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AN ASSESSMENT OF THE ENVIRONMENTAL EFFECTS OF DREDGED MATERIAL --ETC(U)
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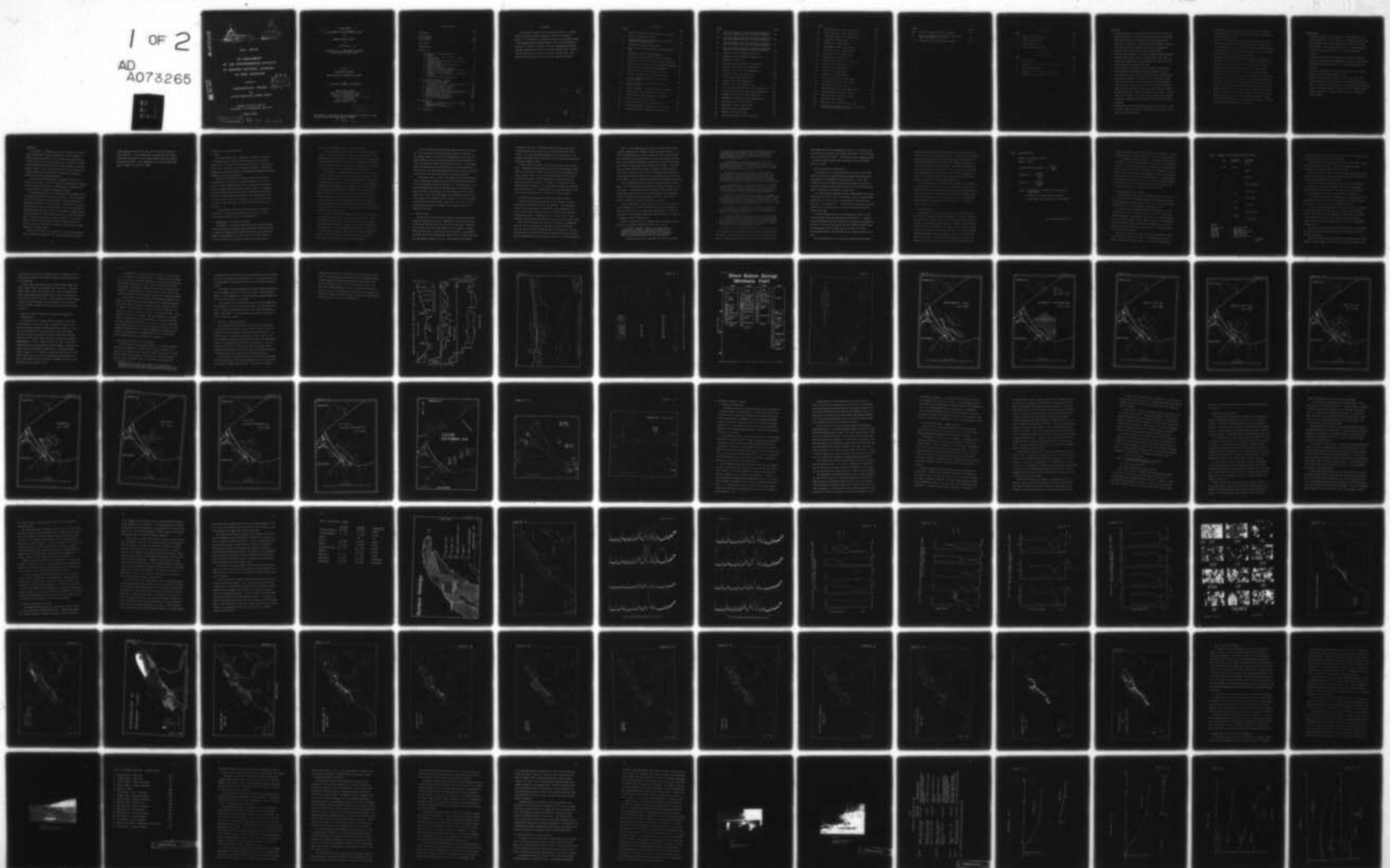

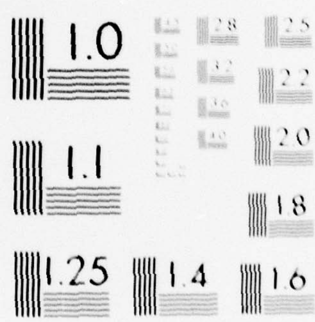

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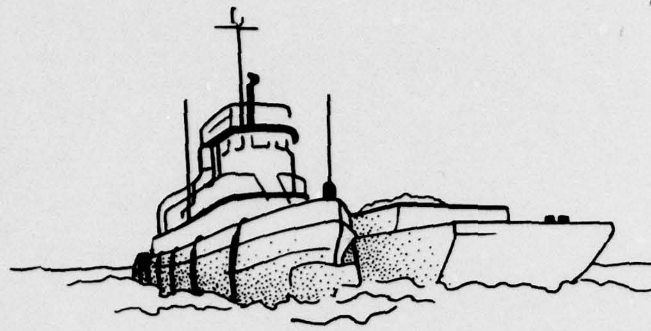

FINAL REPORT

AN ASSESSMENT OF THE ENVIRONMENTAL EFFECTS OF DREDGED MATERIAL DISPOSAL IN LAKE SUPERIOR

Volume 2

Sedimentation Studies

By

Jay Van Tassell and J. Robert Moore

MARINE STUDIES CENTER
UNIVERSITY OF WISCONSIN, MADISON

March, 1976

FINAL REPORT

AN ASSESSMENT OF THE ENVIRONMENTAL EFFECTS OF DREDGED MATERIAL DISPOSAL IN LAKE SUPERIOR

A REPORT TO THE U.S. ARMY CORPS OF ENGINEERS
FROM THE MARINE STUDIES CENTER

Volume 2

SEDIMENTATION STUDIES:

DULUTH-SUPERIOR AND KEWEENAW STUDY AREAS

By

Jay Van Tassell and J. Robert Moore

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THE AUTHORS

This report was prepared by Mr. Jay Van Tassell and Dr. J. Robert Moore of the Marine Research Laboratory, University of Wisconsin-Madison. Mr. Van Tassell is a research assistant, and a graduate student in the Oceanography and Limnology Program. This study was directed by Dr. Moore. Dr. Moore is Professor of Geology, Oceanography and Marine Sediments and Associate Director of the Marine Studies Center. Much of the work during the first year of this project was done by Dr. James Booth, research associate, and Mr. John James, research assistant.

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CONCLUSIONS

1. The relative fineness of some harbor sediment compared to beach and nearshore sediments of Minnesota and Wisconsin Points indicates that beach nourishment utilizing sediments from these sampled harbor sites would be impractical. Beach nourishment on Minnesota Point has previously been only a temporary solution with noticeable beach additions lasting less than seven years after deposition.

2. Sediment dispersal patterns in the Duluth-Superior area are generally characterized by sand movement in areas shallower than 60 feet. In deeper areas, muddy sand to the south grades into sandy mud in the deep northern portions of the study area.

3. From a geological perspective, the most suitable in-lake disposal sites are those in which bottom material and dredge spoil have equivalent textural and compositional characteristics insuring that the substrate and degree of mobility of the sediment would remain approximately the same. The dual nature of the offshore sediment distribution at Duluth-Superior (sand in the southern and shallower areas, and mud in the deeper areas) limits the areas where offshore sediments are similar to those being deposited in the bay. One site, three miles northeast of the Superior Entry, appears to be texturally suitable for offshore dumping of dredge spoil from the harbor areas we sampled.

4. Keweenaw beach sediments are generally coarser and more poorly sorted in June as compared to November. The foreshores are usually coarser than the berms and backshores.

5. Fine dredge spoil from shallow water dumping north of the Keweenaw Upper Entry seems to have had some measurable effect on the texture of the berm and backshore.

6. Results of a small-scale beach nourishment experiment on the McLain State Park beach north of the Keweenaw Upper Entry indicate that it is possible to create a sandy beach on an otherwise gravelly foreshore using dredge spoil for a limited time (a matter of days to one month) before wind and waves remove the finer material.

7. The present beach nourishment program is effectively maintaining a small part of the shoreline north of the Keweenaw Upper Entry. This nourishment has a temporary effect due to the relative fineness of Waterway sediments and erosive wave action. Continuing yearly renourishment will be required if this beach is to be maintained.

8. Geological changes which have taken place in the area of the Keweenaw Upper Entry as a result of the Corps of Engineers' dredging activity seem to be a relatively small scale enhancement of natural processes. Dumping of dredge spoil in nearshore zones of wave influence puts the sediment trapped in the Entry, back into the natural littoral system.

9. Suitable offshore dump sites, where sediments and dredge spoil have similar textural and compositional characteristics, exist in several areas, notably where Waterway sediments have moved offshore. One such area is northwest of the Keweenaw Upper Entry.

RECOMMENDATIONS

1. If beach nourishment is to be attempted at Duluth-Superior, a preliminary size analysis of the spoil from each dredging site should be done to determine the textural compatibility of the spoil with the beach sediments. Beach nourishment in areas not previously sampled will also require a size analysis of the beach and near-shore sediments.

2. In-lake spoil disposal, from a geological perspective, should be done only in areas where the sediments and spoil have similar textural and compositional characteristics, the textural aspects being more important.

3. Continuing near-shore spoil disposal at McLain State Park is recommended as a means of reducing shore erosion.

4. Additional study of the wave climate on a year round basis, near-shore sediment texture, and bathymetry at McLain State Park would be helpful in deciding if the current beach nourishment should be extended to cover the northern beaches in the park and if nourishment would be improved by dumping at a different depth or by use of a different disposal pattern.

INTRODUCTION

This report is a sedimentation study, forming part of an assessment of environmental impacts associated with in-lake disposal of dredge spoil on Lake Superior. This assessment was requested by the St. Paul District Office of the US Army Corps of Engineers and funded under contract number DACW37-74-C-0013 to the University of Wisconsin-Madison in August, 1973. Field and laboratory studies focused on two locations where a substantial amount of dredging is done annually: Duluth-Superior and the Keweenaw Waterway.

From one perspective, dredging is a retarding influence on a natural system moving to attain an equilibrium distribution of sediment in harbor areas modified by man. In-lake disposal of dredge spoil is a periodic addition to natural sedimentation processes.

The environmental effects of in-lake spoil disposal depend in part on the quality and quantity of spoil to be dumped. Coarse sediments in the spoil are potentially valuable as beach nourishment material to augment beaches subject to serious erosion. Included in this report is an evaluation of beach nourishment potential in the Duluth-Superior and Keweenaw Waterway Upper Entry areas. Fine sediments in dredge spoil may contain pollutants or create turbidity, making in-lake disposal undesirable. The textural description of harbor sediments in this volume, combined with the chemical analysis of these sediments described in Volume 5, provides information for evaluating the suitability of these sediments for in-lake disposal.

Selection of suitable in-lake disposal sites requires knowledge of natural sedimentation processes. This report includes descriptions of these processes, beach profiles, and maps of sediment distribution in both study areas. In the Keweenaw area, stampsands provide a tracer which shows the patterns of past sediment movement under the influence of waves and currents. This information will aid in predicting where spoil is likely to go when it is dumped.

I. Sedimentation: Duluth-Superior Area

A. Geology

Late Pre-Cambrian basalts, conglomerates, sandstones, and shales of the Keweenawan Series overlie the Canadian shield in the Duluth-Superior area. The coastal zone along the north shore of Lake Superior's western arm is dominated by basalts (Figure 5, page 21). There are no beaches; as a rule, the shoreline is characterized by bedrock and boulders weathered out of local glacial tills.

The Wisconsin shoreline has a history of structural influence. The Douglas Fault, which forms the northern border to the St. Croix horst (a region of uplifted rocks), runs from Minnesota into Wisconsin along and trending towards Wisconsin's northern border. The sandstone cap of the uplifted area south of the fault supplied much sand to the region as it steadily eroded through time. These sandstones lie atop the basalt which is now over a mile beneath the surface. Red in color and rich in quartz, the sandstone outcrops for about two miles near Port Wing

The combination of sandstones and glacial debris has given the South Shore its sandy beaches and red clay till banks - a setting which contrasts markedly with the rocky North Shore.

B. Geomorphology: A Historical Perspective

A knowledge of the geologic events and processes that have shaped the Duluth-Superior area and particularly Minnesota and Wisconsin Points is important in understanding the problems which are being encountered today in the development of this area. Loy (1962, 1963) presents an excellent picture of the evolution of the Duluth-Superior region.

Most of the following discussion is based on his work.

The last retreating glacier (the Valders Ice Lobe) became stagnant for a time in the vicinity of what is now Lake Superior. The meltwater from the retreating ice, laden with red clay, formed glacial Lake Duluth (an ancestral Lake Superior). When the glaciers withdrew, a ten to fifty foot layer of red clay was left behind atop a thickness of 100 to 600 feet of till (rock debris) from former glaciers.

As the Valders ice retreated from the Superior basin, a series of lakes - higher and then lower than the present lake level - formed in the Lake Superior basin. As the lake stabilized near its present level 4100 years ago (Nipissing level), deposition of river-carried sediment and the movement of this sediment in the swash and backwash of oblique waves (beach drifting) resulted in a smooth bottom composed of red clay till and in the filling of stream valleys at the head of the lake. The orientation of the South Shore to the fetch of the prevailing waves and the abundance of sand to be moved has ensured the effectiveness of beach drifting in this area. There were no points at this time. A smooth shoreline approximately followed the present 610 foot contour line.

As the lake level stabilized, waves began to move sand from the till bluffs of the South Shore toward the head of the lake. Gravel from nearby North Shore beaches and stream deltas drifted into the area. Wave action pushed the sand into a mound which formed the base of Connor's Point. This spit lengthened from east to west until the St. Louis bay was closed off, diverting the migration of North Shore gravel. The St. Louis River soon breached this bar, creating the inner points: Rice and Conner's Points (Figure 5, page 21).

Lake level dropped to the eleven foot lower Algoma level 3200 years ago. As the processes of sediment transport became less effective in the shallower water, the old points were abandoned and a new sand spit began building out near the present base of Wisconsin Point parallel to storm waves advancing down the maximum fetch of the lake. Waves pushed material drifting down the face of the bar into constructional berms. As the sand dried, the prevailing winds moved the smaller grains up from the beach to form a long dune ridge parallel to the trend of the bar.

As the water level rose slowly, the supply of beach drifted material from the South Shore extended the bar across the head of the lake until it reached the North Shore about 200 years ago. This dammed the St. Louis River and diverted the drift of North Shore gravel to Minnesota Point, where it formed a thin veneer over the South Shore sand on the extreme western end. The St. Louis and Nemadji Rivers breached the bar over the former channel of the Nemadji River and scoured out a channel separating the Minnesota and Wisconsin Points. Most of St. Louis Bay was less than eight feet deep except for the drowned river channel that was up to twenty-five feet deep.

C. Natural Forces

The same forces that work to bring sediment into the Duluth-Superior region can be destructive as well. Storm waves tear beach-drifted sand off the points and high winds carry the sand from the dunes. During the spring freshets, the rivers scour material from the bottom as channels deepen and move about in response to the river discharge. Large amounts of sediment may be carried through the Superior Entry and Duluth Ship Canal into Lake Superior (Figure 16, p. 32). As the waves of Lake Superior nourish the lake sides of Minnesota and Wisconsin Points with beach-drifted sand and gravel, waves and ice in the bay erode their inner margins. It is the ever-changing balance of wave, wind, and river deposition and erosion which has given this area its present form and which continues to change it today.

Man has altered the harbor to suit his needs over the past hundred years. Channels have been dredged, the harbor has been deepened, and the harbor dredgings used to triple the area of Rice's Point and double the area of Conner's Point. Despite these modifications, the activities of the Corps of Engineers and other groups have not changed the overall plan of the harbor significantly. The natural forces which built the harbor continue to maintain it to a large extent, although not always the way that man would like. The modifications that have been made will continue to require maintainance in response to the whims of nature.

D. Contemporary Sedimentation on Wisconsin and Minnesota Points

The Red Clay Inter-Agency Committee (1972) recognized the erosion problem along the Wisconsin coast of Lake Superior. They categorized erosion rates along streams as "accelerated" during flooding and "continuing" during regular discharge partly as a result of poor farming and construction practices. Shoreland erosion is critical in many areas, according to the committee, and most of the Wisconsin coast is under attack.

Dudley (1973) concluded that over one million tons of suspended sediment per year are contributed to Lake Superior by Wisconsin rivers. Dickas and Tychsen (1969) concluded that most of the material in the traction (bed) load of the Bois Brule River was derived from glacial till and could be transported out into the lake more than one mile offshore (Figure 5).

There is little doubt that the erosion of the South Shore has contributed a large volume of sediment to the Duluth-Superior region. Hess (1973) calculated that the shoreline between the Superior Entry and Bark Point, Wisconsin, had retreated 280 feet in the period between 1852 and 1966. This retreat has accelerated in recent times, with 133 of the 280 feet being lost from 1938 to 1966 (a rate of 4.8 feet/year). The total amount of material eroded since 1852 is estimated at over 150 million cubic yards. Just west of the entrance to Port Wing harbor 1766 feet of erosion occurred during the 114 year span with 1335 feet being lost from 1939 to 1966 - a rate of retreat of 47 feet/year during that 28 year period.

There are some points on the South Shore where accretion is taking place. Hess (1973) noted that these sites are generally related to rivers and streams. The greatest advance has occurred at the west end of Wisconsin Point, where one profile increased 652 feet in length from 1852 to 1966, or just under 6 feet/year during that time. Since 1938 the shoreline advanced at a rate of 15 feet/year. (Figure 1).

The U.S. Army Corps of Engineers, St. Paul District, has found accretion at Wisconsin Point and erosion near the Duluth entry of Minnesota Point to be occurring in the studies they have conducted since 1861 in association with their dredging operations (Grant Westall, U.S. Army Corps of Engineers, written communication).

Major D.C. Houston, Corps of Engineers, noted the effects of storms and waves on Minnesota and Wisconsin Points (1872, pp.7-9):

> "...it follows that what is known as the natural entry is, to some extent, accidental, depending on a particular combination of storms and freshets by which the channel was forced to its present location, and not fixed by permanent banks, like the Saint Louis River on its upper portion.
>
> It would not have been an impossible or unheard of occurrence

for a great storm to have made a breach through Minnesota Point, on the very site of the Duluth Canal, and a new entry been formed at that point by natural causes, leaving the present entry (the Superior Entry), if unprotected by piers from the actions of storms, to fill up.

The only storms which have any appreciable effect upon Minnesota and Wisconsin Points are northeasterly storms, and the effect of these storms is to cause littoral currents, bringing gravel along the north shore of the lake and sand along the south shore, and depositing them on the Point...

These storms also have a direct action on the shores of Minnesota Point similar to that of storms on all beaches. The exact character of the changes produced by this action has not, to my knowledge, been determined in any case, but it is known that they are very variable. Sometimes shores are washed away, and again large quantities of material are thrown up from the bottom.

As to the effect of the (Duluth) canal and (Superior) entry in modifying the effect of storms on Minnesota Point, ...with the oblique action, i.e., when the waves strike the beach obliquely, so as to produce littoral currents capable of moving the material of which the beach is composed, they have a marked influence.

We find that at Duluth this resultant current is southward, there being an accretion of 55 feet on the north side of the Citizen's dock and 70 feet on the north side of the north canal piers, while at the (Superior) entry the resultant current is northward, ...and the accretion taking place on the outside of the Wisconsin pier, which is much in excess of that on the Minnesota pier...

From these facts it appears that not only the (Duluth) canal piers, but those at the entry have the effect of arresting the material carried by the littoral currents by which Minnesota Point was formed and constantly supplied...

...We must conclude that the wearing away of Minnesota Point, from the entry up to the place where we come to gravel, a distance of five miles, is due, to a certain extent, to the (Superior) entry piers; this being the point where the resultant littoral current from the south meets that from the north, leaving only a distance of about a mile to be affected by the canal piers."

This report, submitted by Major Houston over a hundred years ago, nicely summarized the shore processes affecting Minnesota and Wisconsin Points today. The addition to the points of material dredged from the harbor has changed the natural profile of the points. Between 1873 and

1939 roughly half of the 48,979,808 cubic yards of silt and sand, which was removed from the harbors, was dumped five-eighths of a mile into the lake in 40 to 50 feet of water. The addition of these dredgings resulted in an accretion beach 100-200 feet wide along the face of Minnesota Point (Loy, 1963).

E. Beach Nourishment on Minnesota Point

The one-half mile of beach adjacent and south of the Duluth Ship Canal has been severely eroded due to the concentration of wave action and blockage of the movement of sands by the canal. In May, 1963, 270,000 cubic yards of dredge material from the harbor was used to restore this section of beach (section 103 Public Law 87-874 Reconnaisance Report, Minnesota Point, Minnesota, 18 June, 1970).

