BEACH AND NEARSHORE SEDIMENTATION, WESTERN LAKE MICHIGAN

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Prepared by the

ILLINOIS STATE GEOLOGICAL SURVEY
for
THE ILLINOIS COASTAL ZONE
MANAGEMENT PROGRAM

The preparation of this document was financed in part by the National Oceanic and Atmospheric Administration, United States Department of Commerce under the Coastal Zone Management Act of 1972, and in part by the State of Illinois Department of Transportation, Division of Water Resources.

October 1975

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ABSTRACT

Systematic measurement of barometric pressure, wind speed, wind direction, wave period, breaker height, angle of wave approach, and longshore current velocity at Illinois Beach State Park in 1974 and Sheboygan, Wisconsin in summer 1972 shows the relationship between these parameters and sediment movement on the beach and in the nearshore for a common summer storm event. The order of natural events involved in sediment movement in such a storm is shown.

Determination of the amount of sediment transported adds to the basic information that must be accumulated for the purpose of estimating the longshore sediment budget for the Illinois shore.

Introduction

Two time-series studies of wind, wave, and sediment process-response mechanisms that operate in the beach and inner nearshore areas of western Lake Michigan were conducted as part of a long term field program (Fox and Davis, 1973a) as well as part of the Illinois Coastal Zone Management Project. The ultimate objective of this program is the quantitative prediction of coastal changes utilizing computer modeling techniques. The study areas at Illinois Beach State Park, Zion, Illinois (1974) and at Sheboygan, Wisconsin (1972) (Figures 1 and 2),which represent the only large stretches of sand beach on the western coast of Lake Michigan, were occupied for 15 and 30 days respectively during the summers of 1974 and 1972 respectively. The studies included systematic observation of environmental parameters and daily surveys of the beach and adjacent inner nearshore zone.

Among the environmental parameters measured were barometric pressure, wind speed and direction, wave period, breaker height and angle of approach, and longshore current velocity. Detailed topographic maps

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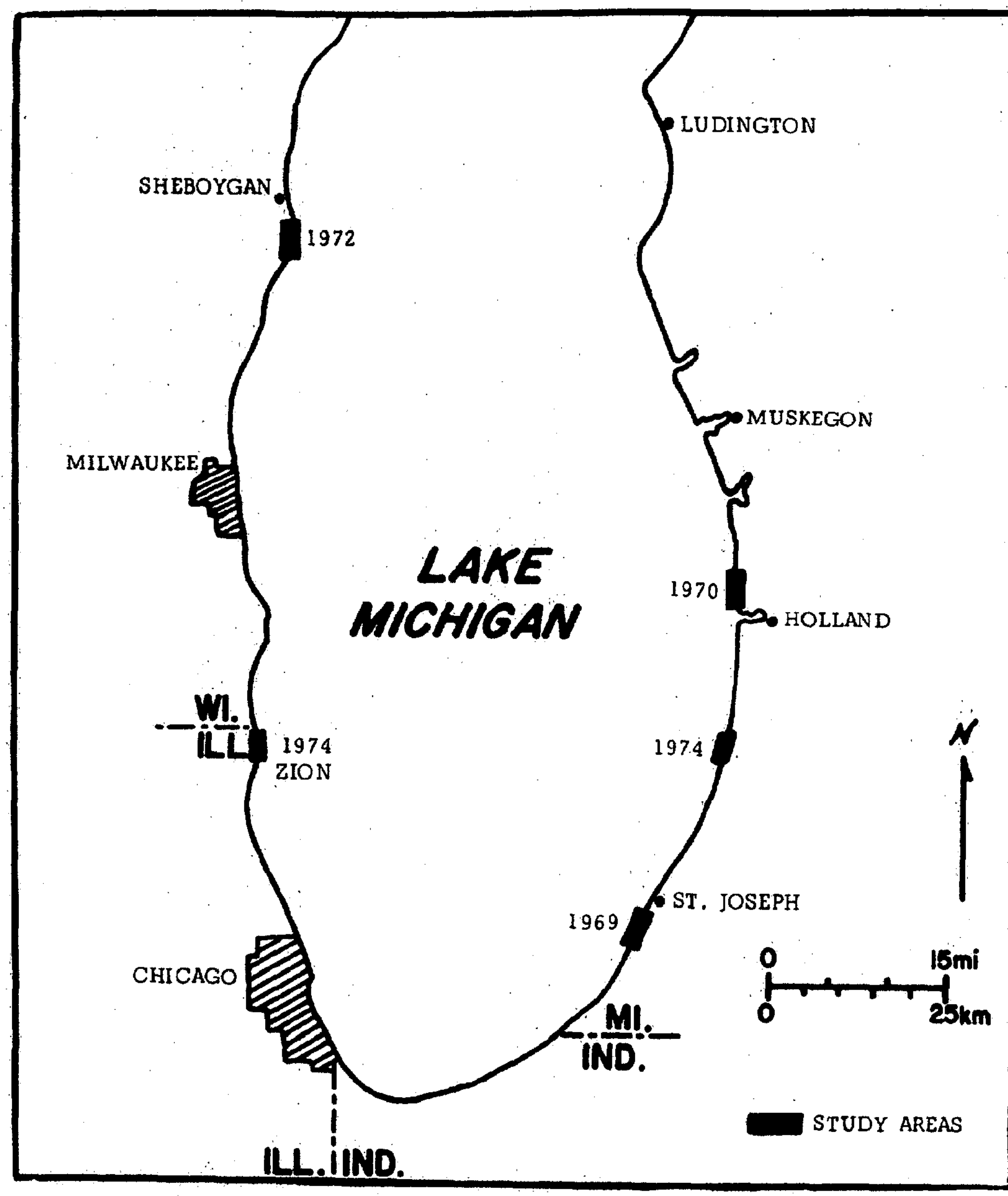

Fig. 1 - Index map showing location of study areas.

