B. Shore characteristics — Chrzastowski, Thompson

1. Engineered structures — Chrzastowski, Terpstra

C. Sediment distribution

1. Thickness — Foster, Folger, Colman, Shabica, Pranschke

2. Bottom texture (nearshore) — Folger, Foster

3. Bottom texture (offshore) — Foster, Colman

D. Summary-where and how much sand? — Foster, Folger, Shabica, Chrzastowski, Pranschke

III. Lake Level

A. Introduction- Lake level history — Colman, Larsen, Hansel

B. Holocene beach ridges — Thompson, Chrzastowski, Hansel, Dott

C. Isostatic tilting — Larsen

D. Deep lake sedimentary record

1. Stratigraphy — Colman, Foster, Forester, Reynolds, King, Keigwin

2. Sedimentation rates and chronology — Colman, Jones, Forester, Bothner, R. Thompson, Foster

3. Summary-can lake level get higher (lower)? — Colman and others

IV. Processes affecting coastal erosion

A. Introduction — Barnes and others

B. Active sediment transport processes

1. Bluff and lake bed recession — Jibson, Booth

2. Waves and currents — Haines, Booth, Hunter

3. Ice — Kempema, Reimnitz, Barnes, Haines, Holman

4. Wind — Olyphant, Thompson

C. Sediment Budget-Sources, pathways, sinks — Colman, Chrzastowski, Foster, Barnes, Haines, Wood, Olyphant

D. Summary-How will the shoreline respond to future lake level changes?

1. Beaches — Barnes, Chrzastowski, Haines, Todd, Hunter, Shabica

2. Bluffs — Jibson

3. Lake bed	Colman, Foster, Chrzastowski, Booth, Folger
4. Man-made structures	Terpstra, Chrzastowski,
5. Models	Wood

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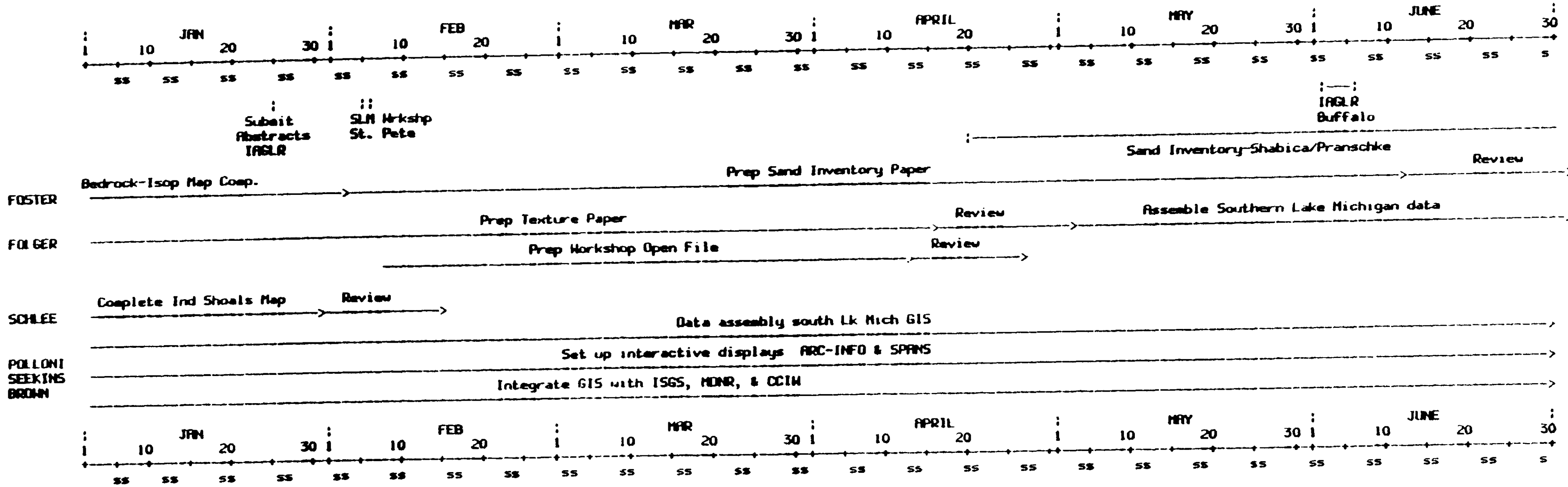
SOUTHERN LAKE MICHIGAN