Loy (1963) observed the movement of the dredged material down Minnesota Point in the fall of 1963. He found that a half mile down the beach from the spoil a ridge of pebbles and driftwood had formed along the waterline. Two and one-half m[illegible] further south a broad berm of new sand had built up. As the sand dried, it was carried along the beach and inland by the wind.

The entire restored beach, which had extended out about 600 feet from the property line, had eroded away by 1970 (Figure 2). Surveying showed that 200,000 cubic yards of material had deposited on the beach to the south. The rest of the material was either deposited farther south or had settled out into the lake (section 103 Public Law 87-874 Reconnaissance Report). Nourished material was almost all gone from the beach.

Data furnished by the U.S. Army Corps of Engineers from shoreline bottom borings and shore bottom samples taken in 1972 indicate shoaling south of the beach nourishment area (Figure 3). Mean grain size increases progressively along Minnesota Point towards Wisconsin Point and there is some indication that finer, less well sorted sediment moving out from the shore is responsible for the shoaling. The addition of dredge material to the sediment carried into the region by natural shore processes is probably responsible for the poorer sorting. Shore bottom borings taken in 1971 (Figure 4) show a layer of fine and silty sand overlying gravelly sand offshore of the beach nourishment area.

There has been little interest in beach nourishment since then due to three factors: the unfavorable cost to benefit ratio for the construction of beach nourishment projects; the relatively large amounts of fines in the spoil which become wind-borne and create a nuisance or move offshore; and the possibility that the dredge spoil is polluted (Grant Westall, Advance Planning Section, Planning Branch, St. Paul Office, Corps of Engineers, 10/2/74).

F. Textural Parameters

Sedimentologists have found it convenient to describe the texture of a sample using several statistical parameters. These were calculated from sieve data by computer analysis using the formulas shown in Table 1. The mean is simply the arithmetic average. It measures the central tendency of the curve. The median is the point on the curve where one-half of the sample is coarser and the other half finer. Phi size at the 84th and 95th percentiles are the sizes where 84% and 95% of the sample are coarser respectively. These two parameters are sensitive to the finer portions of a sample. The phi scale, a logarithmic base two scale, is

Table 1 - Moment Measures

Median = $\phi 50$ (midpoint of curve)

Mean $\overline{X}_\phi = \frac{\Sigma fm}{n}$

Standard Deviation (sorting) $\phi = \sqrt{\frac{\Sigma f(m-\overline{X}_\phi)^2}{100}}$

Skewness $sk\phi = \frac{\Sigma f(m-\overline{X}_\phi)^3}{100-\phi^3}$

Kurtosis $K\phi = \frac{\Sigma f(m-\overline{X}_\phi)^4}{100-\phi^4}$

where f = weight percent (frequency) in each grain size grade present.

m = midpoint of each grain-size in phi values

n = total number in sample (100 when f is in percent)

from: Kohler and Moore, 1974

used for convenience instead of the standard millimeter scale. The relation between phi size and the Wentworth size classes is shown in Table 2.

The standard deviation or "sorting" is a measure of the uniformity of a sediment. A verbal classification of sorting values is also shown in Table 2. Skewness is a measure of the assymetry of the distribution about the mean. A positive value means that the sediment has an excess amount of fines and a negative value indicates an excess of coarse material compared to a normal curve with the same median. Kurtosis measures the sorting of the fine and coarse ends of a size distribution compared to the central portions. High values indicate better sorting in the central portion compared to the tails of the distribution.

G. Characteristics of Lake Sediments

Sediment samples taken in the Duluth-Superior region in the fall of 1973, July, 1974, and in September, 1974 have been analyzed for texture and the petrology of selected samples taken in the fall of 1973 has been determined as part of the sedimentary studies of this area.

The station locations and bathymetry based on depths at the July, 1974 stations are shown in Figures 5 and 6. The bottom in depths less than twenty meters is predominantly sand (Figure 7). Bathymetry appears to be a controlling factor in the sediment distribution. With deepening water the sediment changes to muddy sand and then to sandy mud in the deepest and northern portions of the sampling area. The rocky area offshore is based on one station.

Mean grain size (Figure 8) shows a progressive decrease in a northerly direction in depths over 20 meters. This suggests an influx of coarser sediment from the south shore. This sediment is coarsest near

Table 2 - Wentworth Size Classes and Sorting Categories

PHI	MILLIMETERS	SIZE CLASS
		Cobble
-6Φ	64 mm	
		Pebble
-2	4	
		Granule
-1	2	
		Very Coarse Sand
0	1	
		Coarse Sand
1	0.5	
		Medium Sand
2	0.25	
		Fine Sand
3	0.125	
		Very Fine Sand
4	0.0625	
		Silt and Clay

Sorting:

Less than 0.35ϕ	Very well sorted
0.35-0.50	Well sorted
0.50-0.71	Moderately well sorted
0.71-1.00	Moderately sorted
1.00-2.00	Poorly sorted
2.00-4.00	Very poorly sorted

From Folk
(1974)

the southern part of the sampling grid and just north of the Superior Entry. Median size (Figure 9) shows a similar pattern.

Sorting (Figure 10) decreases progressively in a northward direction to a minimum and then increases. The region of muddy sand roughly coincides with the poorly sorted range of sediments.

Skewness (Figure 11) exhibits a tendency for near-zero values in the southern section of the sampling area and increasing negative skewness in a northerly direction and in shallow water.

Kurtosis (Figure 12) is very high in the fine-grained northern part of the sample grid and shows increasing values close to the Superior Entry and towards the South Shore. This suggests increased sorting of the fine and coarse ends of the size distributions in these areas.

Phi sizes at the 84th and 95th percentiles are coarsest in the shallower depths (Figures 13 and 14). The September, 1974 samples show the same trends as the July, 1974 offshore samples (Figure 15).

A pattern begins to emerge when all of these parameters are compared. Sand dominates the shallow water sediments, especially near the South Shore, while finer sediment characterizes the deeper water in the north. In intermediate waters the mixing of these two well-sorted sediment types produces a poorly sorted muddy sand or sandy mud with intermediate skewness values.

The very high values of kurtosis of the finer sediments at the northern margins of the sampling area reflect the settling process by which the mud was deposited.

The offshore sediment dispersal pattern in the Duluth-Superior region appears to be the movement of sand in areas shallower than twenty meters and deposition of fine muds in the deeper waters with some mixing of the coarse and fine material in intermediate depths in the central portions of the study area.

These findings agree with the work of Farrand (1969a, 1969b), Dell (1972), Nussman (1964), and Callender (1969) on this area. Dickas and Tychsen (1969), Dickas (1970), Horten et al., (1970) and Bahnick et al. (1972) analyzed grab samples from Wisconsin Point east to the Amnicon River and out to a depth of 40 feet. They discovered an initial decrease in grain size (medium grading into fine and then to very fine sand at 30 feet) followed by a dramatic increase in mean diameter (coarse sand at 40 feet).

H. Comparison of Harbor Sediments and Sediments on Wisconsin and Minnesota Points

The mean grain size of sediment samples collected in the Duluth-Superior Harbor as part of this study is generally finer than that of the outer beaches on Wisconsin and Minnesota Points (Figures 3, 8, and 16), with the exception of the sample taken in Allouez Bay Channel. The harbor sediments are more poorly sorted than the beach sediments, especially in the Superior Harbor basin near the mouth of the Nemadji River (Figures 3, 10, 16). Samples from the 21st Avenue slip and the Duluth Harbor basin show the greatest negative skewness. Otherwise the skewness of the harbor samples resembles that of the Wisconsin Point samples (Figures 11, 16). Kurtosis is high both on the beach and in the harbor (Figures 12, 16). Phi size at the 84th and 95th percentile is finer in the Superior Harbor basin (near the Nemadji River) than in the Duluth Harbor basin (Figures 13, 14).

The petrology of the beach and harbor sediments is similar (Figure 17). The samples are roughly 70% quartz. The percentage of lithic fragments is over 18% in the harbor samples (with the exception of the Allouez Bay Channel), compared with 9 to 12% lithic fragments in the Wisconsin Point samples. Plagioclase content of sediments near the Duluth side of the harbor is approximately 6%. Near the Superior Entry it falls to 4%. The beach sediments on Wisconsin Point average 4 to 6% plagioclase content.

If these samples are representative of the sediment removed from the harbor, beach nourishment using the dredge spoil is probably impractical due to the relative fineness of the harbor sediments compared to that of the beaches. The finer material could be moved about by the wind. Although this is part of the natural process of resupplying the bay - facing margins of the points with sediment - the wind-blown sand is a nuisance and may contribute to the infilling of the bay. Experience gained from the beach nourishment on Minnesota Point indicates that beach nourishment using dredge spoil can at best be only a temporary solution to the erosion problems on Minnesota Point. If beach nourishment is attempted, a preliminary size analysis of the dredged material at each site should be done to ascertain the textural suitability of the spoil.

I. Comparison of Harbor and Offshore Sediments

The Duluth-Superior bay sediments sampled in this study are generally finer than the sediments in depths less than 20 meters offshore of the Superior Entry (except for the Allouez Bay Channel) and more poorly sorted than the northern and southern portions of the area offshore (Figures 8, 10, 16). Most of the deeper areas of the offshore region sampled are

[1]Percentages of quartz and lithic fragments were determined by identification of at least 300 grains on a petrographic thin section made from a portion of the sample impregnated with a polyester resin.

considerably finer, except for a part of the eastern margin of the central portion of the sampling grid (near Station 22). The sorting and phi size at 84th percentile, in this area are also similar to that of the harbor sediments.

Quartz makes up a large percentage of offshore sediments (Figure 17). Lithic percentages range from 7 to 20% in the area of the old Superior dumpsite. This compares with 7% in the northernmost offshore sample and 18 to 20% lithic fragments in the harbor.

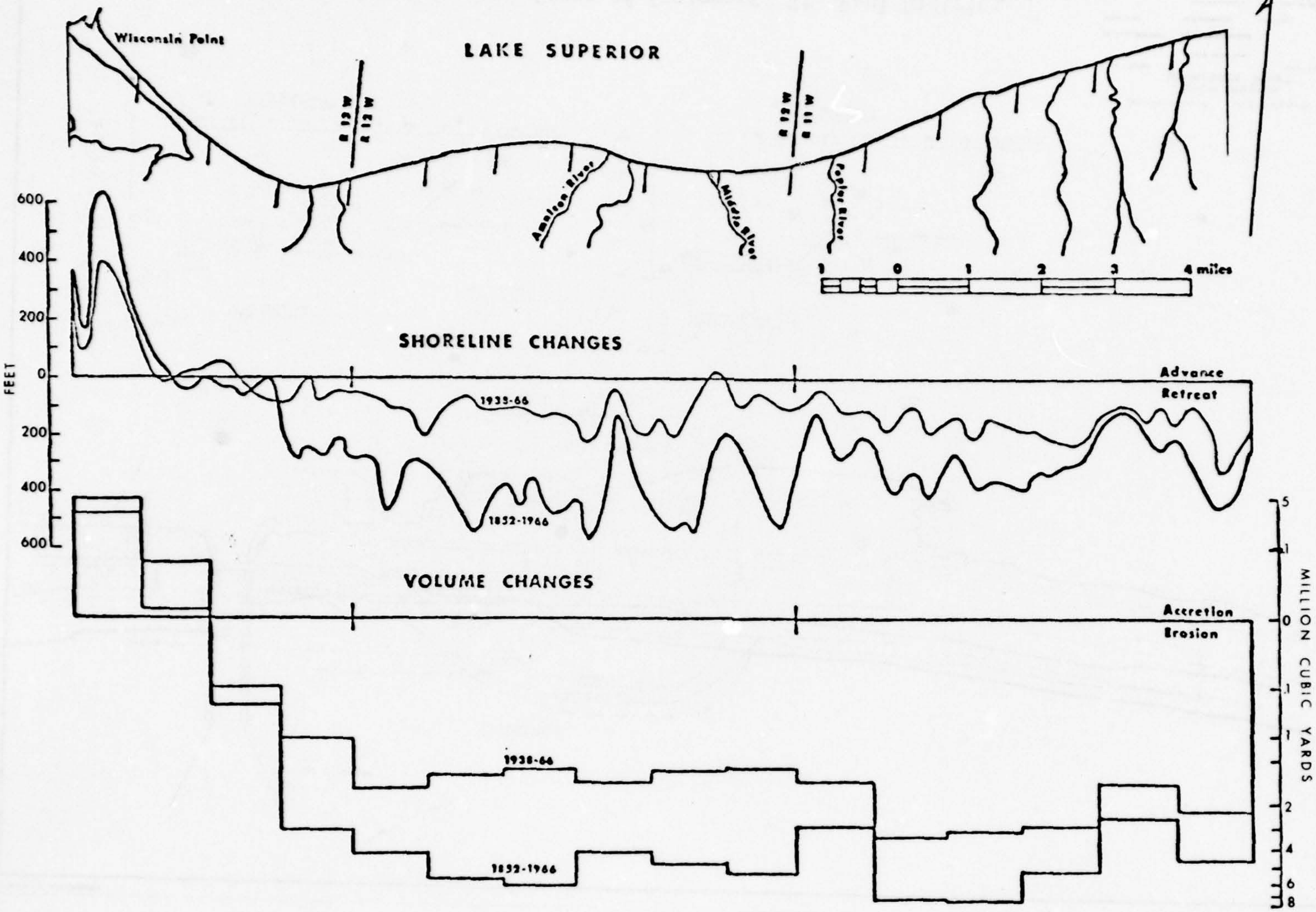
Past experience has shown that wave action will remove dredged material dumped in 40 to 50 feet of water and deposit it on the face of the points. Material dumped beyond the zone of wave action would not be as likely to be removed. Local wave action and the depth of influence of waves is described in Volume 4.

J. Conclusion: Duluth-Superior Area

Sand derived from the South Shore and transported by wave action along the beach and in depths less than 60 feet is the main source of sediment to the outer margins of Wisconsin and Minnesota Points. The offshore region is generally characterized by sand in depths of less than 60 feet and in deeper areas by muddy sand to the south grading into sandy mud in the deep northern portions of the study area. The interruption of the transport of South Shore sand by the Superior Entry breakwaters and of gravel from the north shore by the Duluth Ship Canal is responsible for the accelerated erosion on Minnesota Point.

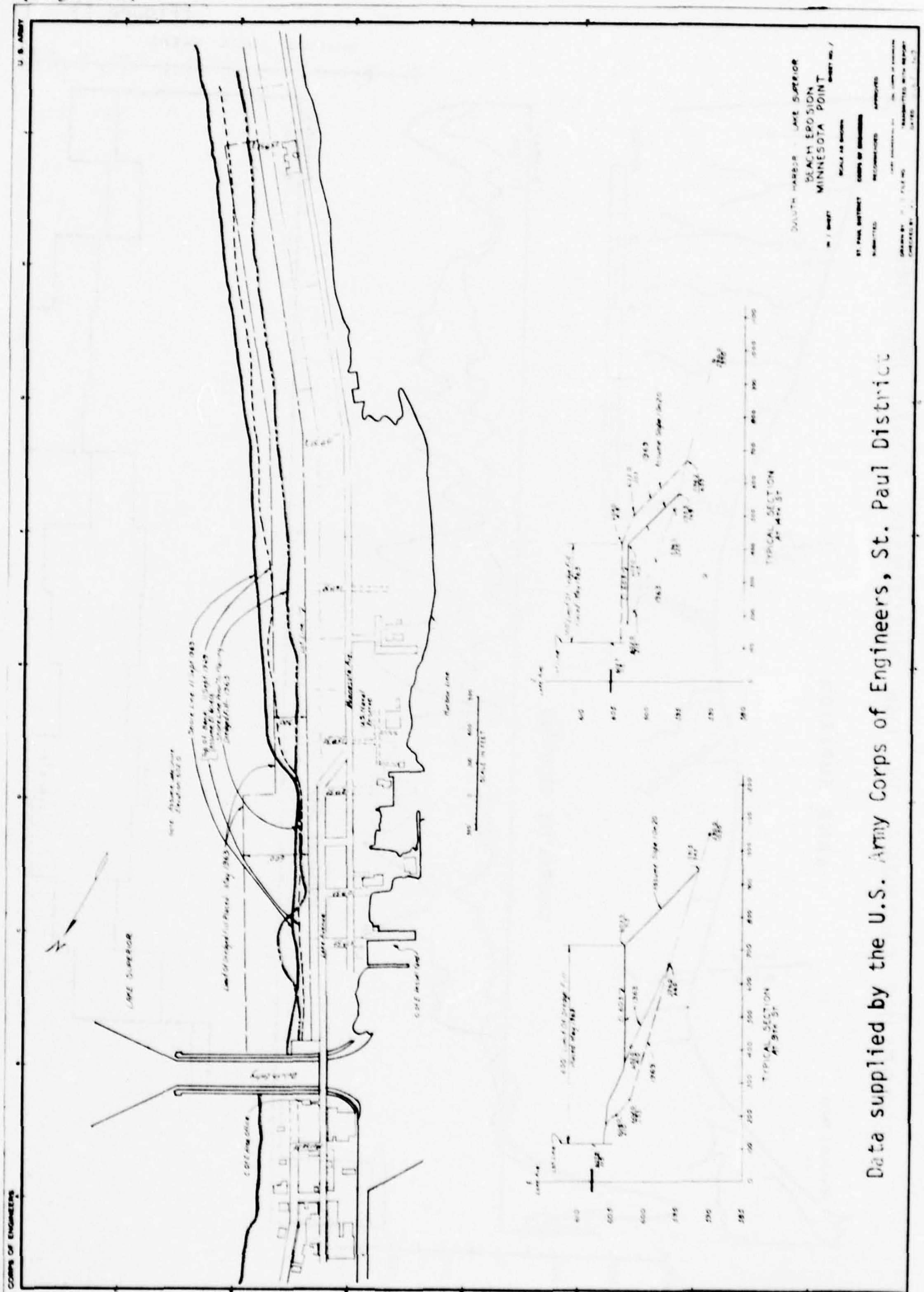
River sediment, wind blown sand from the outer points, and erosion of the inner portions of the bay are responsible for the silting up of the channels and harbors within the bay. This material is rapidly removed when placed in the higher energy regime of the zone of wave action. Beach nourishment has proved to be only a temporary solution. The dual nature of the offshore sediment distribution (sand in the southern and shallower areas, mud in the deeper areas) limits the areas where offshore sediment is similar to that being deposited in the bay. One site to the northeast of the Superior Entry appears to be texturally suitable for offshore dumping, although the distance (about three miles) from the entry may be prohibitive.