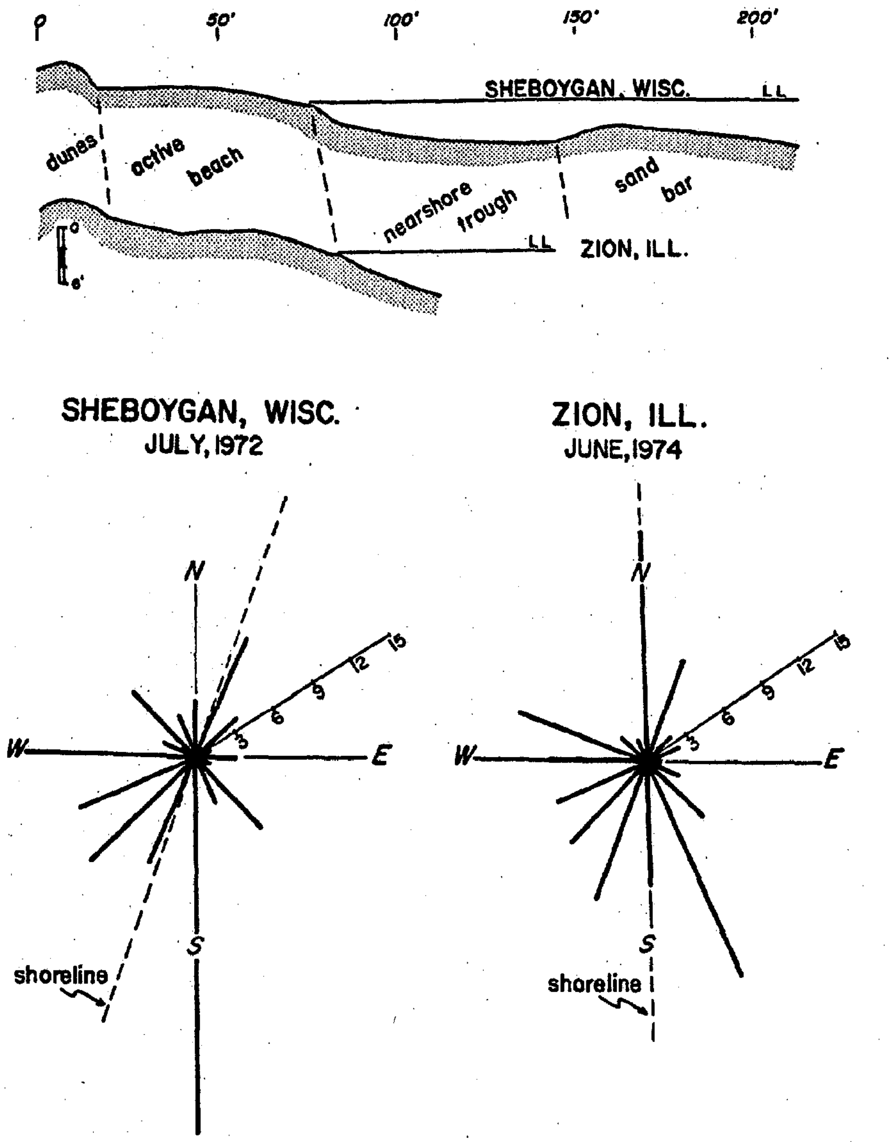

Fig. 2 - (Top) Beach and nearshore profiles from Sheboygan (above) and Zion (below).
(Bottom) Wind direction and duration in hours for Sheboygan and Zion.

were prepared from daily surveys of a small portion of the coast; 800 feet at Zion and 1600 feet at Sheboygan. Comparison of daily maps utilizing computer techniques permits quantitative analysis of the changes in the beach and adjacent nearshore areas. Erosion and deposition data can be related to trends in the environmental variables thus providing the framework for preliminary or conceptual models. These models are then formulated into quantitative simulation models which may have prediction capabilities as well as broad application to Lake Michigan's western shore. To date such a simulation model has been developed for the eastern coast of Lake Michigan (Fox and Davis, 1973b) with gratifying results. The Zion portion of the study was partially supported by funds made available through the U. S. Coastal Zone Management Act of 1972, Office of Coastal Zone Management, NOAA, the Illinois Division of Water Resources and the Illinois State Geological Survey. The Sheboygan portion of the study was supported by the Geography Branch, Office of Naval Research Contract #388-092. Thanks are due to Mr. Robert Needham, Ranger in Charge at Illinois Beach State Park for permission to conduct the studies on the park shore and for many other kindnesses.