FRAMEWORK

Data Acquisition, Processing,
Compilation, & GIS Development

CY 1991



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APPENDIX A

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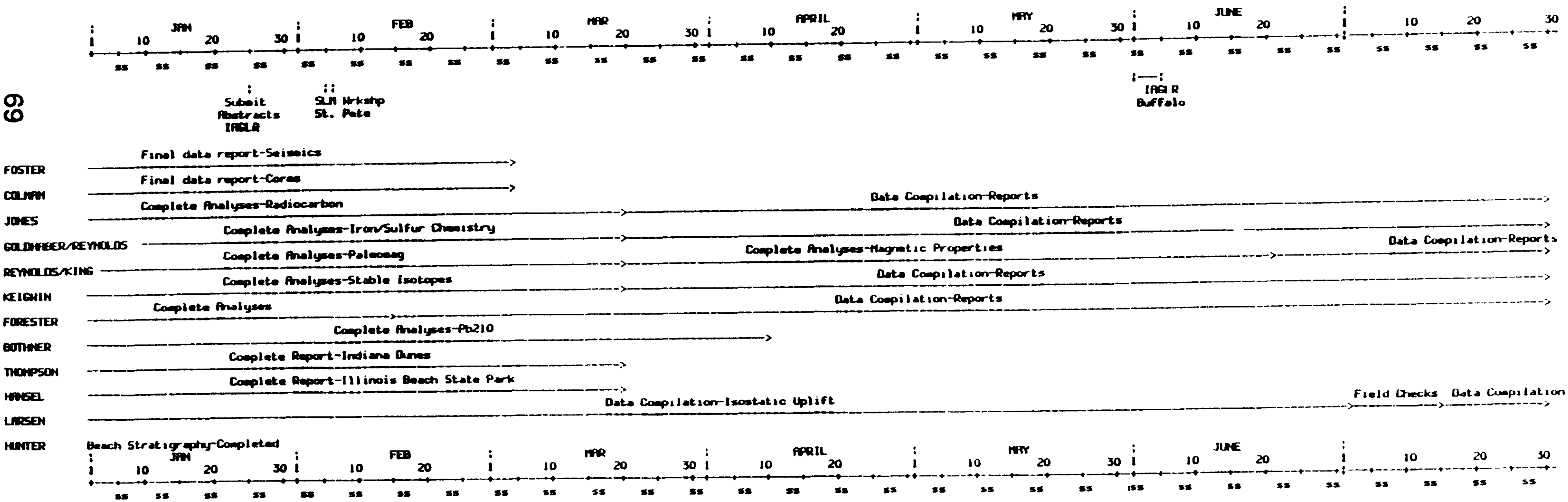
SOUTHERN LAKE MICHIGAN