SHORELINE CHANGES ON THE WISCONSIN COAST 1852-1966



From Hess (1973)

(Figure 2) 18



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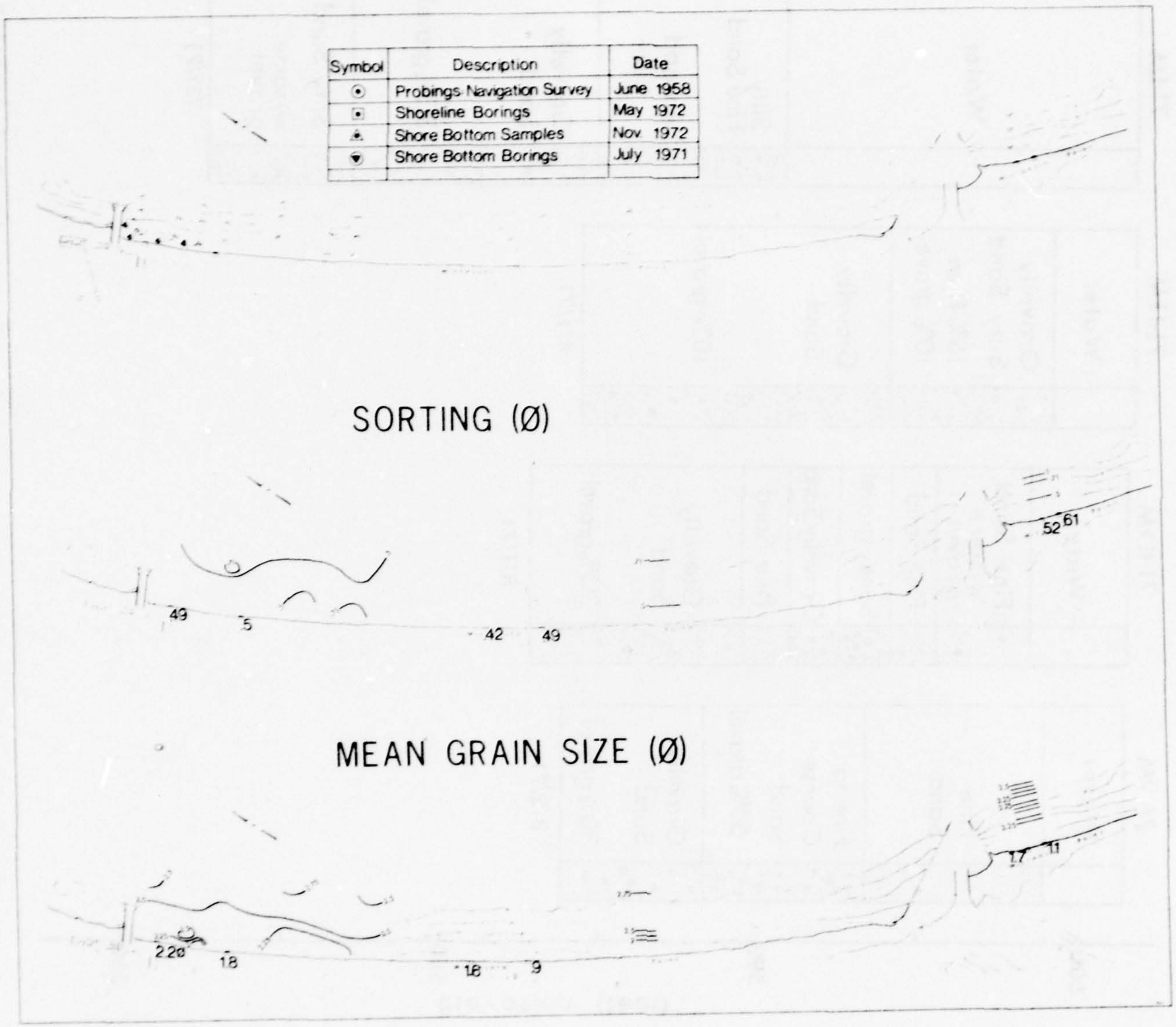
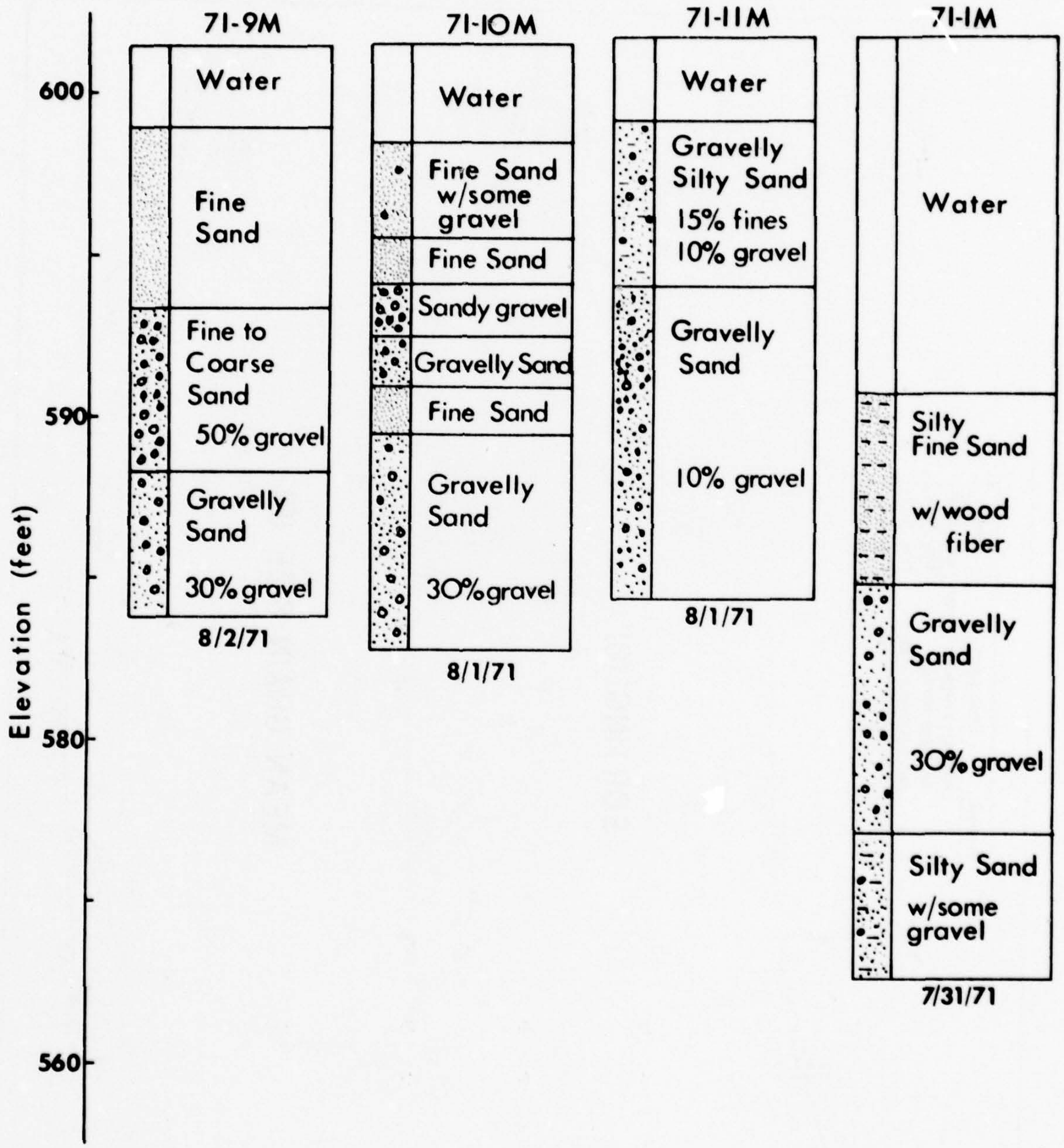


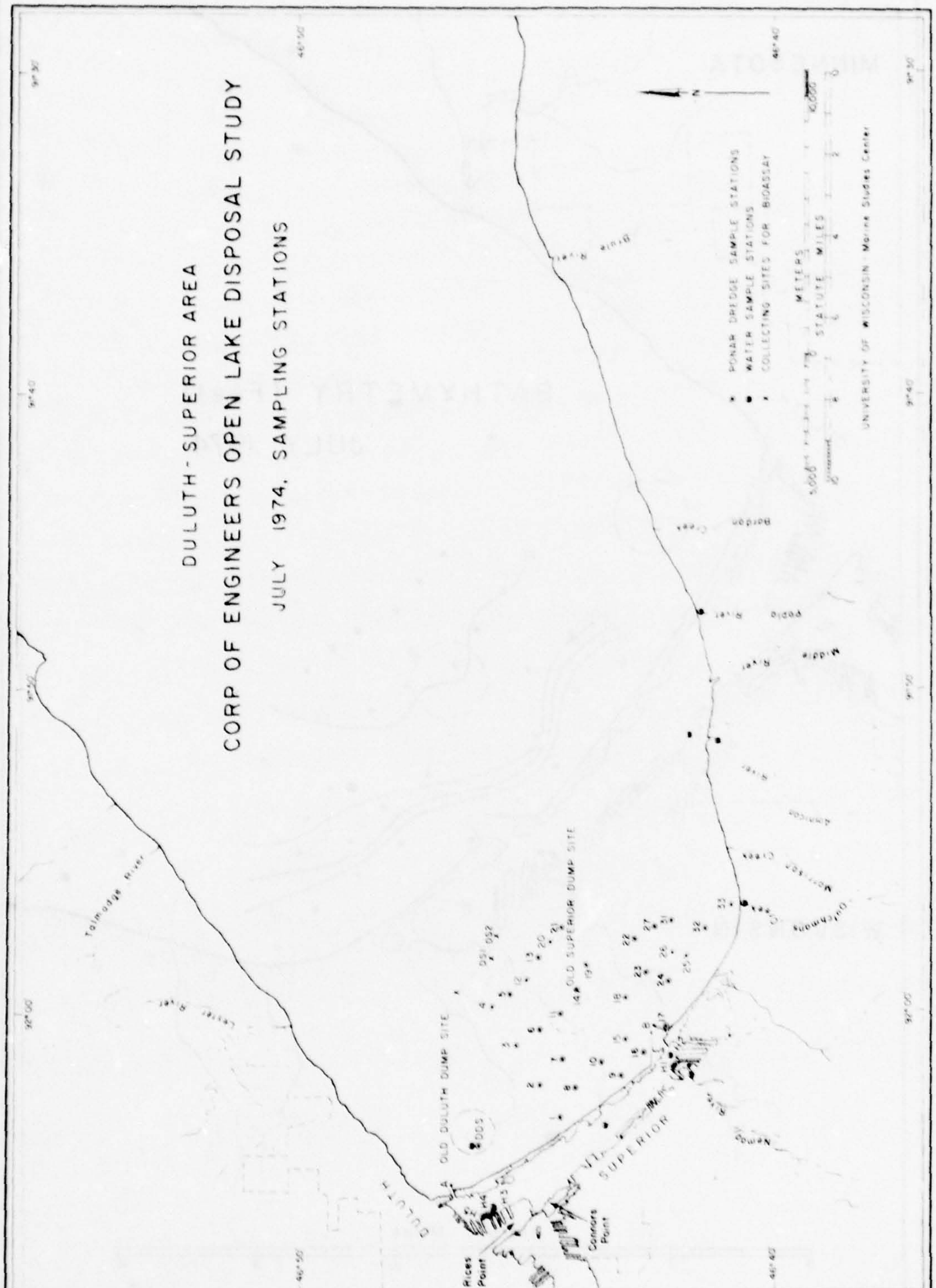
Data supplied by U.S. Army Corps of Engineers, St. Paul District

(Figure 4) 20

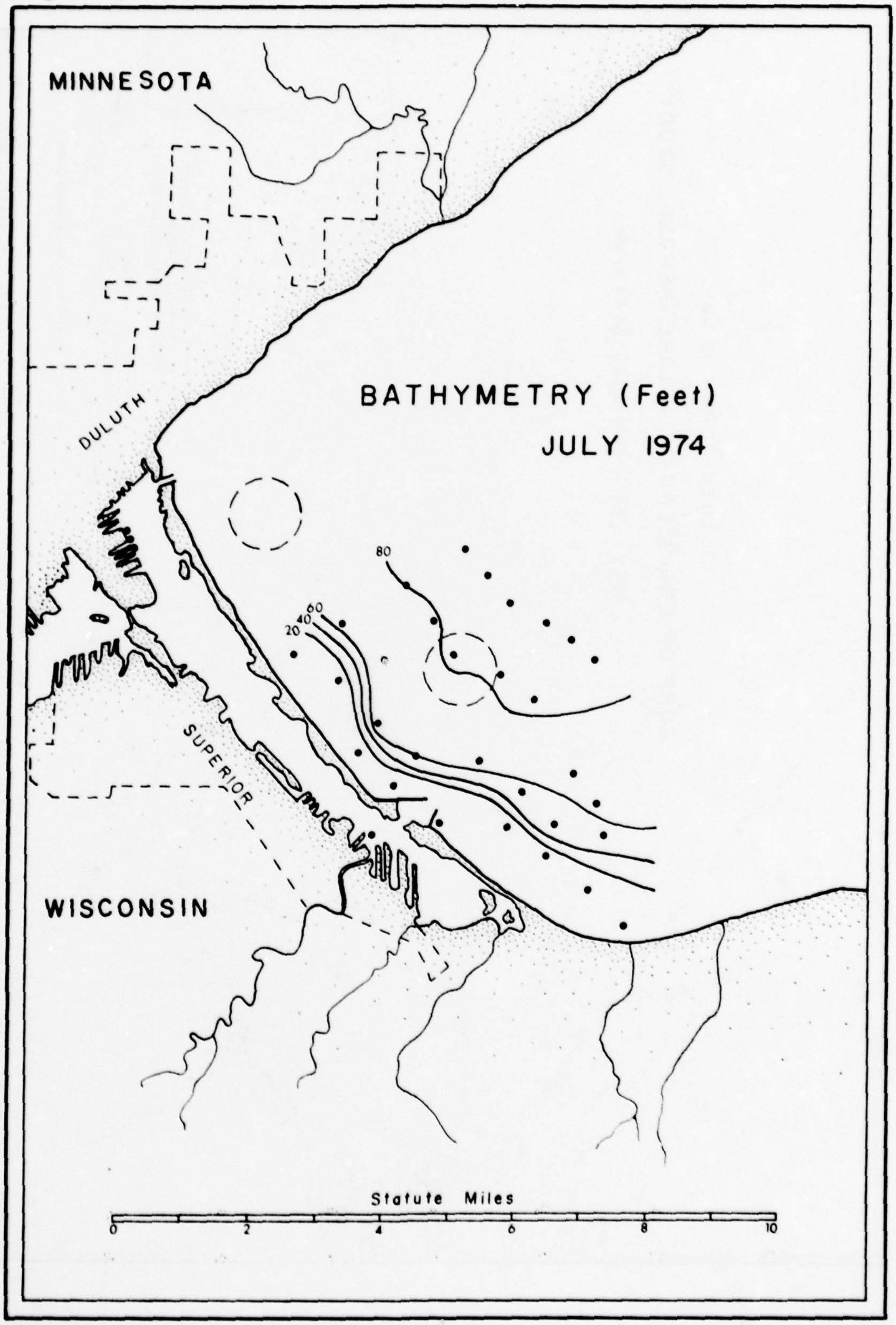
Shore Bottom Borings
Minnesota Point

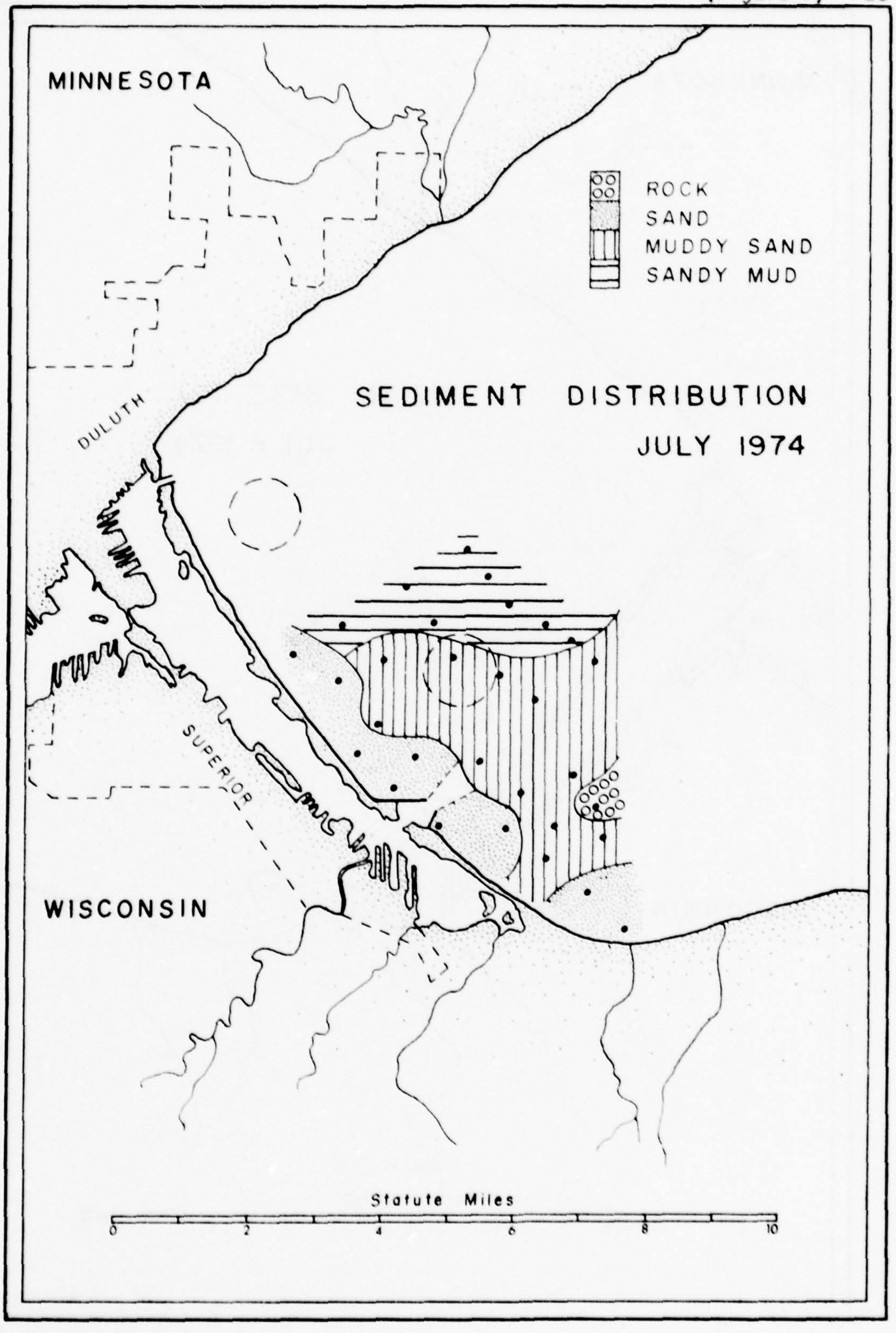


Textural Data Furnished by U.S. Army Corps of Engineers, St. Paul District

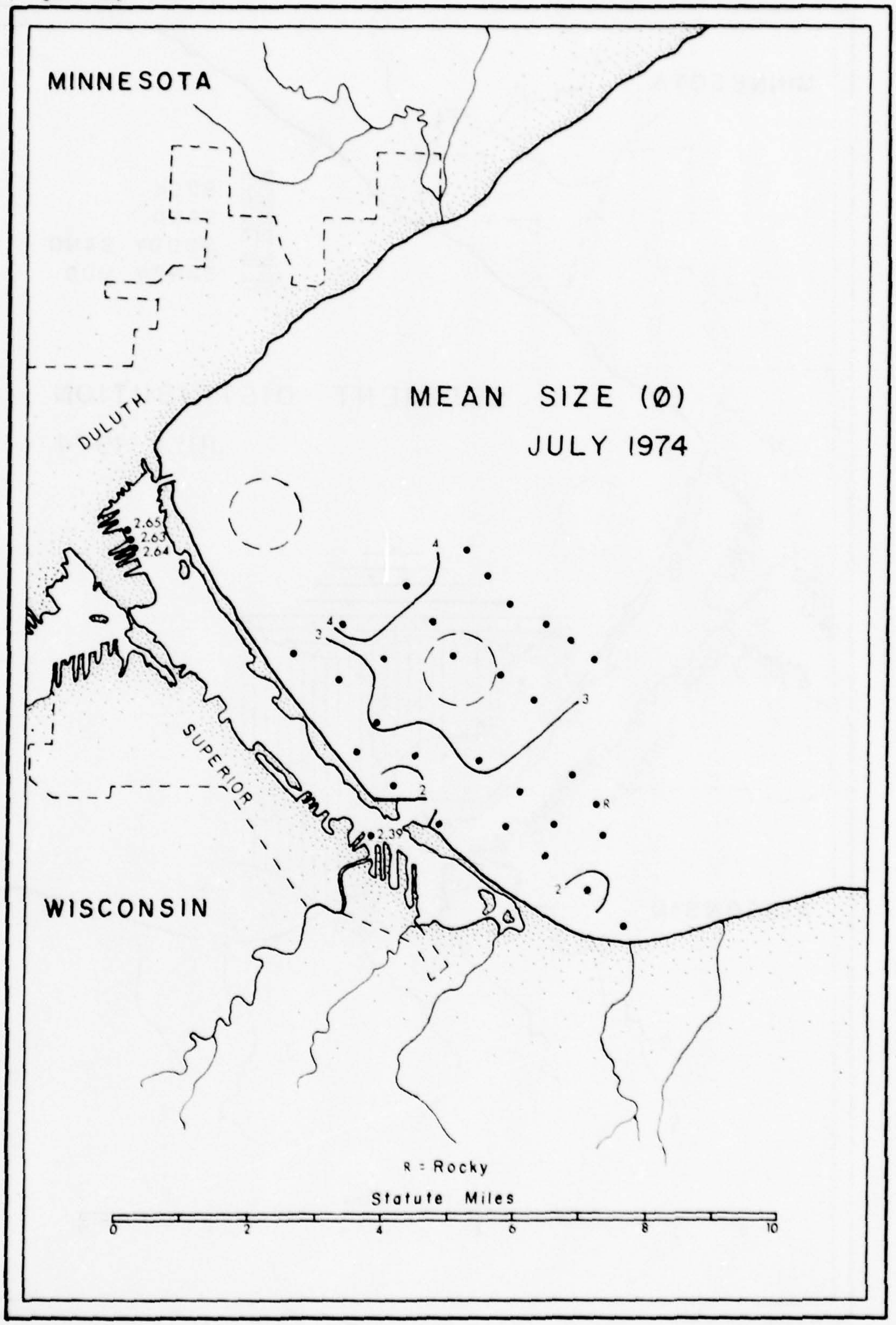

DULUTH-SUPERIOR AREA
CORP OF ENGINEERS OPEN LAKE DISPOSAL STUDY
JULY 1974, SAMPLING STATIONS
PONAR DREDGE SAMPLE STATIONS
WATER SAMPLE STATIONS
COLLECTING SITES FOR BIOASSAY
METERS
STATUTE MILES
UNIVERSITY OF WISCONSIN-Marine Studies Center
OLD DULUTH DUMP SITE
OLD SUPERIOR DUMP SITE
DULUTH
SUPERIOR
Rices Point
Connors Point
Lester River
Talmadge River
Brule River
Bardon Creek
Poplar River
Middle River
Amnicon River
Morrison Creek