Study Areas

The western coast of Lake Michigan has few stretches of well developed sand beaches. There are significant gravel fractions present on the beach and adjacent nearshore zone in both study areas. Gravel was the dominant beach sediment at Zion, Illinois during the summer of 1974. Low coastal dunes landward of the beach (Fig. 3) serve as a primary source of sediment for the beaches in both areas. They consist mainly of medium to fine sand. The shoreline is slightly sinuous at both sites with the greater amplitude at Sheboygan. Late spring and early summer beach accretion was evident at both sites in the form of welded ridges of sediment and relatively wide beaches considering the lake level rises of 1968-1974. A description of the general area and the nature of its sediments and their distribution is given by Hester and Fraser (1973) and Fraser and Hester (1974).

A marked difference existed between the longshore sand bars in the two areas. At Sheboygan there were two bars (Fig. 2); one at a distance of about 100 feet from shore with its crest at a depth of 3.5-4.0 feet and another more continuous bar at a distance of 350-400 feet with its crest 6 feet deep. Only a single, continuous bar was present at Zion (Fig. 4). It was about 300-350 feet from shore with its crest at a depth of 7 to 8 feet.

The lakeward slope of the nearshore was steeper at Zion than at Sheboygan. This coupled with the absence of a shallow nearshore sand bar (Fig. 4) caused significant differences in the monitored variables at the two sites. The steep and effectively non-barred configuration at Zion is an important factor in the recent erosion rates and is discussed in more detail later.

Because the emphasis of this report is on the Illinois portion of the Lake Michigan shore, the detailed discussion of the process-response phenomena is restricted to the study area at Illinois Beach State Park. The site is located a few hundred yards south of the lodge at Illinois Beach State Park. A detailed analysis of the Sheboygan, Wisconsin site has been published by Fox and Davis (1973a). The same site at Illinois Beach State Park has been occupied for continuation and expansion of these studies for the 1975 and 1976 field seasons for the purpose of monitoring large storm events and measuring the amount of work done by storms of specific energy.

Fig. 3 - Site of the Zion shore study, just south of Illinois Beach Lodge. A partially eroded dune is in the foreground. The Zion Nuclear Generation Station is in the background.

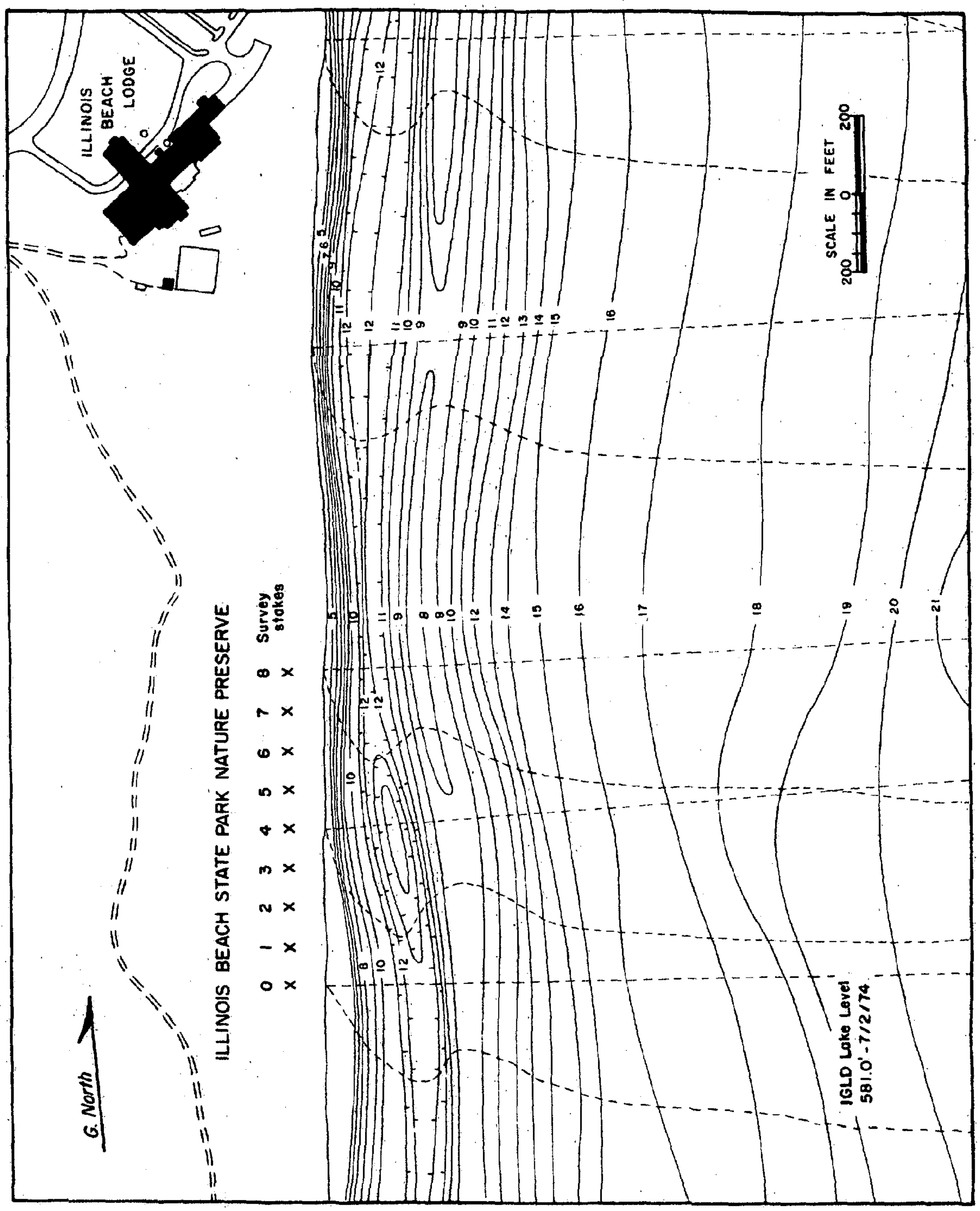
ILLINOIS BEACH STATE PARK NATURE PRESERVE
ILLINOIS BEACH LODGE
G. North
0 1 2 3 4 5 6 7 8 Survey stakes
SCALE IN FEET
200 0 200
IGLD Lake Level 581.0'-7/2/74