LAKE LEVEL

Data Acquisition, Processing,
& Compilation

CY 1991



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APPENDIX B

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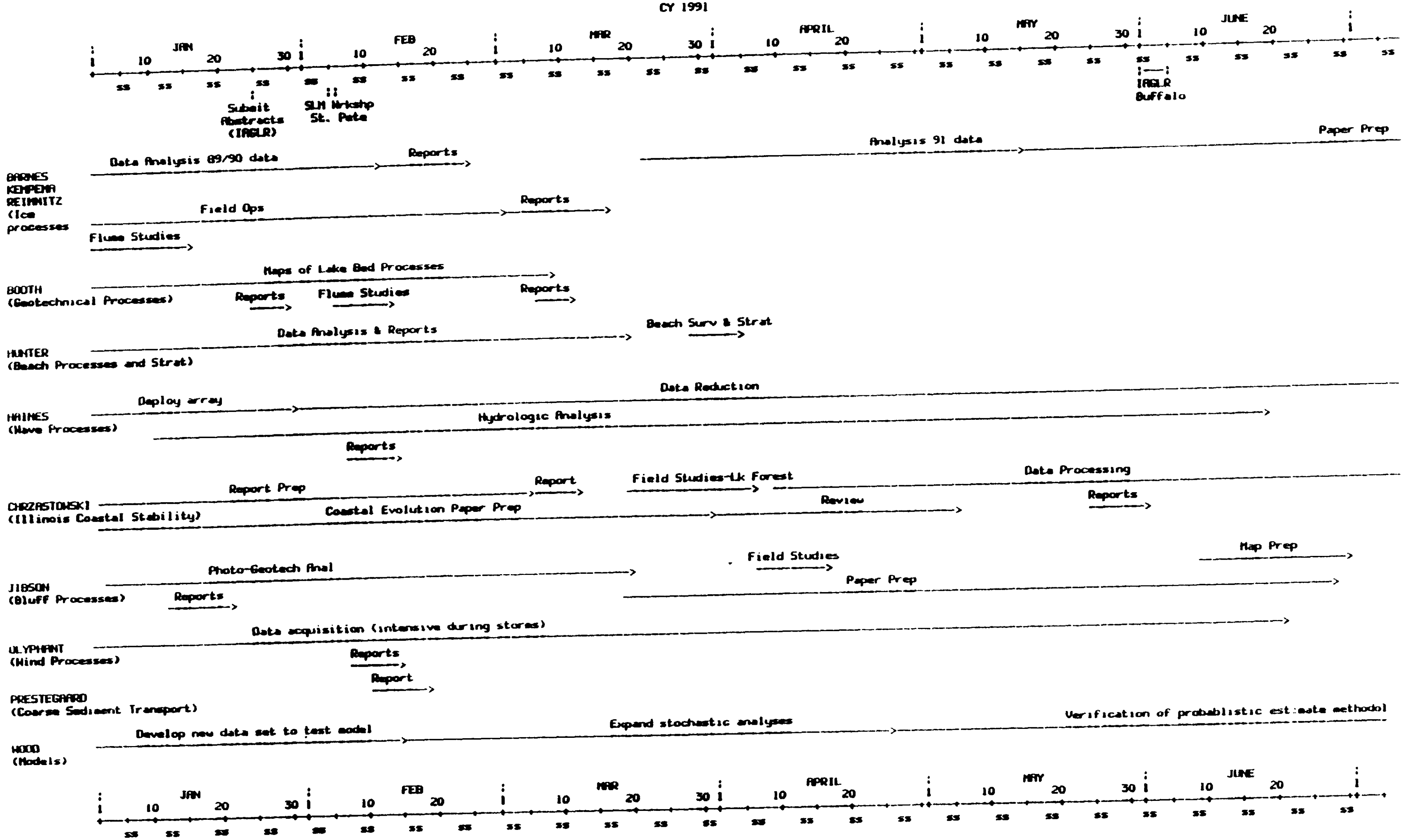
SOUTHERN LAKE MICHIGAN

PROCESSES

Data Acquisition, Processing, Compilation

CY 1991



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APPENDIX C

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SOUTHERN LAKE MICHIGAN

SYMPOSIUM VOLUME

COMPLETION SCHEDULE

1991-1992

1991

MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
1 10 20	1 10 20	1 10 20	1 10 20	1 10 20	1 10 20	1 10 20	1 10 20	1 10 20	1 10 20	1 10 20	1 10 20	1 10 20 1

Vol Outline for Review ——> Prepare expanded outlines of Framework and Lake Level papers for review ——> Prepare expanded outlines of Process papers ——> :: Papers completed and

Present Symposium Vol. Papers at 4th Annual Southern Lake Michigan Workshop

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1992

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submitted for review ——> Papers in review ——> Papers revised and assembled ——> Papers to IAGLR

APPENDIX D

APPENDIX E

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