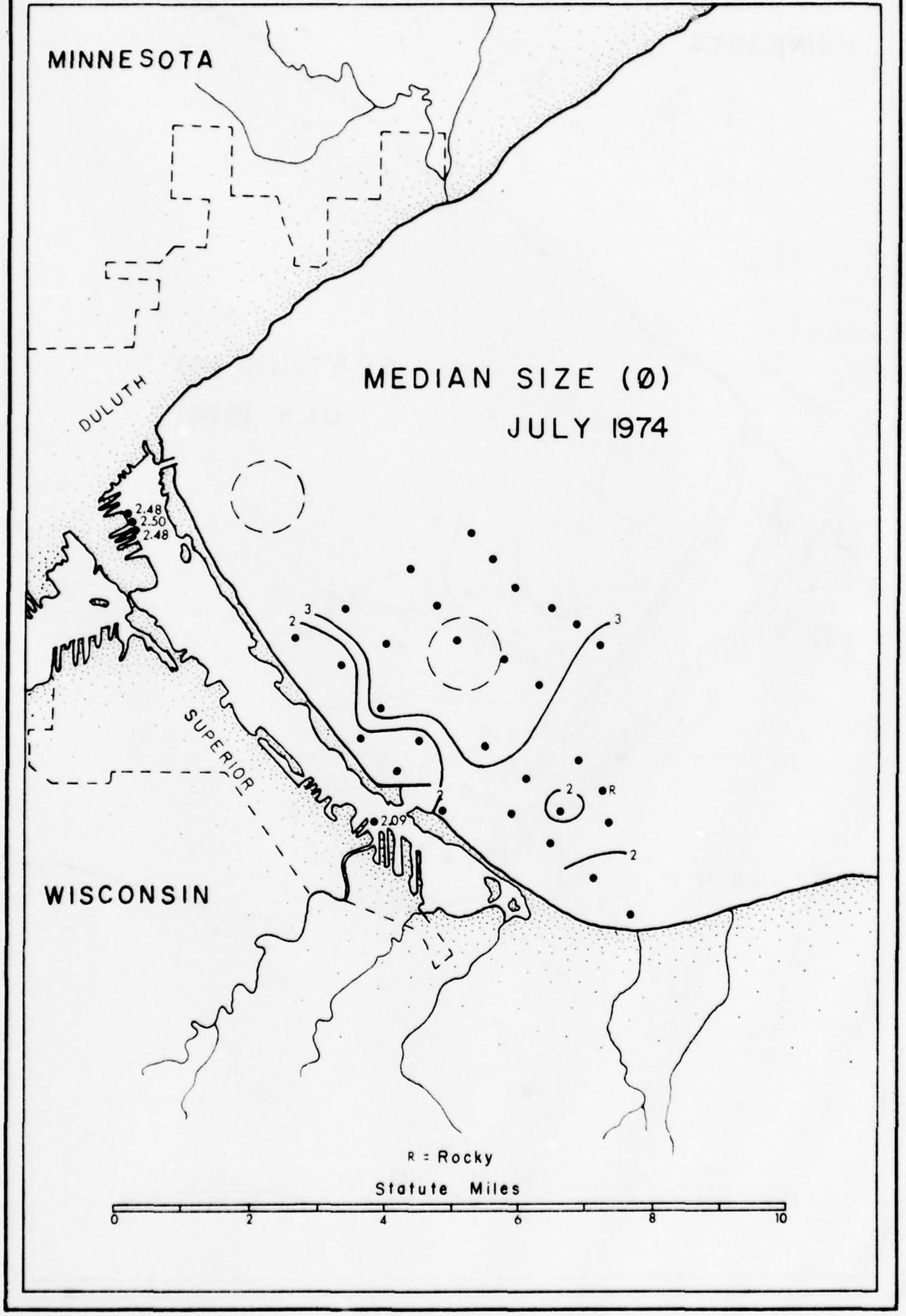
(Figure 6) 22


MINNESOTA
BATHYMETRY (Feet)
JULY 1974
DULUTH
80
60
40
20
SUPERIOR
WISCONSIN
Statute Miles
0
2
4
6
8
10

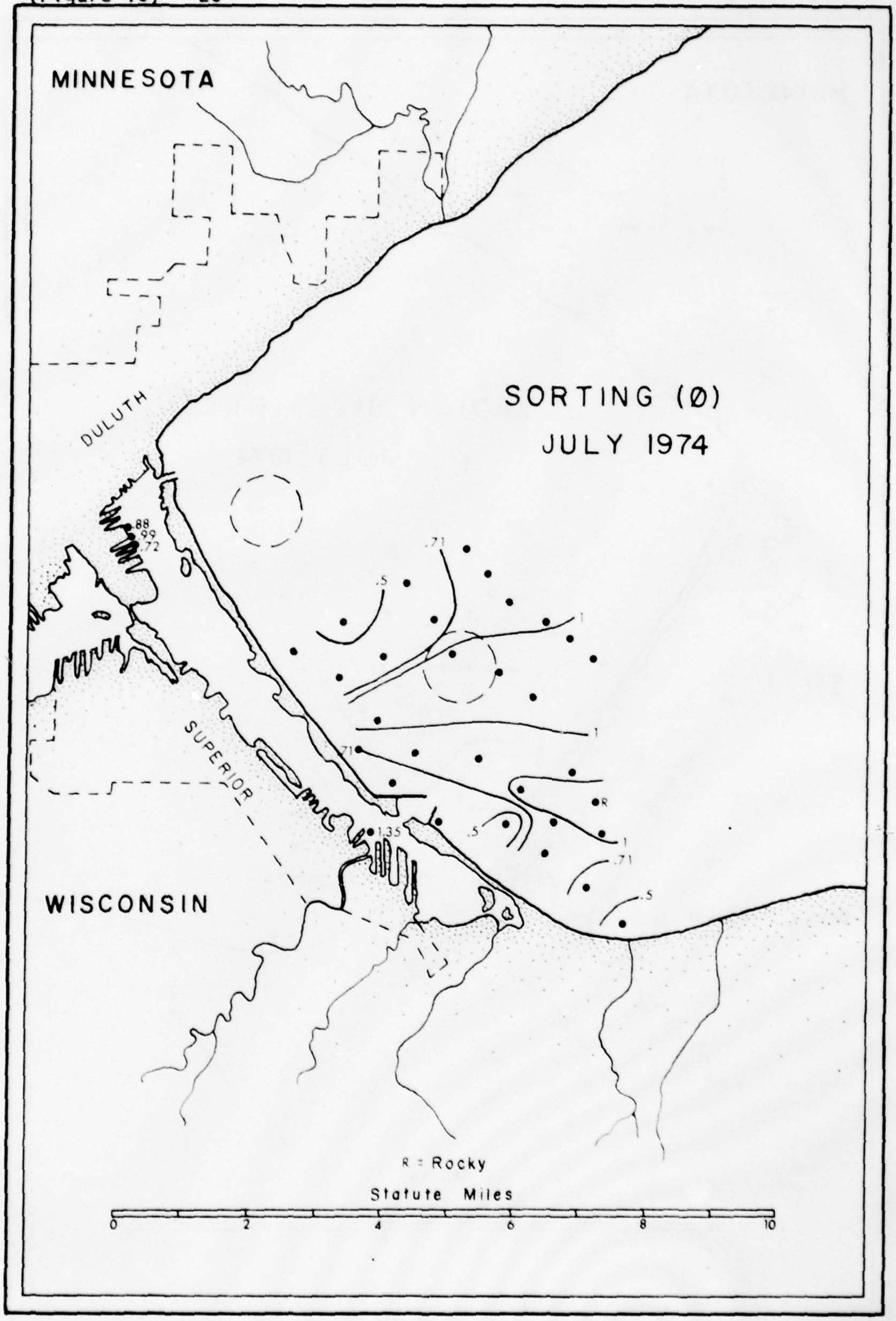

MINNESOTA
ROCK
SAND
MUDDY SAND
SANDY MUD
SEDIMENT DISTRIBUTION
JULY 1974
DULUTH
SUPERIOR
WISCONSIN
Statute Miles
0
2
4
6
8
10

(Figure 8) 24

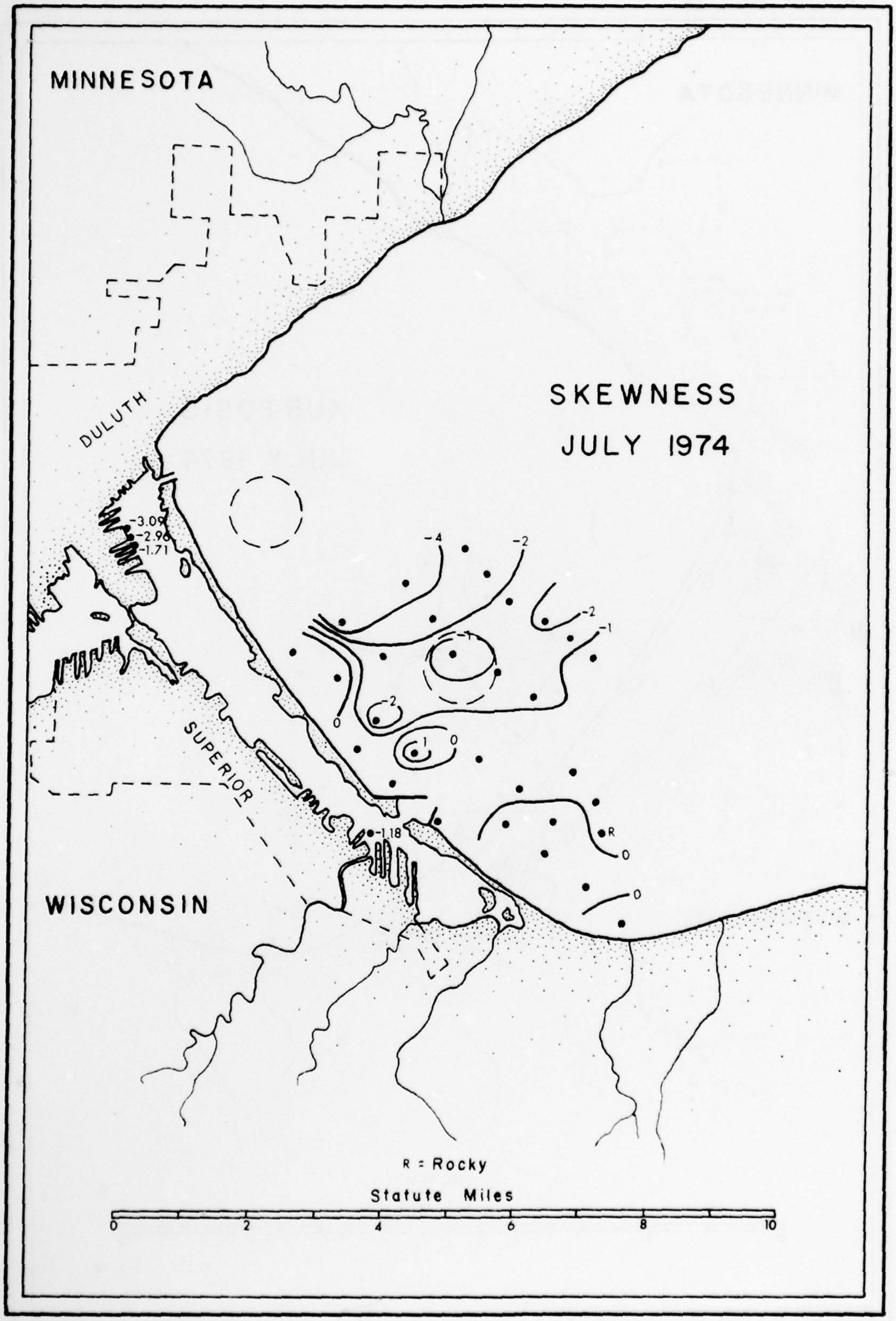

MINNESOTA
MEAN SIZE (Ø)
JULY 1974
DULUTH
2.65
2.63
2.64
4
4
3
3
2
2
R
2.39
SUPERIOR
WISCONSIN
R = Rocky
Statute Miles
0
2
4
6
8
10


MINNESOTA
DULUTH
MEDIAN SIZE (Ø)
JULY 1974
2.48
2.50
2.48
2
3
2
2
R
2
2.09
SUPERIOR
WISCONSIN
R = Rocky
Statute Miles
0
2
4
6
8
10

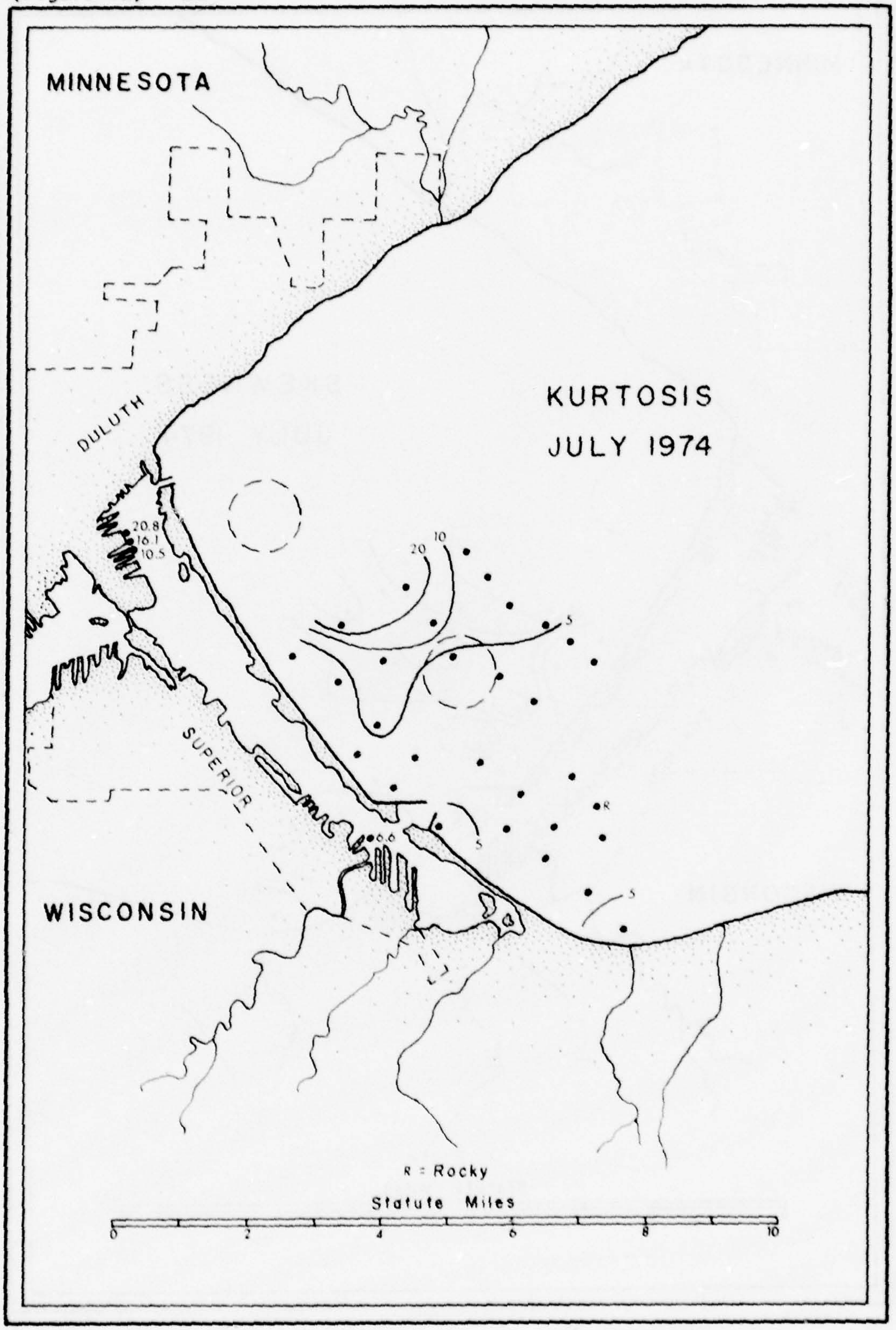
(Figure 10) 26

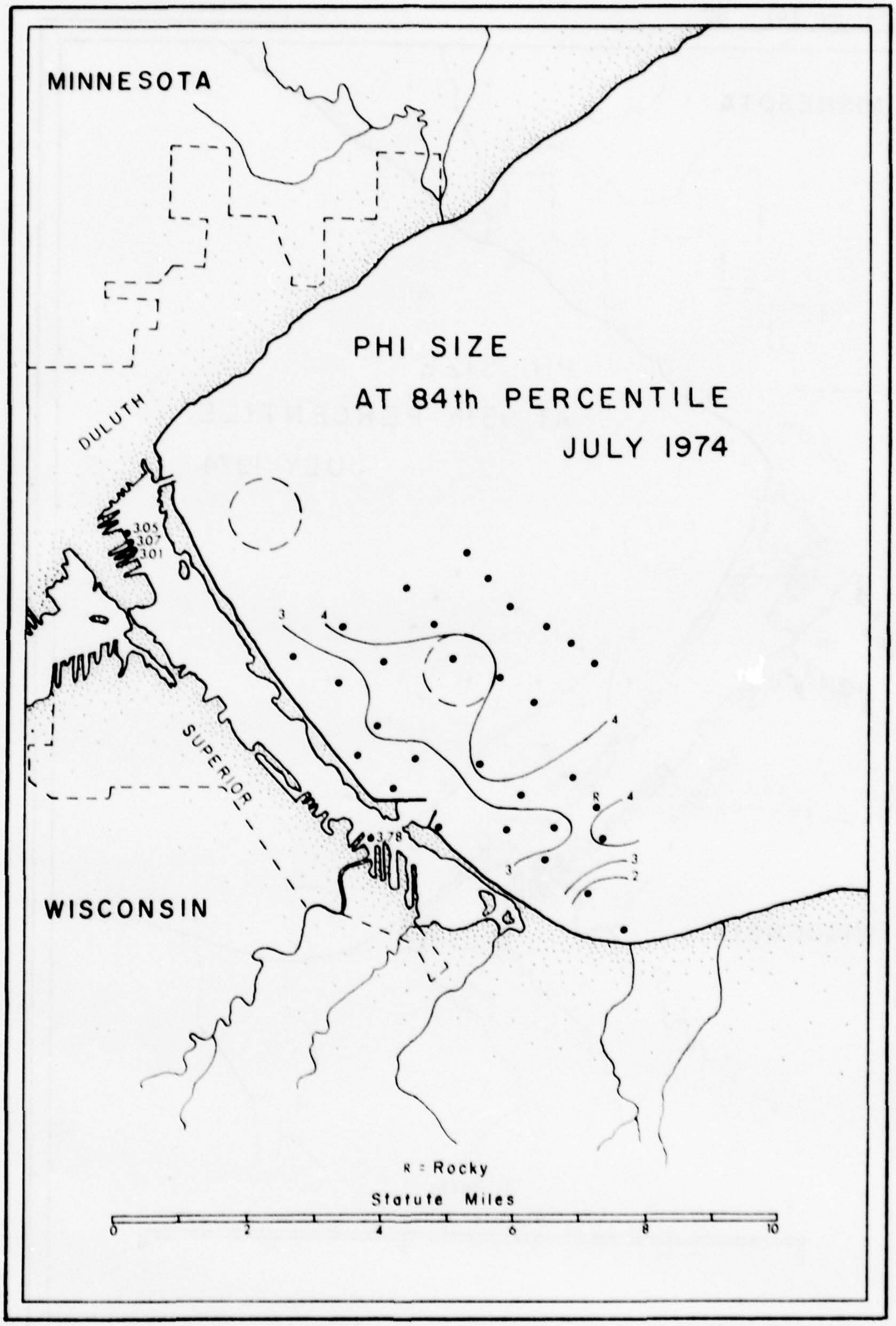


MINNESOTA
SORTING (Ø)
JULY 1974
DULUTH
SUPERIOR
WISCONSIN
R = Rocky
Statute Miles
0
2
4
6
8
10