Fig. 4

Meteorology

Any consideration of coastal sedimentation must include an analysis of the weather systems which affect the study areas and their relationships to coastal processes. A general summary of weather in the area is presented by Dugas and Mecum, 1975. Western Lake Michigan is in the belt of prevailing westerly winds with cyclonic low pressure systems as the dominating energy generating mechanism. During the summer months, which is the season during which these field studies were conducted, cyclones move in a west to east direction and pass across the Great Lakes area. Prevailing winds are from the south and southwest (Fig. 2).

As the low pressure system approaches the west coast of Lake Michigan, winds are from the southwest to south-southeast along the beach. After the center of the cyclone passes over the west coast there is a reversal of wind direction to the north. It is at this time that wind speed is generally quite high and large waves are generated.

Coastal Processes

Previous studies both on Lake Michigan and on marine coasts have demonstrated that fluctuations in barometric pressure are of prime importance in the generation of coastal processes and in the eventual morphologic responses. The periodic passage of cyclonic systems and the accompanying fall and rise in barometric pressure causes winds to change speed and direction. This in turn changes the size and direction of wave approach. The waves themselves, coupled with the longshore currents generated by the waves bring about significant changes to the beach and inner nearshore zone.

Observations on wave period, wave steepness, breaker height, breaker angle, longshore current, temperature, and wind direction were made five times each day (0500, 0900, 1300, 1700 and 2100 hrs.) during the 15-day time-series study. Barometric pressure and wind speed were added to these raw data and were smoothed using computer derived Fourier analysis as described by Fox and Davis (1971). Smoothed curves representing the first ten harmonics were then plotted in order to analyze trends and compare curves for the observed variables (Fig. 5).

Fig. 4 - (Opposite) Location of Zion shore study showing the nearshore hydrography with one foot contours. Depth is measured from water level, 581 feet IGLD. The curved dashed lines represent profiles of the bottom along the straight dashed survey lines. The scale for the profiles is 1 foot = one tenth foot.