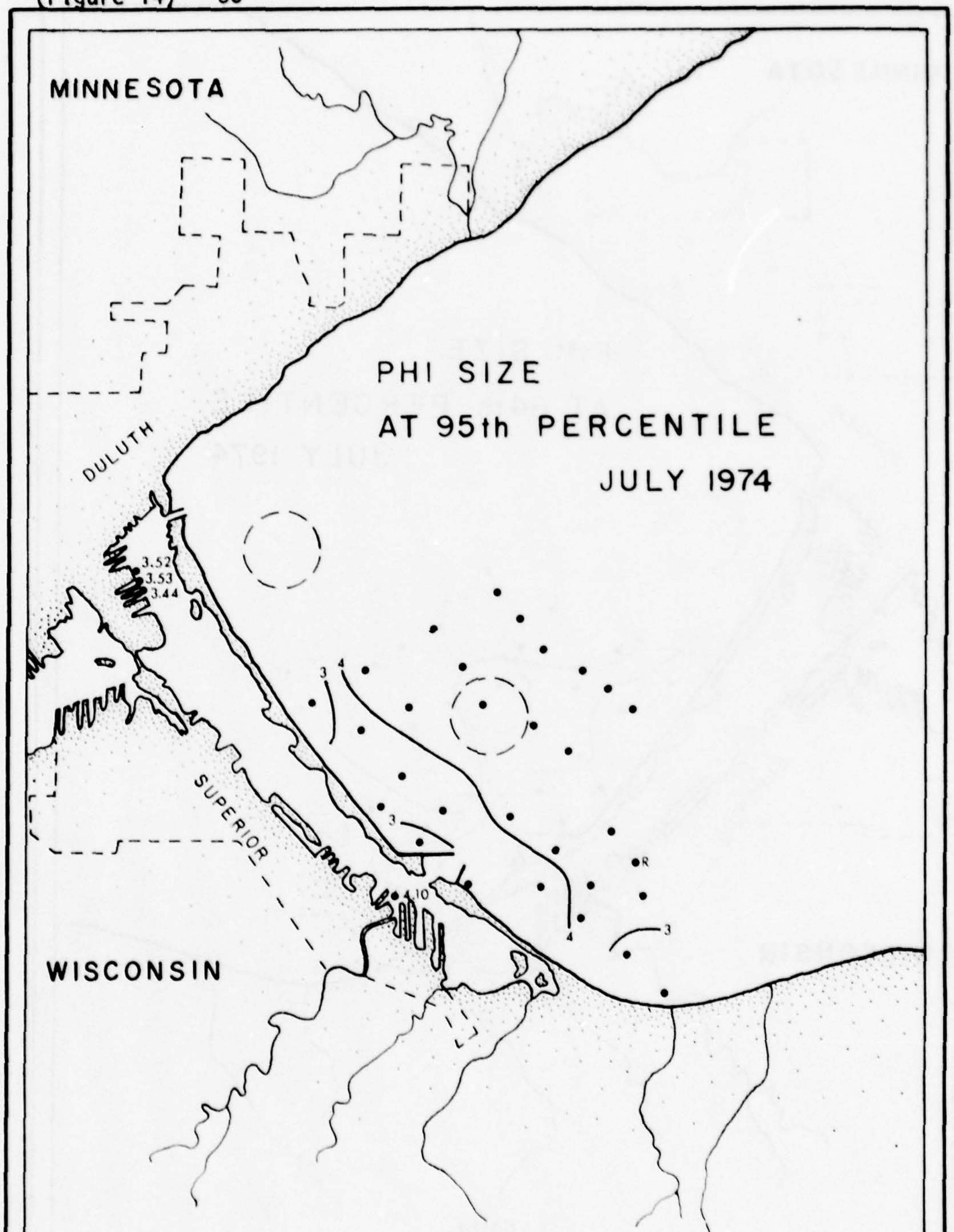

MINNESOTA
SKEWNESS
JULY 1974
DULUTH
-3.09
-2.96
-1.71
SUPERIOR
-1.18
WISCONSIN
R = Rocky
Statute Miles
0
2
4
6
8
10

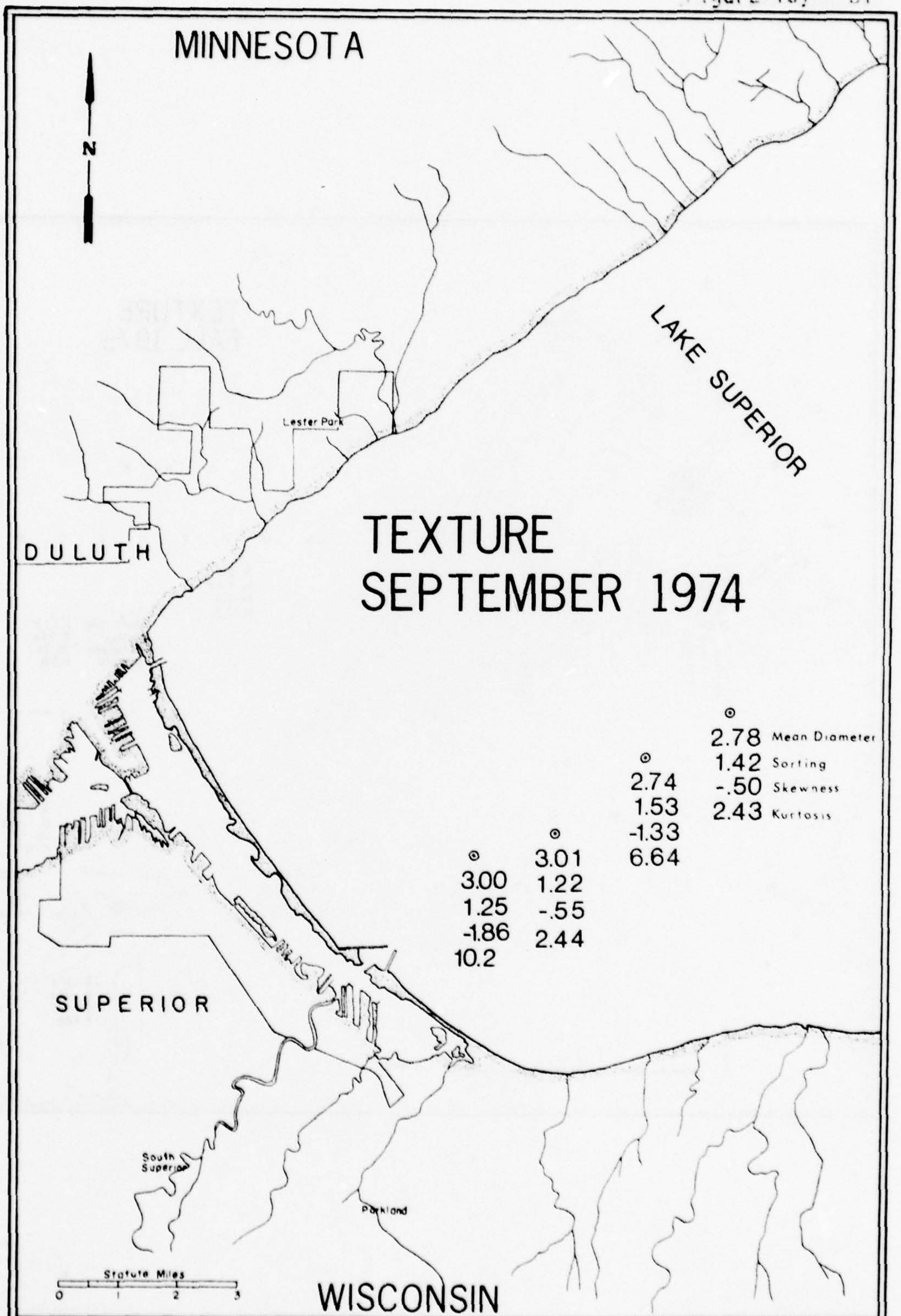
(Figure 12) 28

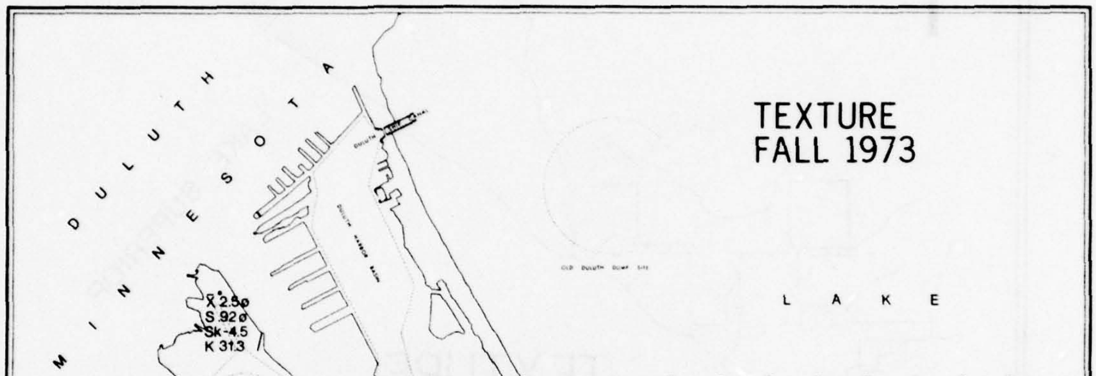

MINNESOTA
KURTOSIS
JULY 1974
DULUTH
20.8
16.1
10.5
20
10
5
SUPERIOR
6.6
R
5
5
WISCONSIN
R = Rocky
Statute Miles
0
2
4
6
8
10

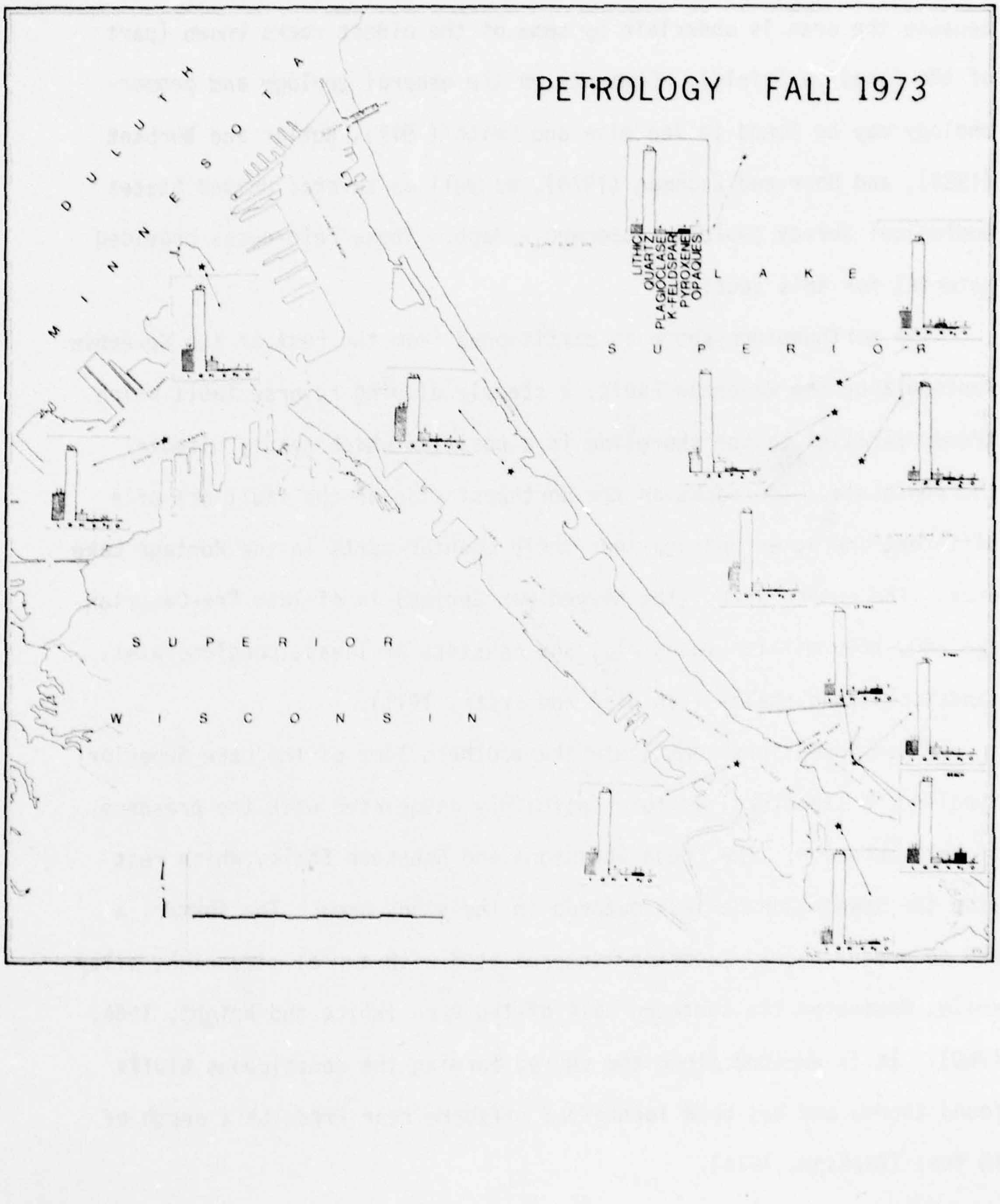

MINNESOTA
PHI SIZE
AT 84th PERCENTILE
JULY 1974
DULUTH
3.05
3.07
3.01
SUPERIOR
3.78
WISCONSIN
R = Rocky
Statute Miles
0
2
4
6
8
10

(Figure 14) 30


MINNESOTA
PHI SIZE
AT 95th PERCENTILE
JULY 1974
DULUTH
3.52
3.53
3.44
SUPERIOR
WISCONSIN
R = Rocky
Statute Miles
0
2
4
6
8
10


MINNESOTA
N
LAKE SUPERIOR
Lester Park
DULUTH
TEXTURE
SEPTEMBER 1974
2.78 Mean Diameter
1.42 Sorting
-.50 Skewness
2.43 Kurtosis
2.74
1.53
-1.33
6.64
3.01
1.22
-.55
2.44
3.00
1.25
-1.86
10.2
SUPERIOR
South Superior
Parkland
Statute Miles
0 1 2 3
WISCONSIN


TEXTURE
FALL 1973
DULUTH
MINNESOTA
LAKE
SUPERIOR
SUPERIOR
WISCONSIN
X̄ 2.5ø S .92ø Sk -4.5 K 31.3
X̄ 2.9ø S 1.0ø Sk -1.0 K 4.8
X̄ 2.4ø S 1.4ø Sk -2.8 K 13.4
Mean Size X̄ 2.1ø
Sorting S .84ø
Skewness Sk .78
Kurtosis K 3.9
X̄ 2.3ø S .56ø Sk -.51 K 6.1
X̄ 2.1ø S .45ø Sk -.25 K 4.4
X̄ .64ø S .68ø Sk -1.1 K 10.3
X̄ 1.97ø S .98ø Sk -.08 K 4.68


PETROLOGY FALL 1973
LITHIC
QUARTZ
PLAGIOCLASE
K-FELDSPAR
PYROXENE
OPAQUES
M I N N E S O T A
D U L U T H
L A K E
S U P E R I O R
S U P E R I O R
W I S C O N S I N

II. Sedimentation Studies: Keweenaw

A. Geology and Geomorphology

The Keweenaw Peninsula has been extensively studied with regard to its geology because of its importance as a copper mining district and because the area is underlain by some of the oldest rocks known (part of the Canadian Shield). Comments on the general geology and geomorphology may be found in Van Hise and Leith (1911), Butler and Burbank (1929), and Dorr and Eschman (1970), as well as several United States Geological Survey geologic quadrangle maps. These references provided material for this section.

The northwestern shore is partitioned from the rest of the Keweenaw Peninsula by the Keweenaw Fault, a steeply dipping reverse fault which trends parallel to the shoreline in a position which nearly bisects the peninsula. The rocks on the northwest side of the fault are of a different character and age than their counter-parts in the Portage Lake area. The entire group (the Keweenawan Series) is of late Pre-Cambrian age (800-1600 million years old) and consists of lavas, conglomerates, sandstones, and shales (Van Hise and Leith, 1911).

These formations constitute the southern limb of the Lake Superior Syncline, a structural feature intimately associated with the presence of Lake Superior. The Freda Sandstone and Nonesuch Shale, which rest atop the Keweenawan Series, outcrop in the study area. The former, a red to greenish-gray sandstone intercalated with a red, mica-rich, silty shale, dominates the southern half of the area (White and Wright, 1954, 1960). It is exposed along the shore, forming the conspicuous bluffs found there, and has been identified offshore near Freda at a depth of 40 feet (Berkson, 1974).

Although bedrock in the area shows great age and was given its origin form during the Pre-Cambrian Era, the succession of continental glaciers which passed through the region of the present Keweenaw Peninsula during the Pleistocene Epoch modified the landscape to give it its present form. Despite this later day influence, the strong suggestion of a trellis pattern displayed by the local streams indicates an underlying structural control of the drainage in the area.

Glacial action, plus the normal shore weathering processes, has shaped the shoreline. A strongly developed system of glacial striae was discovered offshore (Berkson, 1974). Hack (1965) concluded that a thickness of up to 200 feet of glacial till and Pleistocene Lacustrine sediments overlie the Freda Sandstone. This agrees with the studies of the surface geology of the Peninsula by Leverett (1929), which indicate clay lake beds along the shore from the southern part of the study area to north of Redridge, where sandy lake beds continue to the north. An area of moraine, deposited in or later covered by water, overlays the area inland of the shore from Redridge to the Keweenaw Waterway (Figure 18).

Much of the material comprising the beaches in the area is derived from the Keweenawan Series. This source, coupled with a contribution from glacial tills, lake beds, and material transported in from outside the area, constitute the natural sources of littoral and beach sediment.

The completion of the Keweenaw Waterway (which is natural except for the last few miles near and including the Upper Entry) during the late 1800's has greatly affected the adjacent littoral zone near the Upper Entry by providing an escape for sand in the littoral drift system--inside the waterway. It also opened an avenue into Lake Superior for fine-grained material which was generated in the Waterway drainage area and had remained in suspension. This included easily eroded tailings left by the intense mining activity in the area. Miles of Keweenaw beaches and offshore areas receive copper-rich sediment from basaltic stampsands found in the Freda-Redridge region, 10 miles south of the Waterway. These sands were transported into the area as bulk copper ore and were subsequently crushed at the stamping mills there. Native copper has been found in beach material at Beacon Hill, a site between Redridge and Freda.

B. Prior Geological Studies: Keweenaw Study Area

Despite the lack of detailed investigations of the beaches and shallow offshore areas in the project site, several megascopic studies have been conducted which embrace all or part of that region.

The bathymetry, in gross form, is well known. A bathymetric chart, covering Lake Superior in its entirety, was published by Farrand and Zumberge (1966). Since the contours are in 100 foot depth increments on this chart, it could not be utilized in the present study. A more detailed bathymetry of the area may be found in Berkson (1974). He used a contour interval of 10 feet, but only covered the region from three miles south to three miles north of Freda. Enough data could be used from both charts, however, so that a crude idea of the local bathymetry was obtained.

A similar situation was discovered with regard to previous work on the sediments. Berkson (1974) discovered a sandy bottom from shore out to a depth of about 180 feet, with a red till and a red sandy clay beyond this depth extending out to depths of 550 feet. However, because texture was of subordinate interest in his study, he did not present a more exact description. His general survey area was along the coast southwest of the upper Waterway entry. A composite picture of the sediment column in Lake Superior was presented by Farrand (1969a, 1969b) and Dell (1972). Based on core samples, they found, from top to bottom, (1) a surficial sand (generally less than 3 feet thick), (2) brown silty clay (≤15 feet thick), (3) gray clay (≤10 feet thick), (4) gray varved clay (≤25 feet thick), (5) red varved clay (≤10 feet thick), (6) red, non-varved lacustrine sediment containing silt and clay (≤100 feet thick), and (7) a fine to medium, brown sand (≤80 feet thick). Not all of these sediment types are found in any given locality. In fact, rarely more than four are found in one core. The most likely members of this succession to be found in the Keweenaw study area are the surficial sand, brown silty clay, and the red sediment types. In light of this, the red sandy clay found by Berkson (1974) off Freda fits the description of "(6)" above quite nicely. Farrand (1969b) also found a red silty sediment off the upper Waterway entrance in 500 feet of water.

Another broad brush survey of the area was conducted by Adams and Kregear (1969). Concerned with surface sediments in the eastern half of the lake, these authors only collected two grab samples in our project study area. They found, in water depths of 100 and 200 feet, a coarse and medium sand, respectively. And further up the coast near Copper Harbor, silt and clay were found offshore by Smith and Moore (1972). With the exception of the surficial sand, all sediment types reported are of late Pleistocene origin (Farrand, 1969a).

Apart from these physical properties, the geochemistry of Lake Superior sediments has also been studied. For example, Nussman (1964) and Callender (1969) have researched sediments in Lake Superior with Nussman's work encompassing material found off the Keweenaw Peninsula.

A synopsis of the previous work on sediments, then, shows that not only are the overall characteristics including both physical and chemical parameters known, but that the gross sediment types in the study area could be predicted.

Closer to shore, the beach and nearshore zone at McLain State Park was studied by Wilson (1971). This one investigation, which is an unpublished student term project, represents the entire sum of available geological shoreline studies in the area. In this report, data are presented pertaining to rates of littoral drift (3-12 cm/sec) and textural analyses, including mean grain size, sorting, skewness, and kurtosis. Sediment ranged from medium sand to gravel at McLain State Park.

Of greater interest to this project, Balsillie (1972, 1973b) monitored, and is continuing to monitor, wave conditions and transport of sediment in the littoral zone at McLain State Park, as part of the Littoral Environment Observation Program of the Coastal Engineering Research Center. He has developed an equation to calculate the volume of sediment transported in the surf zone. His equation is (Balsillie, 1973a):

$$Q = 0.174\ H_b^{5/2}\ \sin\ (2\theta_b)$$

where Q = volume of sediment moved past a fixed point (millions of cubic yards per year)

H_b = wave height at breaking

θ_b = angle of breaking wave with shoreline

Based on this equation, he computed that for seven ice-free months in 1972, there may have been a net northeastward movement of up to 184,226 cubic yards of sediment at McLain State Park. Similarly, in 1973, the volume for four months was 87,670 cubic yards. He further observed that mean wave height varies from only about half a foot in June to over two feet in September, which has obvious ramifications concerning shoreline planning.

C. The Movement of the Stampsands

The distinctiveness of the basaltic stampsands left behind on the beaches at Redridge and Freda makes them useful in tracing sediment transport. According to White (1955) native copper in the Keweenaw area occurs as fillings in the amygdules and interstices of the fragmental tops of individual flows and is associated with chlorite, prehnite, epidote, and quartz - subordinately with red potash feldspar and zeolites.

X-ray diffractograms of beach samples collected in the fall of 1973 are shown in Figures 20 and 21. The location of the stations is shown in Figure 19. The peaks for chlorite, orthoclase (potash feldspar), plagioclase, and hematite are very high for the Redridge tailings and the foreshore sample at Redridge (R1-C). Peak heights for these minerals farther south at Beacon Hill (BH-1) show a definite decrease. At Agate Beach (AG-2) the peaks are even lower; quartz, however, increases.

A similar trend is shown in a northerly direction from Redridge. Chlorite, orthoclase, plagioclase, and hematite peaks remain high at Portage Entry South (PES-1) and practically disappear north of the breakwater in McLain State Park (M2-A). There is a slight increase in peak height at the Calumet waterworks (C1-C) and a further increase at the Tamarack waterworks (T1-C).

Epidote, calcite, and hornblende were also identified from the X-ray diffractograms. Movement of the tailings along the beaches from Redridge and Freda towards Agate Beach and the Waterway seems to be indicated. The marked decrease in peak heights at McLain State Park suggests a bypassing of the area by the moving stampsands.

The petrology of beach and nearshore sediments sampled in 1973, shows a similar trend (Figure 22 and 23). In these figures, C represents a foreshore sample taken at the waterline, B indicates a berm sample, and A is a sample from the backshore of the beach. The locations of these samples are shown on the beach profiles (Figures 40-50). Quartz and lithic (rock) percentages make up the bulk of each sample. The lithic fragments were predominantly basalt.

Quartz dominates over lithics on the beach and offshore at both of the Agate Beach stations (AG-1 and AG-2). Lithics comprise the major percentage on the beaches and some distance offshore from Beacon Hill to southwest of the Portage Entry (BH-1, R-1, PES-1). Further offshore, quartz assumes dominance again.

At the station in McLain State Park just north of the breakwater (M-3), quartz is the major constituent both on the beach and offshore. Quartz is dominant over lithics on the backshores of the two northerly stations in McLain State Park (M-2 and M-3) and at Calumet (C-1). Lithic fragments are the major components of the berm and foreshore at these stations, but offshore samples at Calumet are mostly quartz. Lithic fragments outweigh quartz on the beach at Tamarack (T-1) and for a distance offshore before quartz becomes predominate.

Petrology (petrographic descriptions and photomicrography) of beach and offshore samples taken in June, 1974 show the same trends (Figures 24 and 25) except that quartz dominates over the lithic percentage at Tamarack. The stampsands appear to be moving nearshore along the beaches and for a short distance offshore south of the Waterway. North of the Waterway, movement appears to be limited to the vicinity of the beaches--except at the stations in McLain State Park, which seem to be less affected by stampsand movement.

The lithic percentages of offshore samples taken in June, 1974 (Figure 19) show the movement of the stampsands clearly. Photographs of thin sections of the samples as seen under the petrographic microscope are shown in Figure 26. The lighter colored fragments are mostly quartz and the darker ones are lithic fragments. The three top photos (221, 150, and 75) (stations taken at a distance offshore) are mostly quartz as are the stations off Calumet (209), McLain State Park (M-1), and the mouth of the Waterway (154). The spoil sample, taken from inside the Waterway, is a mixture of quartz, lithic fragments, and fine-grained material.

Further southwest of the Upper Entry a change occurs. The stations southwest of the Entry near PES-1 (141), between PES-1 and Redridge (98), just north of Redridge (056), and south of Freda (001) are predominantly lithic fragments similar to those in the Redridge tailings.

The lithic fragment distribution map shown in Figure 27 shows the movement of the stampsands from Freda and Redridge in both directions parallel and close to the shore. South of the Waterway entrance, the stampsands are partially deflected offshore. A variety of possibilities occur here--the remainder of the stampsands can: continue moving parallel to the shore where it is deposited along the beach southwest of the breakwater; enter the Waterway; continue past the Entrance and follow a path at a greater distance offshore; or drift along the beaches.

D. Sediment Distribution: June 1974

The bathymetry based on the June, 1974 stations is shown in Figure 28. This map is based on uncorrected raw data. Depths were measured with a Konel fathometer. Sediment distribution (Figure 29) based on visual inspection of the samples as they were brought aboard ship shows a strong resemblance to the bathymetry. The finest sediments are found in the deep area in the northern part of the sampling area. An area of fine sand is found off-shore of the beaches from McLain State Park to Calumet. The coarsest areas are offshore northeast of Redridge.

The mean grain size distribution based on sieve data retains many of the same features (Figure 30). The fine-grained area in the northern section is prominent. The coarse area northeast of Redridge is extended parallel to the coast with fine sediment on either side. Contours of mean grain size (Figure 31) show these features more distinctly. Coarser sediment appears to form a discontinuous band parallel to the coast from Freda to north of the Waterway. Southwest of the Upper Entry coarser material extends further offshore. Finer sediment offshore of Redridge, at the mouth of the Waterway and north from McLain State Park to Tamarack, interrupts the band of coarse sediment. Finer material is found in deeper waters. Median size (Figure 32) shows much the same pattern, as do the other textural parameters (Figures 33-37).

The coarser areas tend to have poorer sorting, less negative skewness, and lower kurtosis than the surrounding fine areas. Booth (1973) showed in the Northern Channel Island Passages off the Southern California coast that mean grain size and sorting can be used as an indicator of sediment dispersion. The basis for the method is that mean grain size will increase with intensifying energy and sorting will be poorer with both increased energy and greater range of energy changes. Close examination of Figures 32 and 33 indicates dispersion of the coarser sediment parallel to the shore from Freda and Redridge toward the Waterway. Between Redridge and the Upper Entry movement shifts partly to an offshore direction. The rest of the coarse material moves along the coast to the Waterway. North of the Waterway the movement shifts offshore once again.

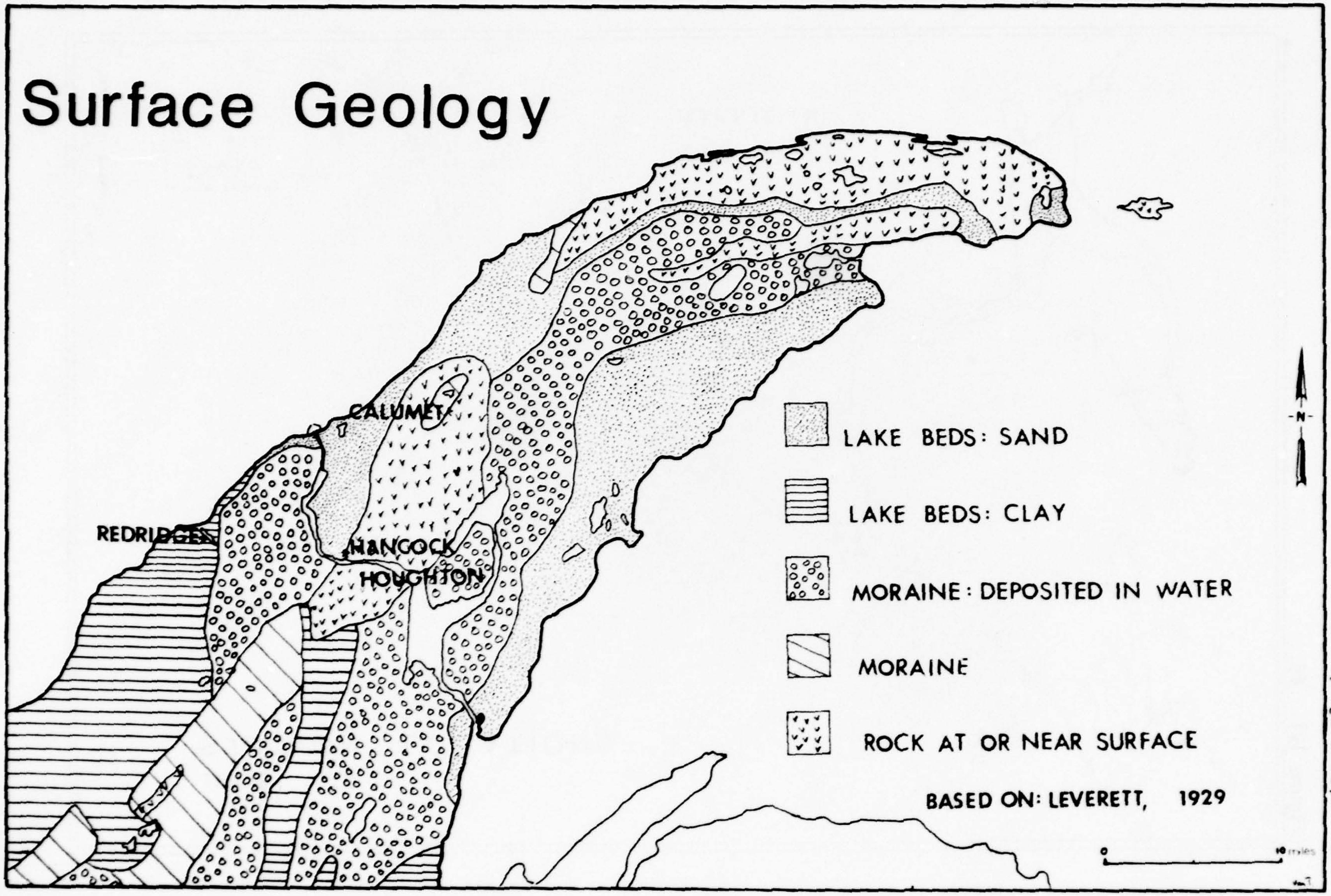
The better sorting and finer character of the sediment close to the shore from Redridge to the Portage Entry is probably due to the wave action and longshore transport in that zone. Phi size distributions at the 84th and 95th percentiles (Figures 36 and 37) indicate fine material originating near Redridge, from the Waterway entrance, and along the shore from McLain State Park to Calumet. Presumably, very fine sediment from the streams and erosion of the shore north of the Entry moves offshore and settles in the deeper water. This would explain the low kurtosis of the deep area in the northern sector.

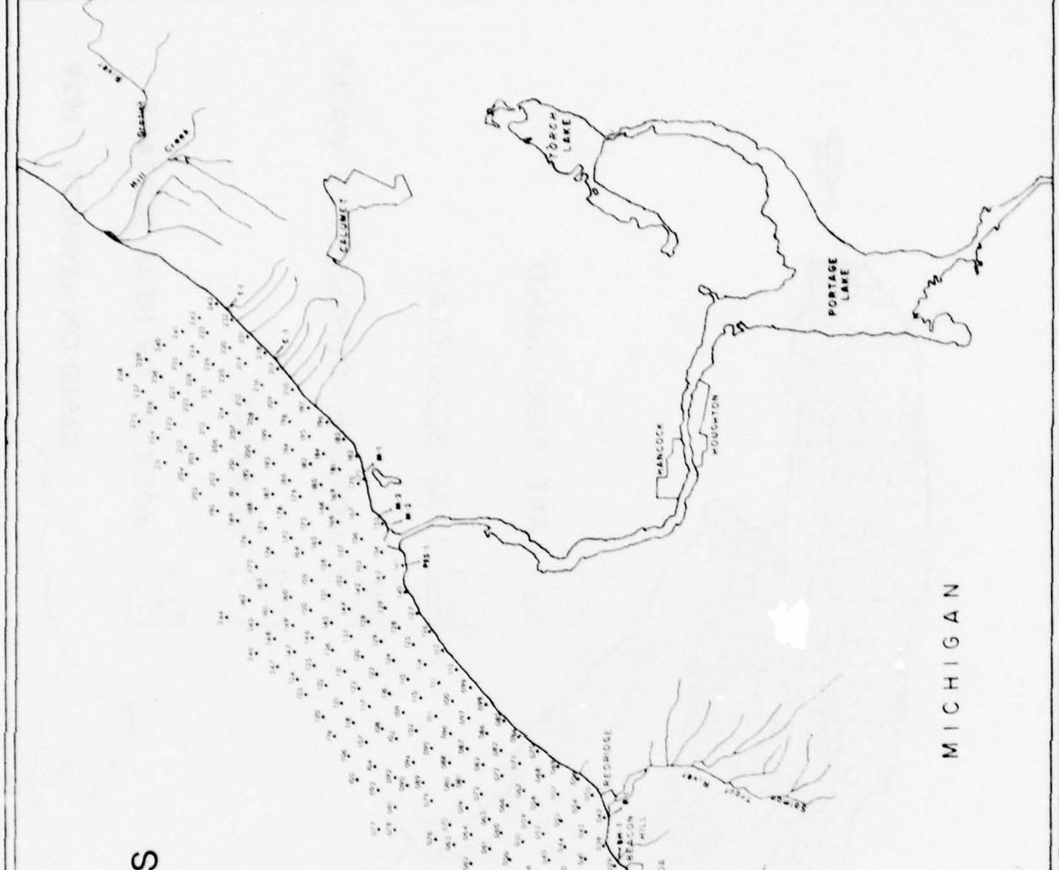
This pattern of sediment dispersal inferred from textural patterns agrees well with that shown by the distribution of lithic fragments. By combining the two it was possible to construct the sediment dispersal map shown in Figure 38.

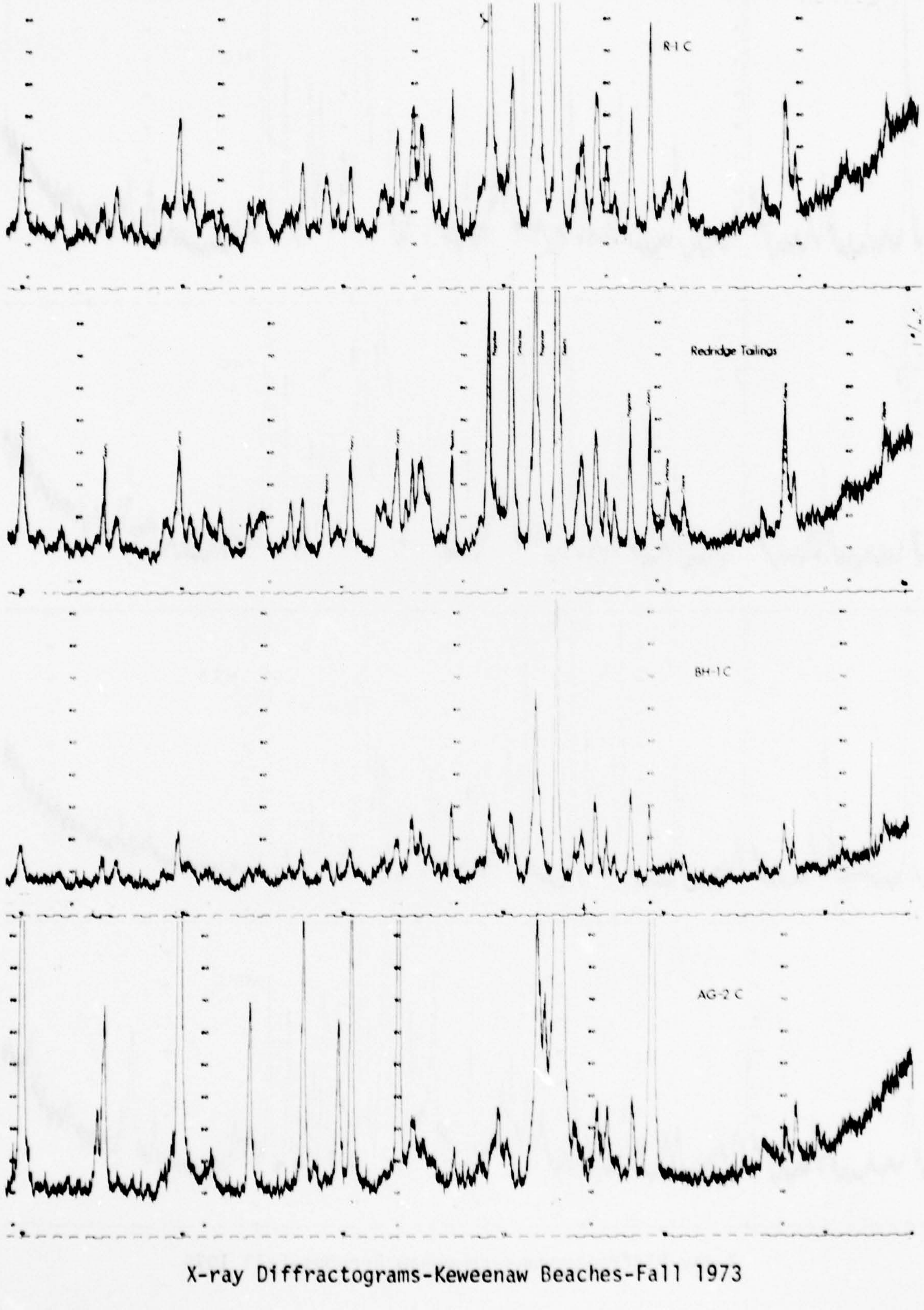
Plotting the sediment dispersal pattern on the bathymetry (Figure 39) reveals an interesting pattern. There is some evidence of shoaling due to deposition of sediment beyond the zone of wave action where the coarse sediment dispersal switches from a longshore to an offshore direction southwest of the Waterway entrance. The zone of highest transport energy approximately follows the 50 foot bathymetric contour. This may be the depth at which most incoming waves are first influenced by the bottom topography. Wave conditions are described in Volume 4, Section IIIE. A wave hindcast of storm conditions showed waves with a depth of influence ranging from 50-150 feet.