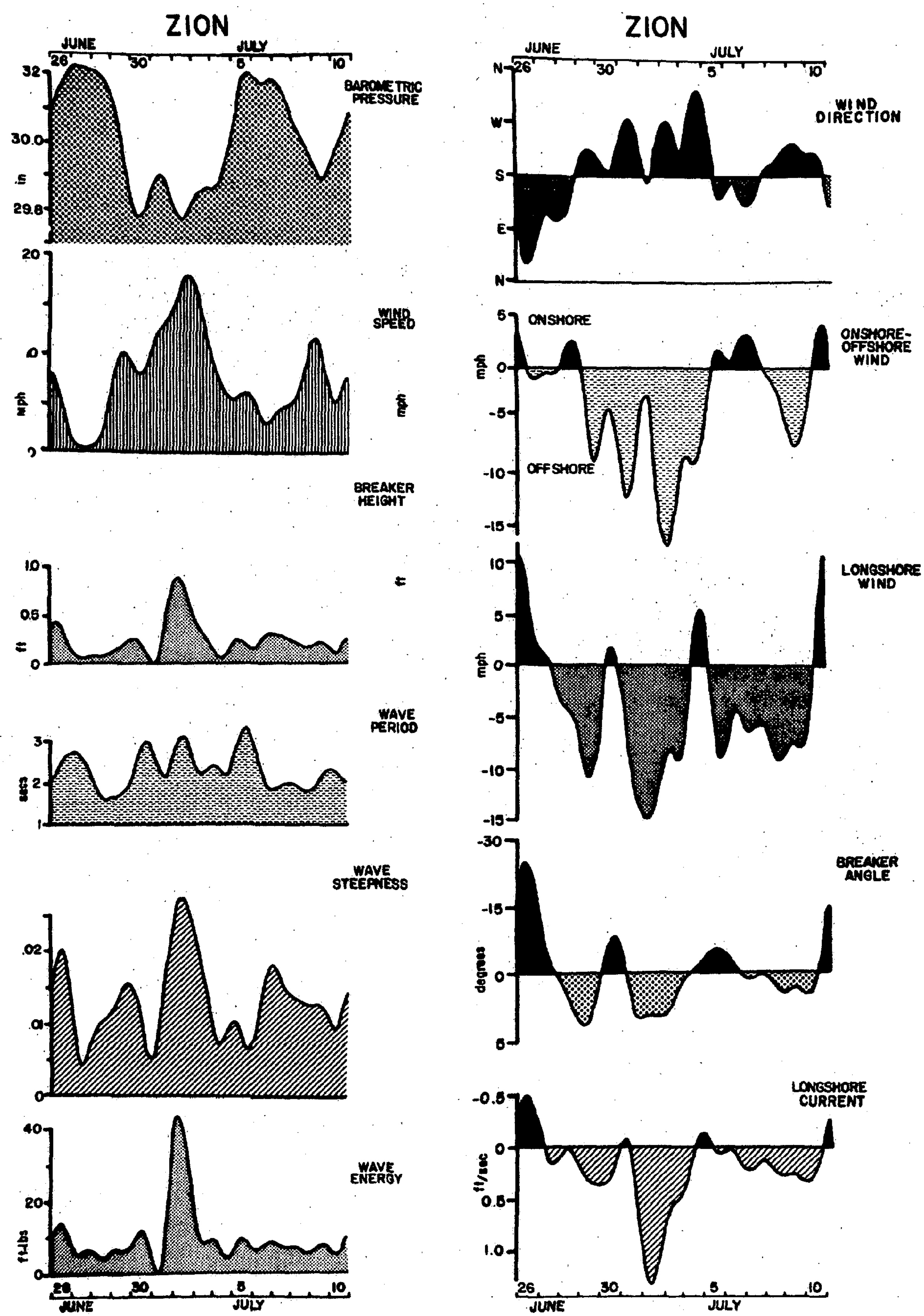
ZION
JUNE
JULY
BAROMETRIC PRESSURE
WIND SPEED
mph
BREAKER HEIGHT
ft
WAVE PERIOD
secs
WAVE STEEPNESS
WAVE ENERGY
ft-lbs
ZION
WIND DIRECTION
ONSHORE
OFFSHORE
ONSHORE-OFFSHORE WIND
mph
LONGSHORE WIND
BREAKER ANGLE
degrees
LONGSHORE CURRENT
ft/sec

Fig. 5

Overall energy conditions during the study period were low in comparison with previous time-series studies on Lake Michigan. Only one low pressure system passed over the study site during the period and the only relatively high energy conditions during the study were associated with this system (Fig. 5). On June 29, the barometric pressure began to drop rapidly and remained low until a rapid rise took place on July 4. The period of July 1 and 2 marked the minimum values for barometric pressure and the maximum energy conditions of the study period.

Wind speed reached 23 mph from the west-southwest (offshore) but had a rather large alongshore component (Fig. 5). This alongshore wind component generated the most rapidly moving longshore currents of the study period; 2.11 ft/sec to the north. This also marked the period of largest breakers. Maximum height of 1.1 ft. was recorded on July 2 at the same time as the highest longshore current velocities were observed. A peak for wave period also occurred at that time although values for this parameter were generally quite low and showed little variation throughout the study period (Fig. 5).

Major peaks for wave steepness and wave energy also coincide with the previously mentioned peaks on July 2 (Fig. 5). The maximum steepness was 0.031 and maximum wave energy was only 594.3 ft. lbs. per linear foot of wave crest. This is quite low in comparison to a maximum of 1403 ft. lbs. during the study at Sheboygan, Wisconsin in 1972 (Fox and Davis, 1973a).

Overall process patterns observed during the 15-day time-series correspond quite closely to those observed during previous studies (Fox and Davis, 1971; 1973a). The conceptual model developed during those previous studies (Davis and Fox, 1972) is therefore applicable to the Zion area as well. As barometric pressure drops, wind speed and breaker height increase with a corresponding increase in longshore current velocity (Fig. 6).

Topographic Responses

The generally low energy conditions that prevailed throughout the study period resulted in only minor topographic changes through erosion and deposition. At no time during the 15-day study did wave and swash action reach the backbeach area; it was confined to the foreshore zone.

Fig. 5 - (Opposite) Diagram summarizing the barometric, wind, wave current and energy measurements made at Zion during the last part of June and the first part of July 1974.

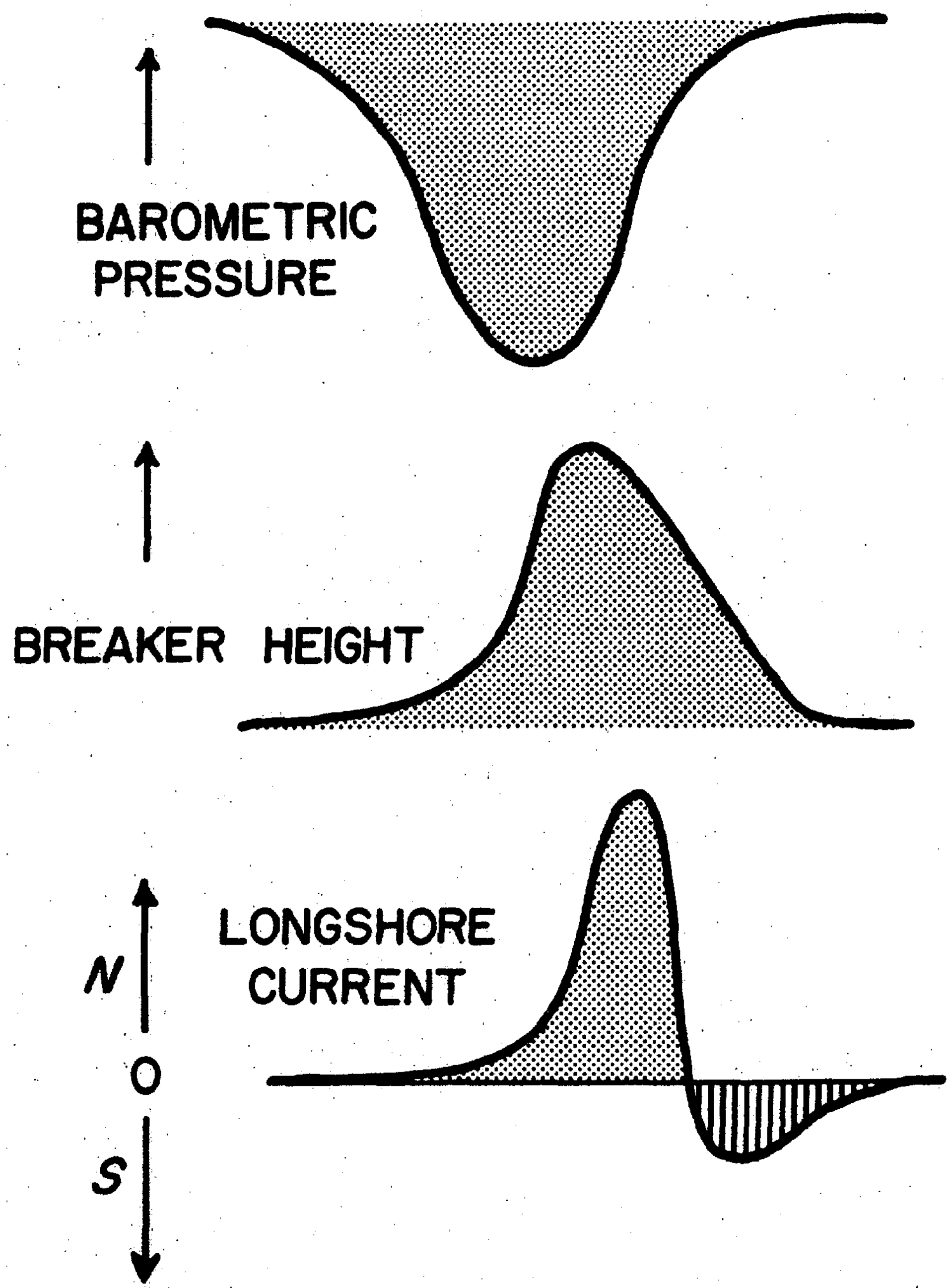

Fig. 6 - Diagram illustrating the relationship between barometric pressure, breaker height and longshore current direction for the Zion beach study.

Daily surveys of the 800 foot long study site were conducted in order to record erosion and deposition. These surveys consisted of nine profile traverses spaced at 100 foot intervals and extending into the lake to a depth of at least four feet (Figs. 2, 8 and 9). The stake and horizon method of Emery (1961) was used for these surveys. Daily maps were compared using the computer in order to locate and quantify beach and nearshore changes. These maps were finally grouped into periods during which similar conditions prevailed in order to show patterns that can be related to the coastal processes which produced the changes. The four map periods utilized are June 25-30, June 30-July 2, July 2-3, and July 3-10. For discussion purposes significant changes will refer only to erosional or depositional changes involving more than 0.5 ft. of elevation.

During the initial six days of the study (June 25-30) there was no significant erosion or deposition in any part of the study area. This reflects the low energy conditions that prevailed during that period (Fig. 5). The next three-day period (June 30-July 2) was marked by significant deposition at both ends of the study area with erosion near the middle (Fig. 7). Erosion was confined to a narrow band along the foreshore zone whereas deposition took place within and just beyond the plunge zone in depths of 1-2 feet. Approximately 50 cubic yards of material were removed from near the strand line and deposited just below water level. The next daily interval (July 2-3) marked the period of maximum energy imparted to the study area (Fig. 5) wherein significant erosion occurred over most of the area adjacent to the strand. It was confined to a rather narrow band including the plunge zone and beyond to a depth of about 2.5 feet (Fig. 8). The material amounted to more than 350 cubic yards and was entirely removed from the study area. The last several days of the study (July 3-10) were much like the first part in that low energy conditions prevailed (Fig. 5) and no significant changes in topography resulted.