Table 3 - Beach Widths - Keweenaw

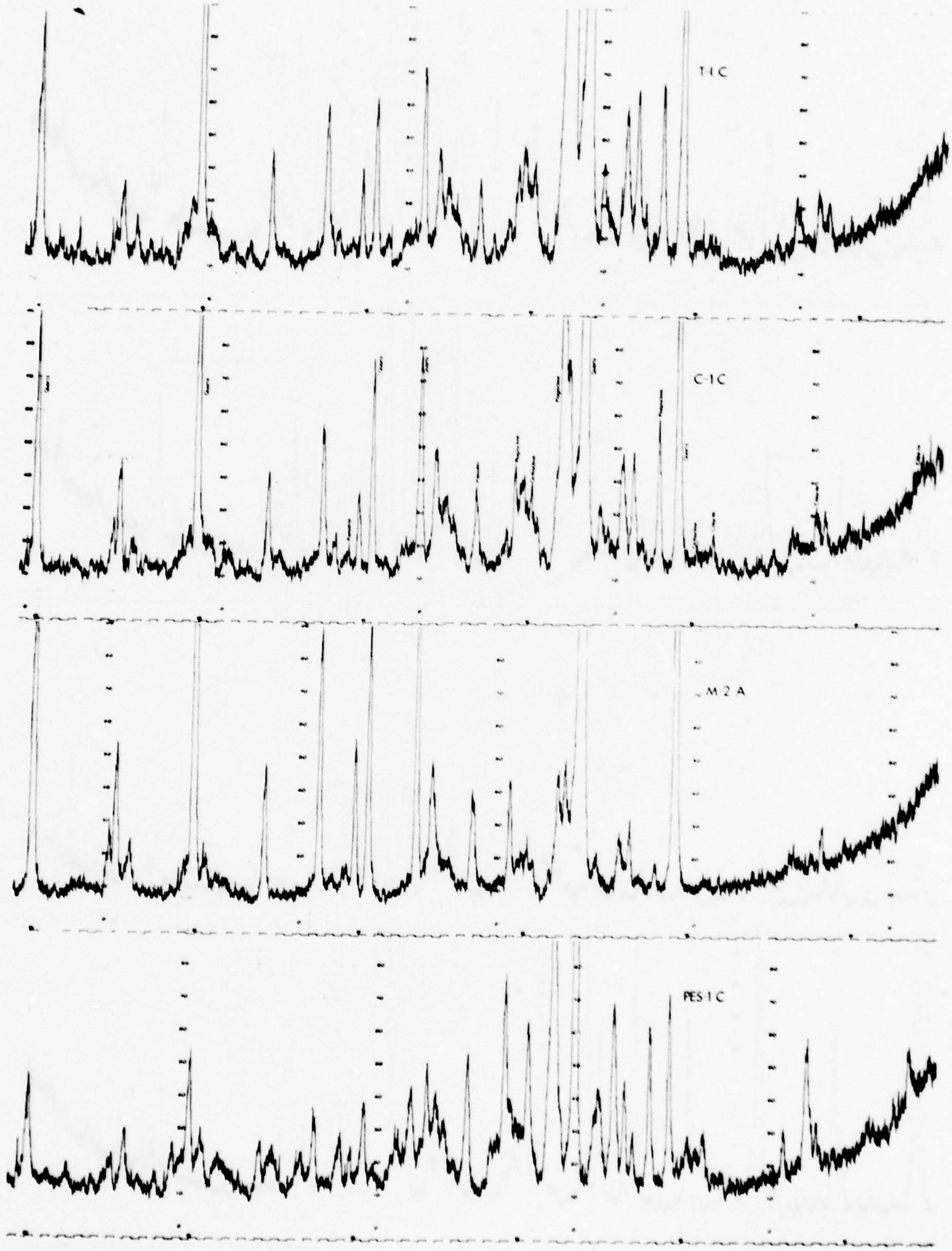
	Fall 1973	June 1974	November 1974
Tamarack Waterworks	44.2 feet	25.5 feet	26 feet
Calumet Waterworks	72 feet	71.2 feet	61 feet
McLain 1	-	lost	lost
McLain 2	52.2 feet	47.5 feet	removed
McLain 3	52.2 feet	61.9 feet	69 feet
Portage Entry South	272 feet	308 feet	327 feet
Redridge	-	129.8 feet	141 feet
Beacon Hill	43 feet	112 feet	47 feet
Agate Beach 2	27.1 feet	37.3 feet	inaccessible
Agate Beach 1	30.7 feet	38.9 feet	inaccessible


Surface Geology
CALUMET
REDRIDGE
HANCOCK
HOUGHTON
N
LAKE BEDS: SAND
LAKE BEDS: CLAY
MORAINE: DEPOSITED IN WATER
MORAINE
ROCK AT OR NEAR SURFACE
BASED ON: LEVERETT, 1929
0
10 miles


JUNE 1974
STATION LOCATIONS
LAKE SUPERIOR
MICHIGAN
TORCH LAKE
PORTAGE LAKE
CALUMET
HANCOCK
HOUGHTON
REDRIDGE
BEACON HILL
FREDA
• OFFSHORE SAMPLES
— BEACH PROFILES
STATUTE MILES
N

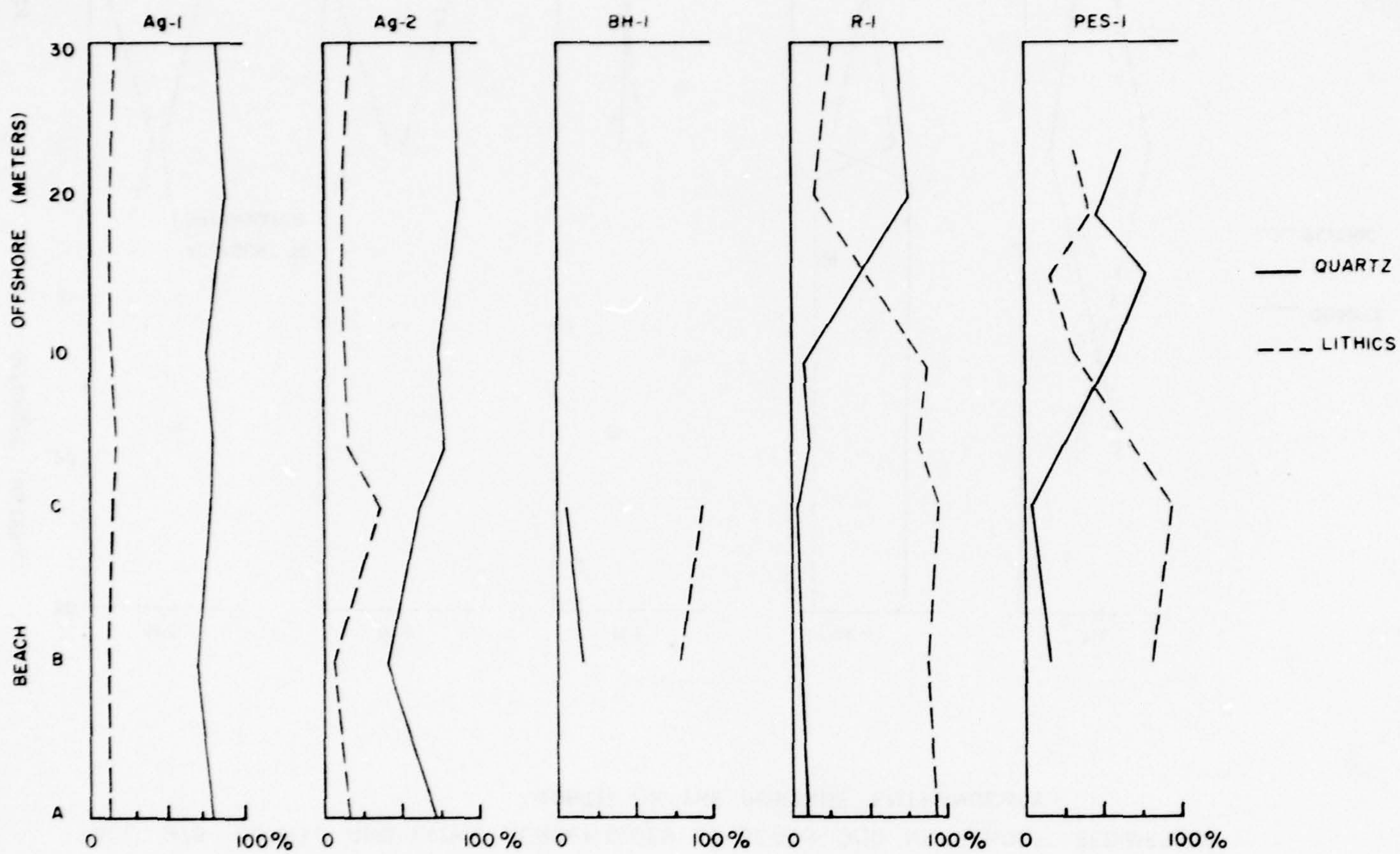


X-ray Diffractograms-Keweenaw Beaches-Fall 1973

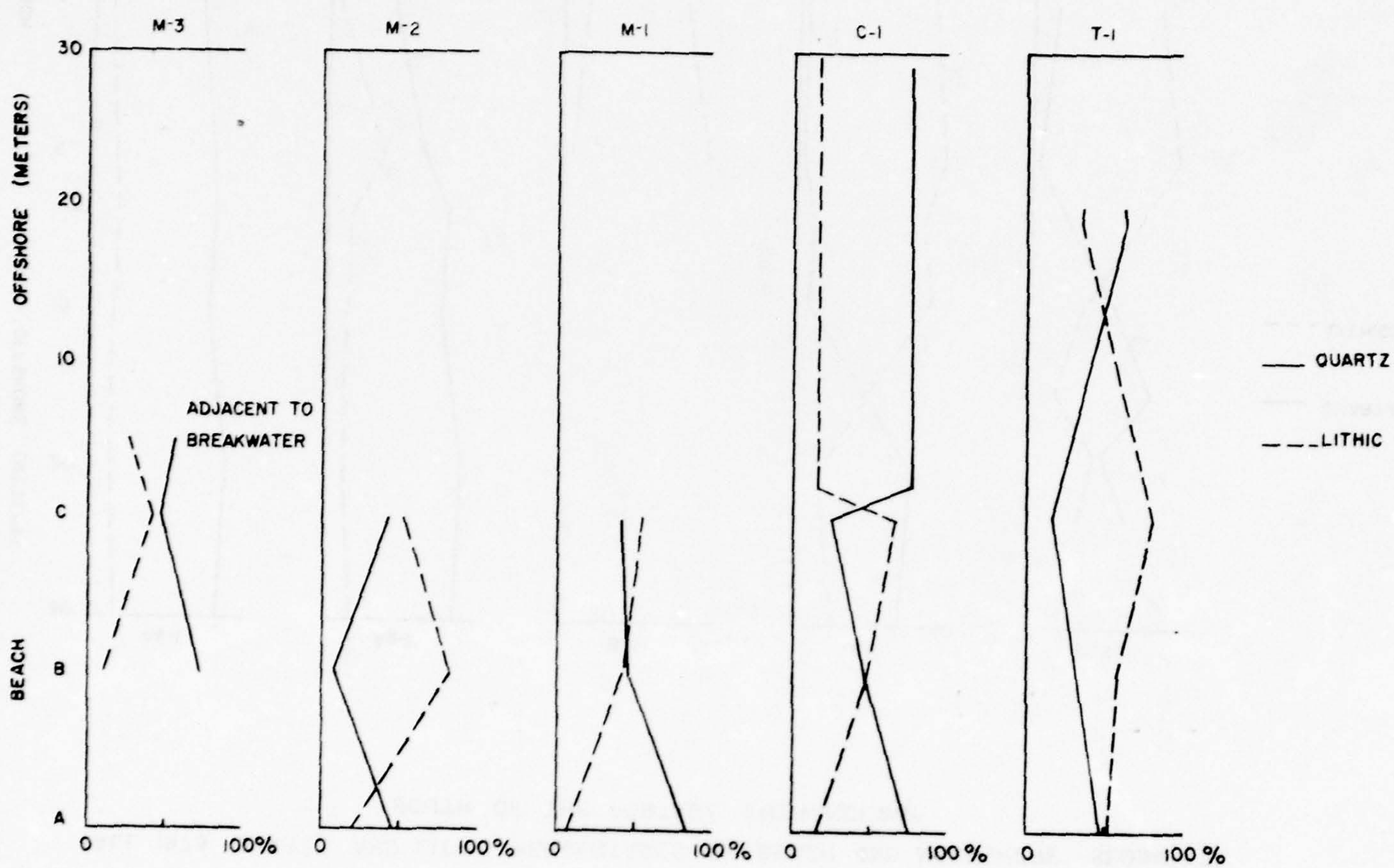


X-ray Diffractograms-Keweenaw Beaches-Fall 1973

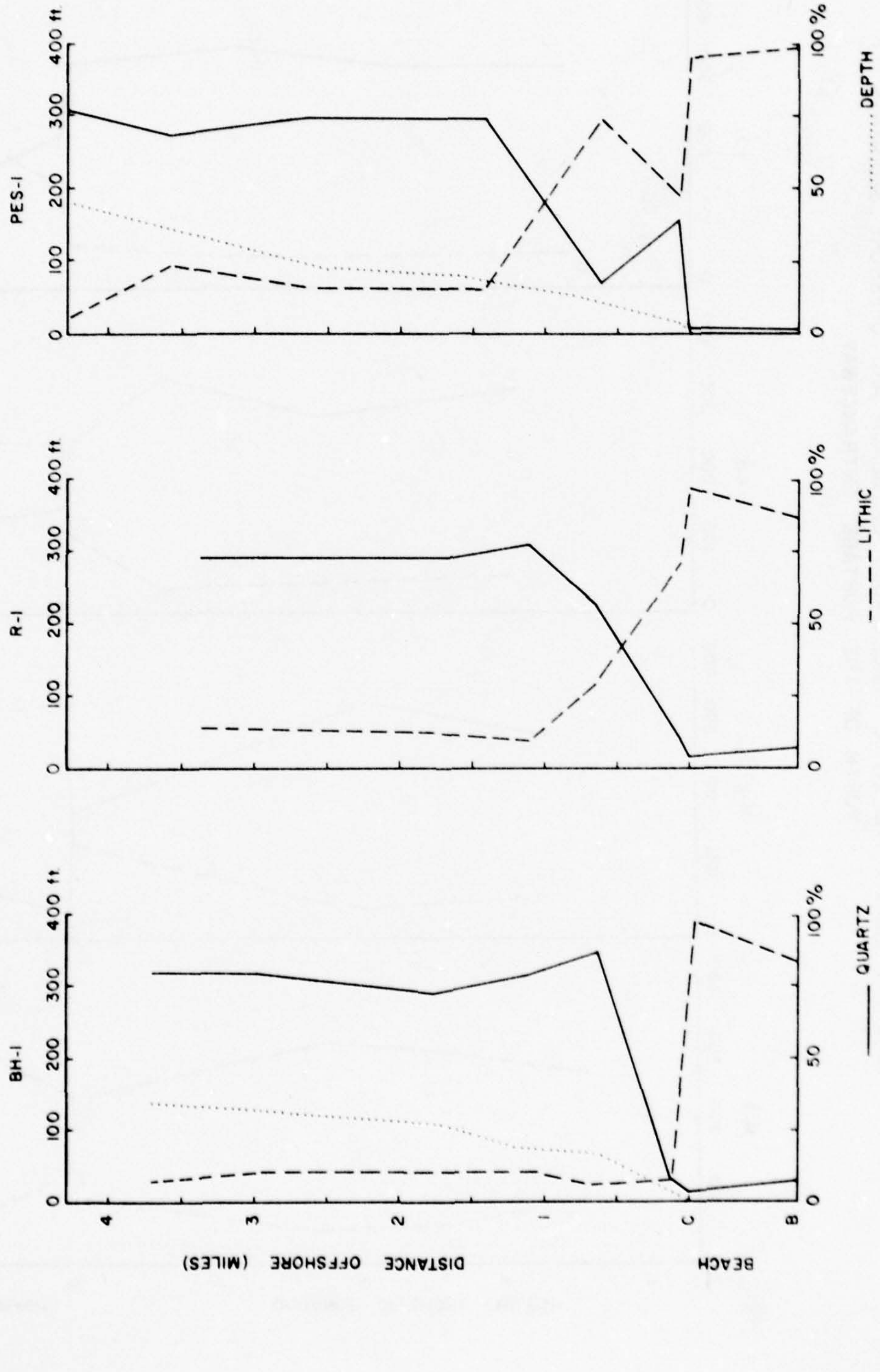
FALL 1973 QUARTZ AND LITHIC PERCENTAGES OF BEACH AND NEARSHORE SEDIMENTS SOUTH OF THE PORTAGE ENTRANCEWAY



FALL 1973 QUARTZ AND LITHIC PERCENTAGES OF BEACH AND NEARSHORE SEDIMENTS NORTH OF THE PORTAGE ENTRANCEWAY



JUNE 1974 QUARTZ AND LITHIC PERCENTAGES OF BEACH AND OFFSHORE SEDIMENTS SOUTH OF THE PORTAGE ENTRANCEWAY



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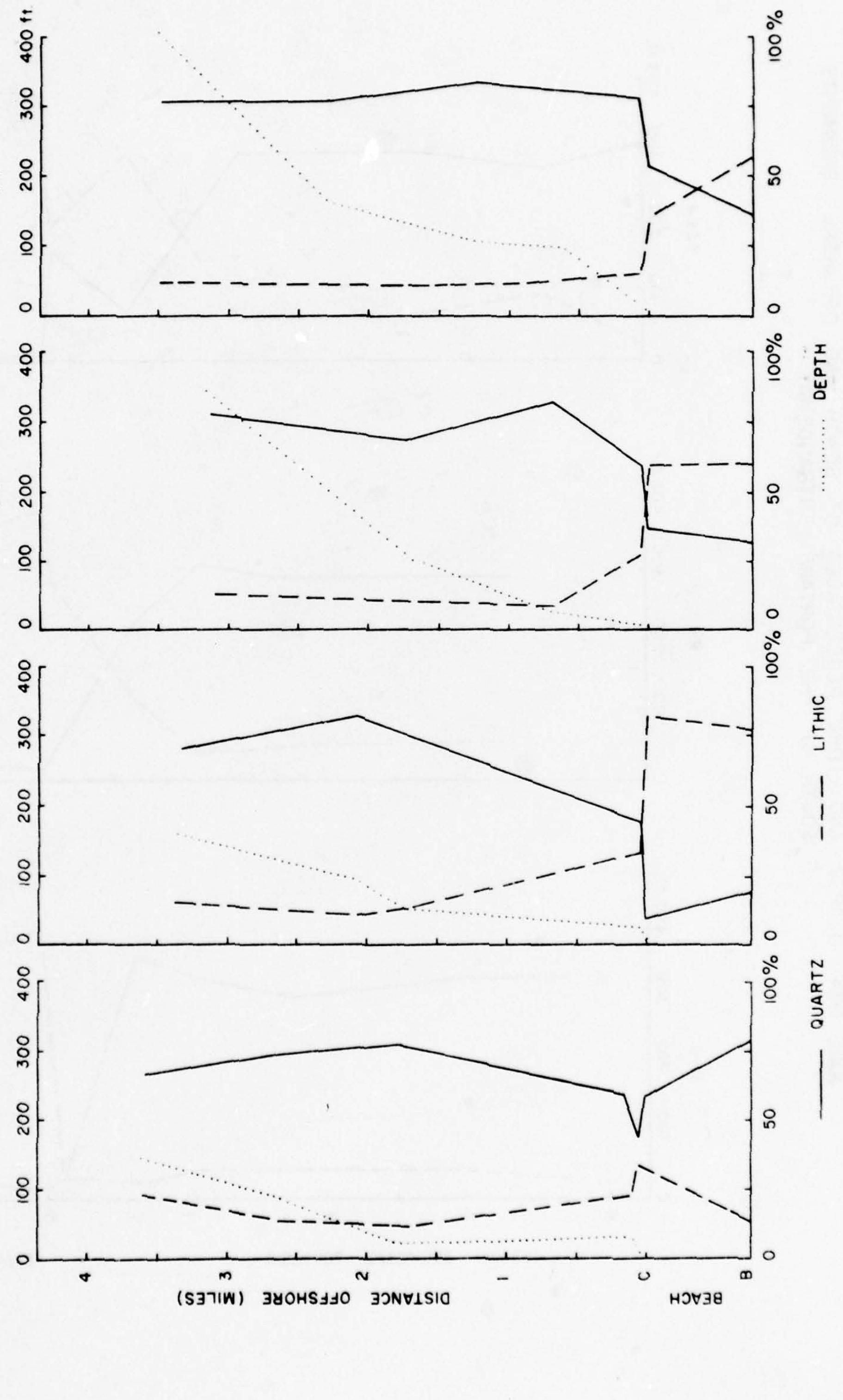

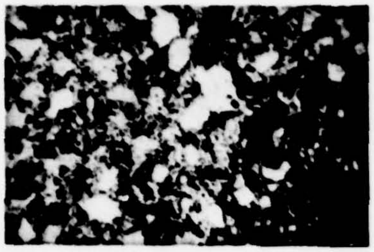

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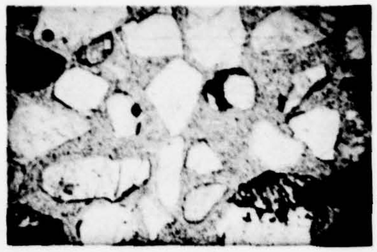

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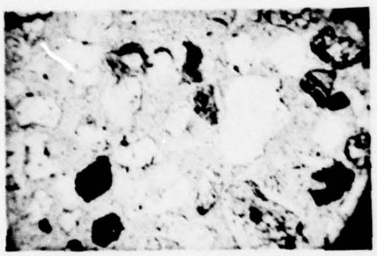

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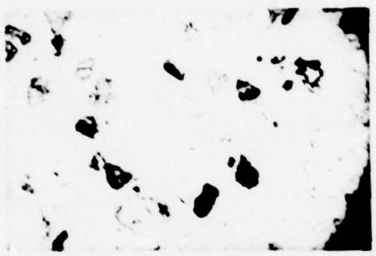