In summary, the only significant topographic changes took place during the relatively high energy period of June 30-July 3. As energy increased, erosion of the foreshore took place with concurrent progradation of the plunge step (Fig. 5). This is in agreement with the observations of Kerhin (1971) on the west side of Lake Michigan. Maximum energy conditions were marked by erosion which took place only in and just beyond, the plunge zone (Fig. 8).

Fig. 7 - (Following page) Diagrams showing changes in nearshore bottom contours before and after the storm event of June 30-July 2. Contours are in feet above (+) or below (-) water level. Distance from the base-line is marked at the left. Sites of erosion and deposition are shown in the bottom diagram.

Zion, ILL.

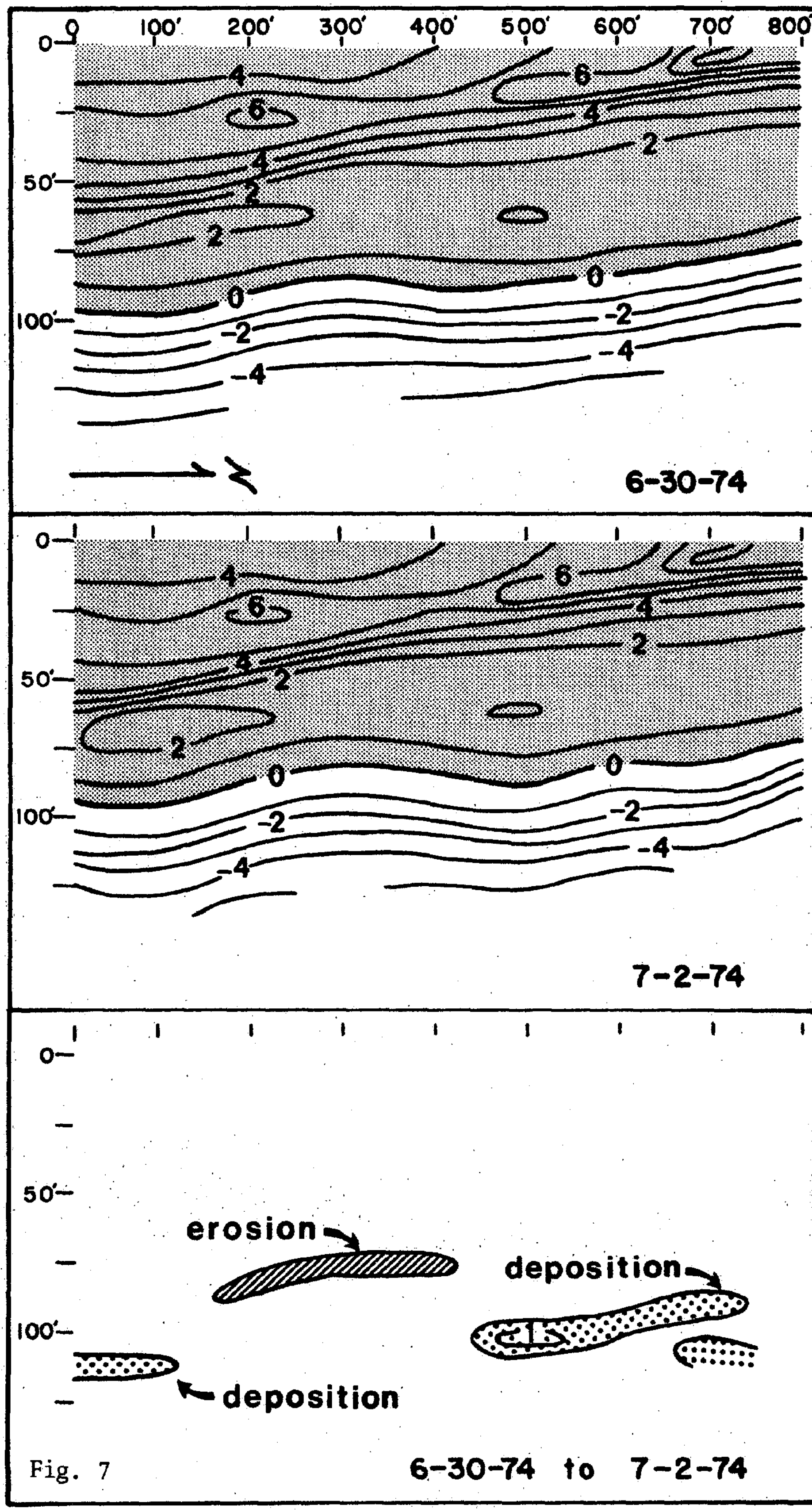

Fig. 7

Zion, ILL.

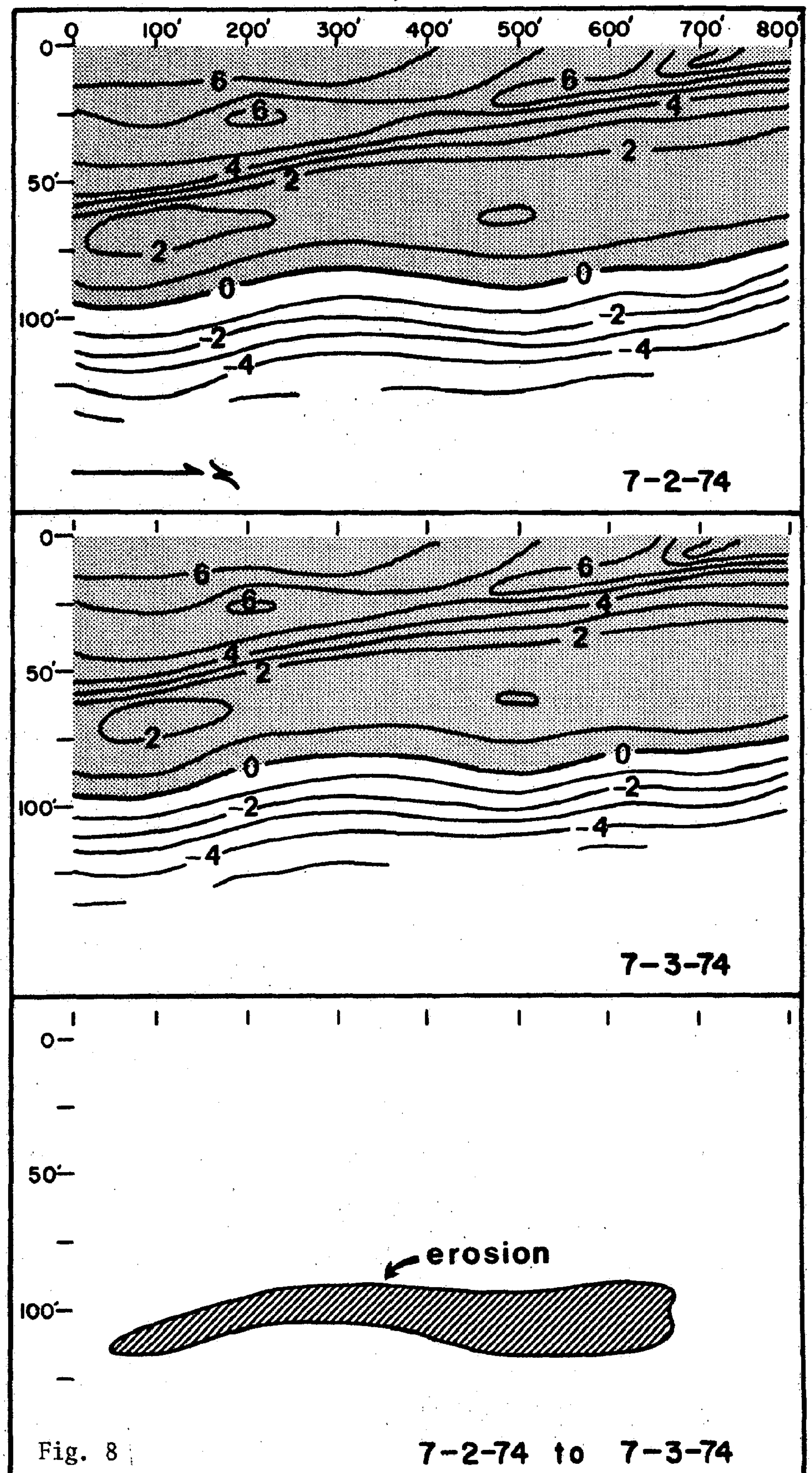

Fig. 8

Summary

Coastal processes along western Lake Michigan respond directly to low pressure systems that move in a generally west to east direction. Previously developed conceptual models of these processes are applicable to this area. Changes in the coastal processes, especially breaker height and direction of approach, and longshore current velocity and direction, are predictable, at least semi-quantitatively.

Topographic changes are restricted to periods of high energy. Initial changes take place in the form of a combination of foreshore erosion and deposition in the plunge zone. Peak energy conditions result in considerable erosion of the plunge zone with eventual retreat of the foreshore beach as these conditions prevail.

The steep nearshore slope and the position of longshore sand bars along western Lake Michigan permits waves to approach the shore with little or no effect from the bottom. Therefore wave energy at the water's edge may be high. In addition, the depth of water causes little refraction until the waves are only a few feet from shore. This results in a narrow effective longshore current for transporting sediment. Consequently there is less lateral sediment transport with respect to onshore-offshore transport than on a coast with a less steeply inclined nearshore such as in eastern Lake Michigan.

The significance of the two storm periods studied here lies in the fact that the one of lesser energy made essentially no change in the shore or nearshore (Fig. 7). On the other hand, the second storm, which was of an energy level that occurs commonly in the study area, moved more than 350 cubic yards of material. Both storms lie near the energy threshold of significant sediment transport and therefore offer a tentative standard for determining storms that move appreciable quantities of material on the portion of the shore occupied by the Illinois-Wisconsin beach ridge sand plain.

Fig. 8 - (Preceding page) Diagrams showing changes in nearshore contours before and after the storm event of July 2-3, 1974. Contours are in feet above (+) or below (-) water level. Distance along the shore is marked along the top. Distance from the base-line is marked at the left. Sites of erosion and deposition are shown in the bottom diagram.

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