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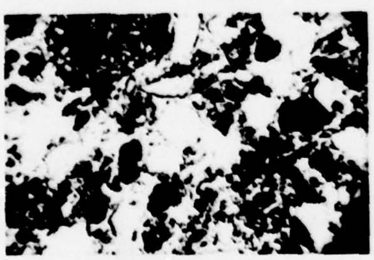

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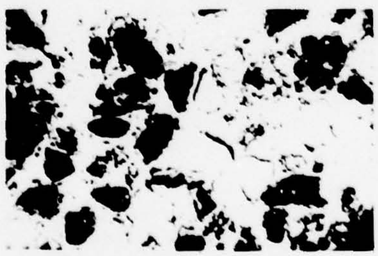

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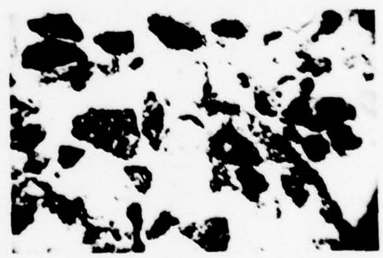

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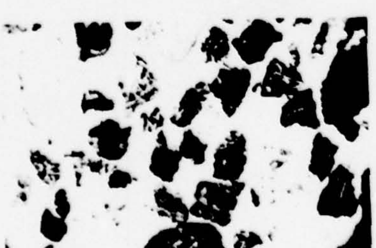

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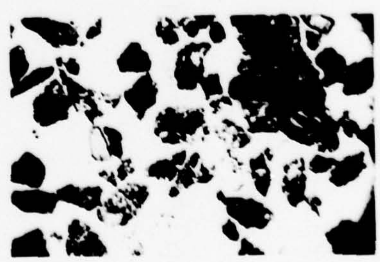

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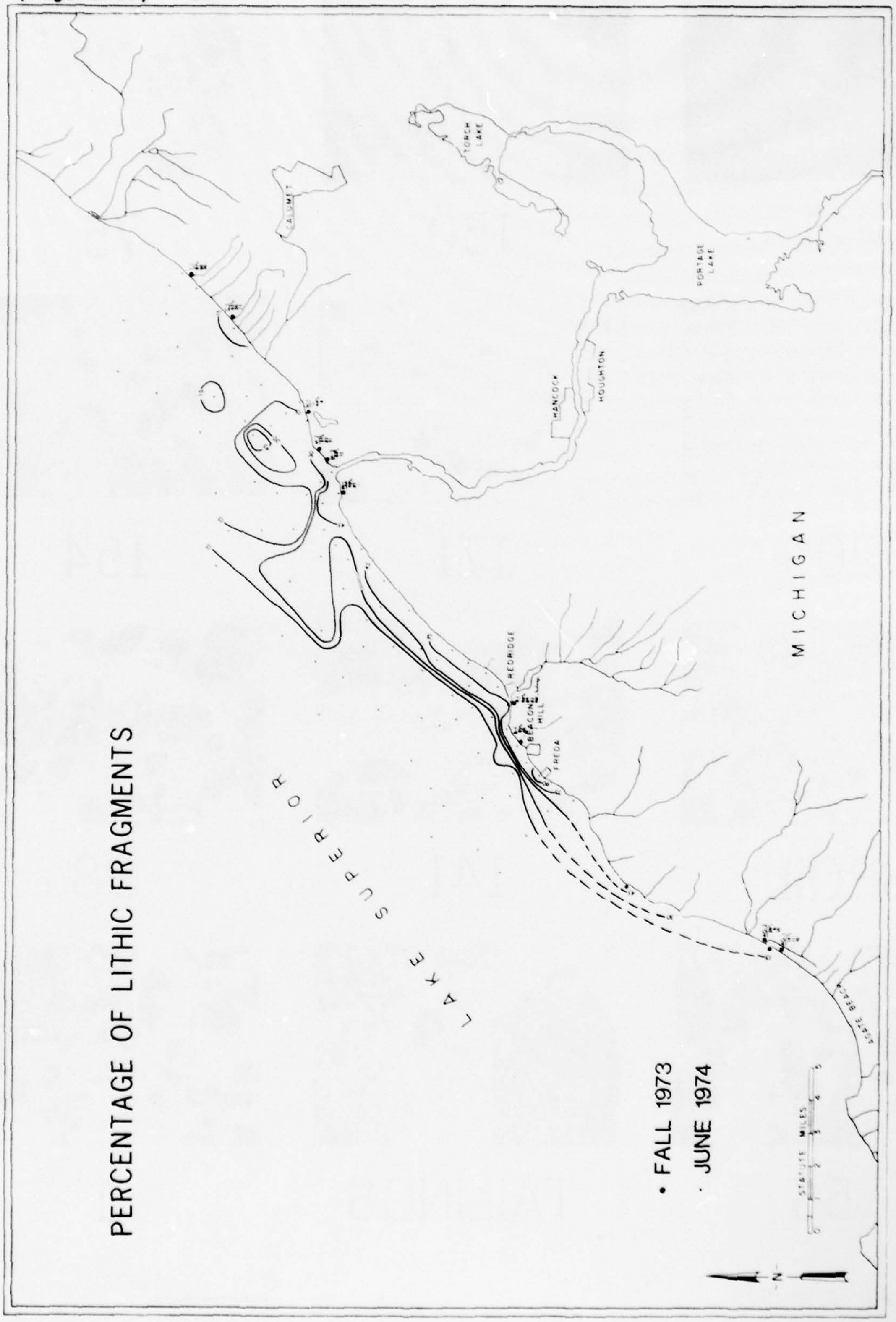
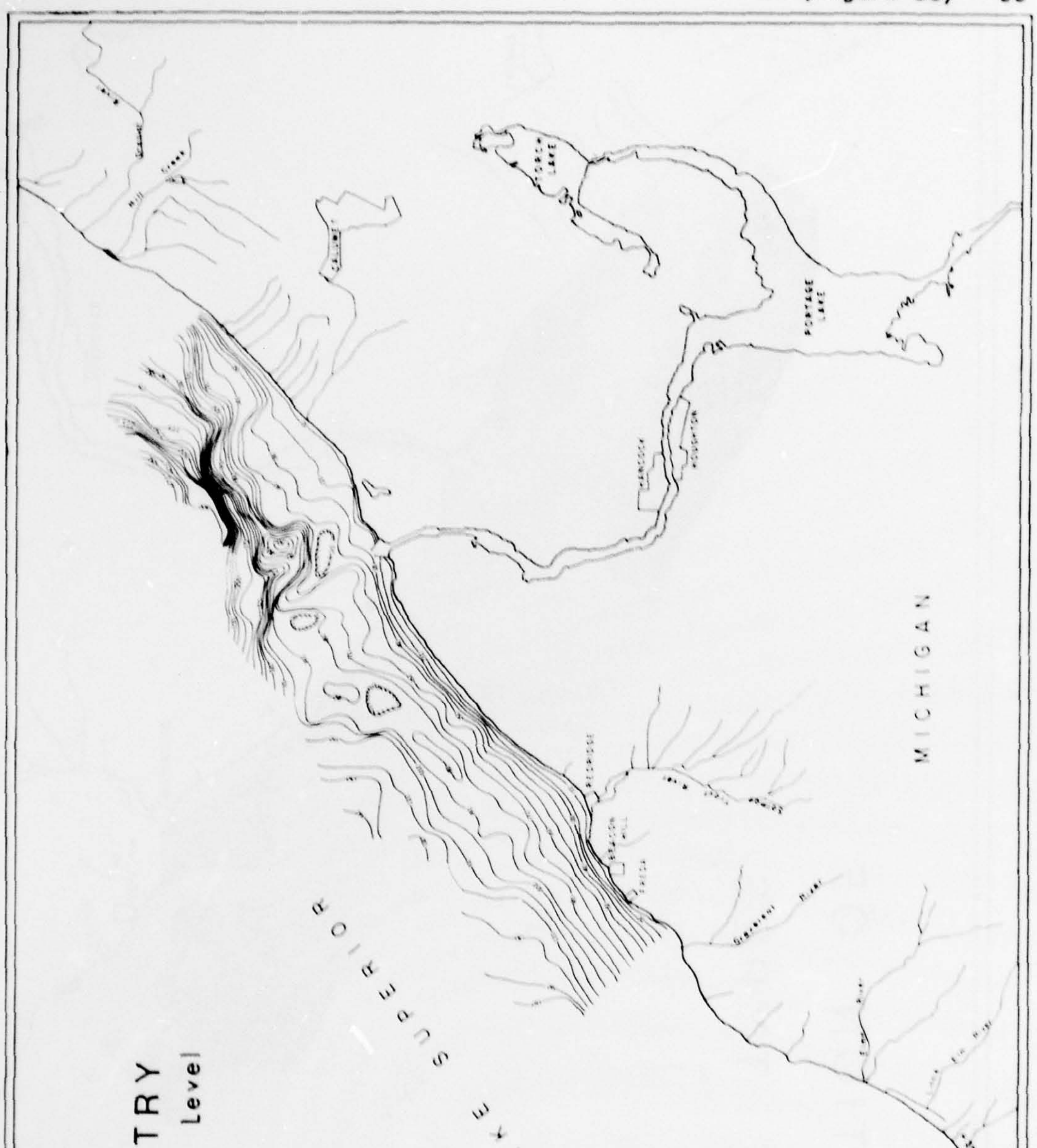
Keweenaw June 1974



PERCENTAGE OF LITHIC FRAGMENTS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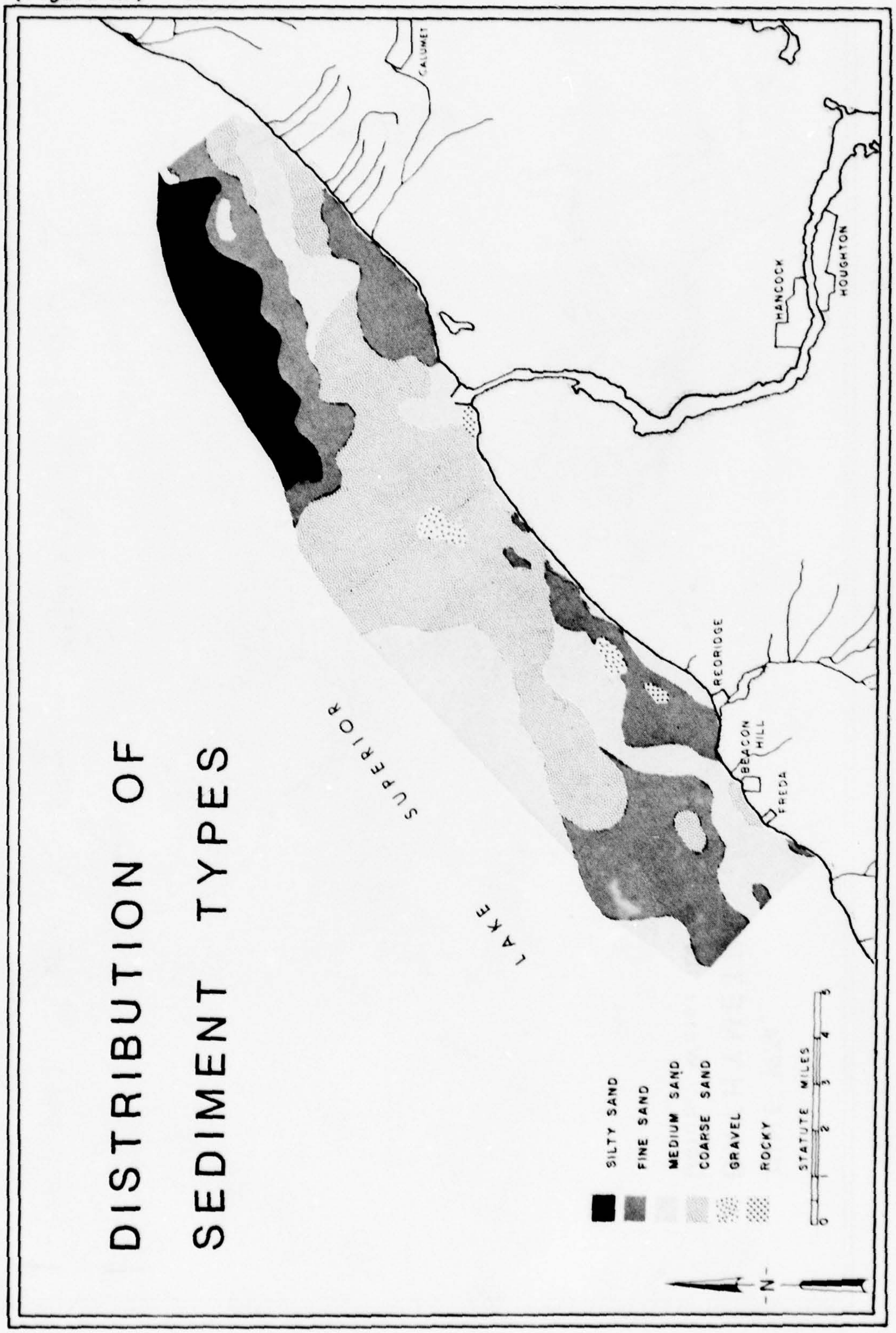
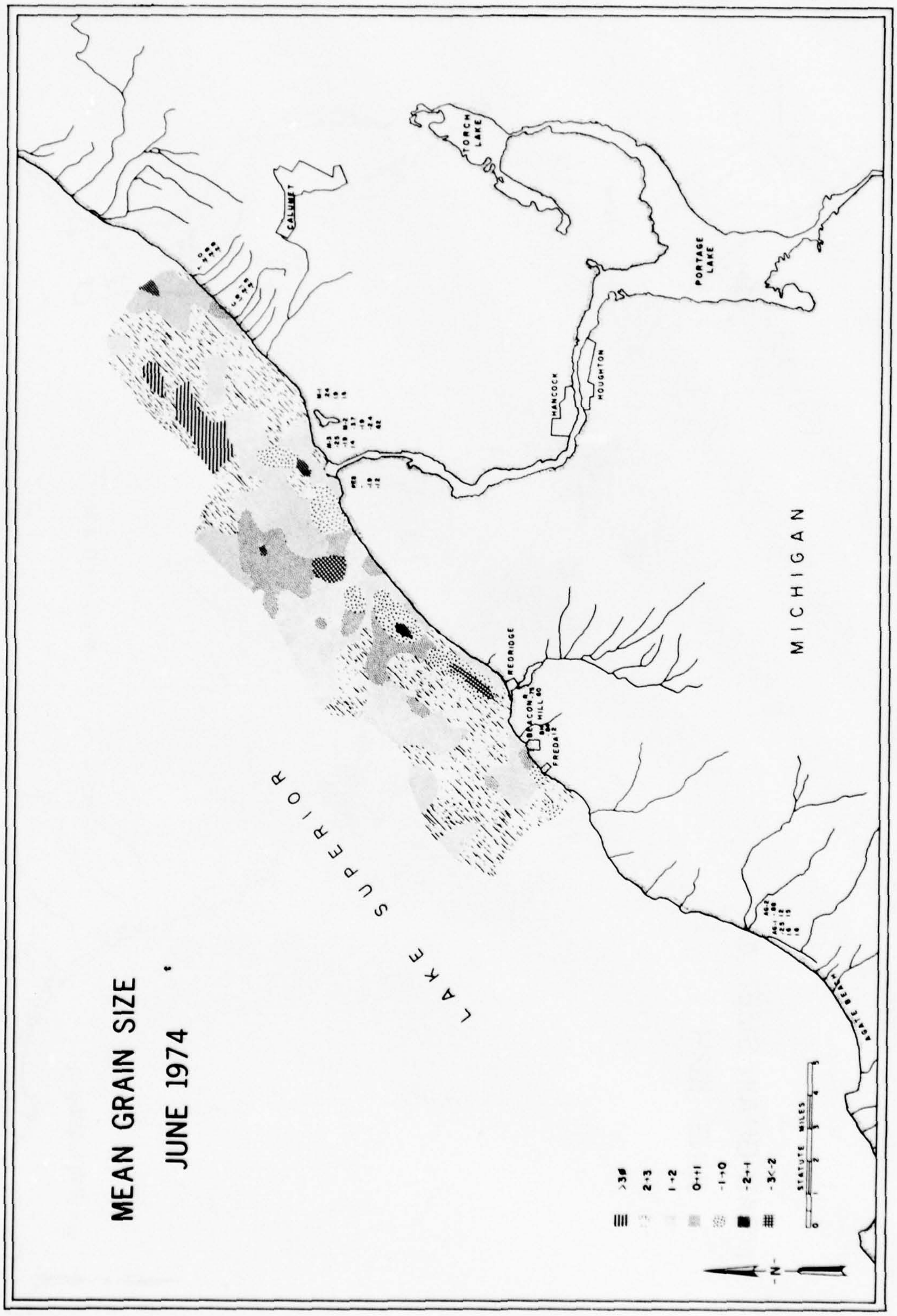
Datum: Water Level
LAKE SUPERIOR
MICHIGAN
PORTAGE LAKE
TORCH LAKE
HANCOCK
HOUGHTON



Based on Visual Inspection at Time of Collection



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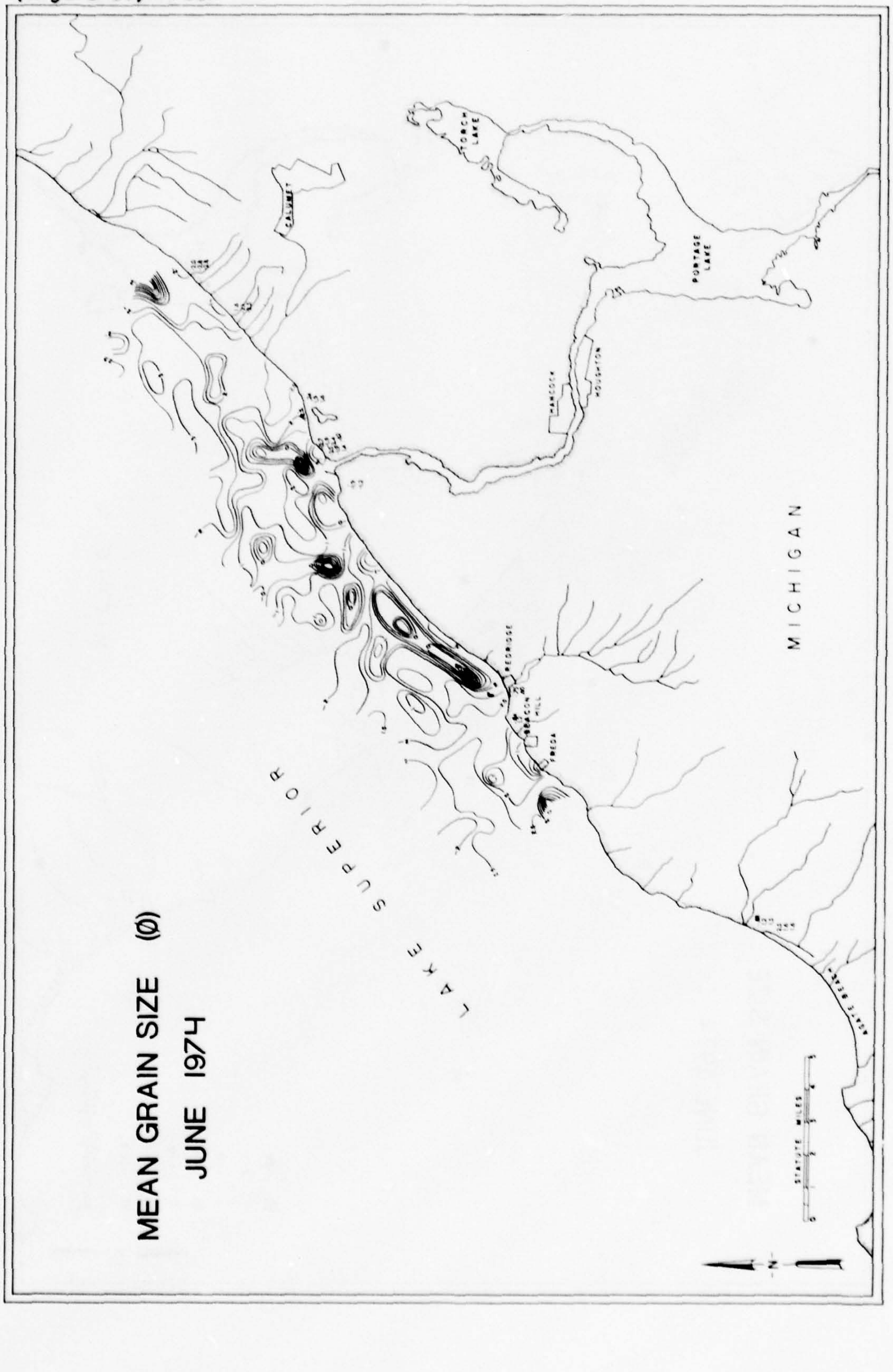
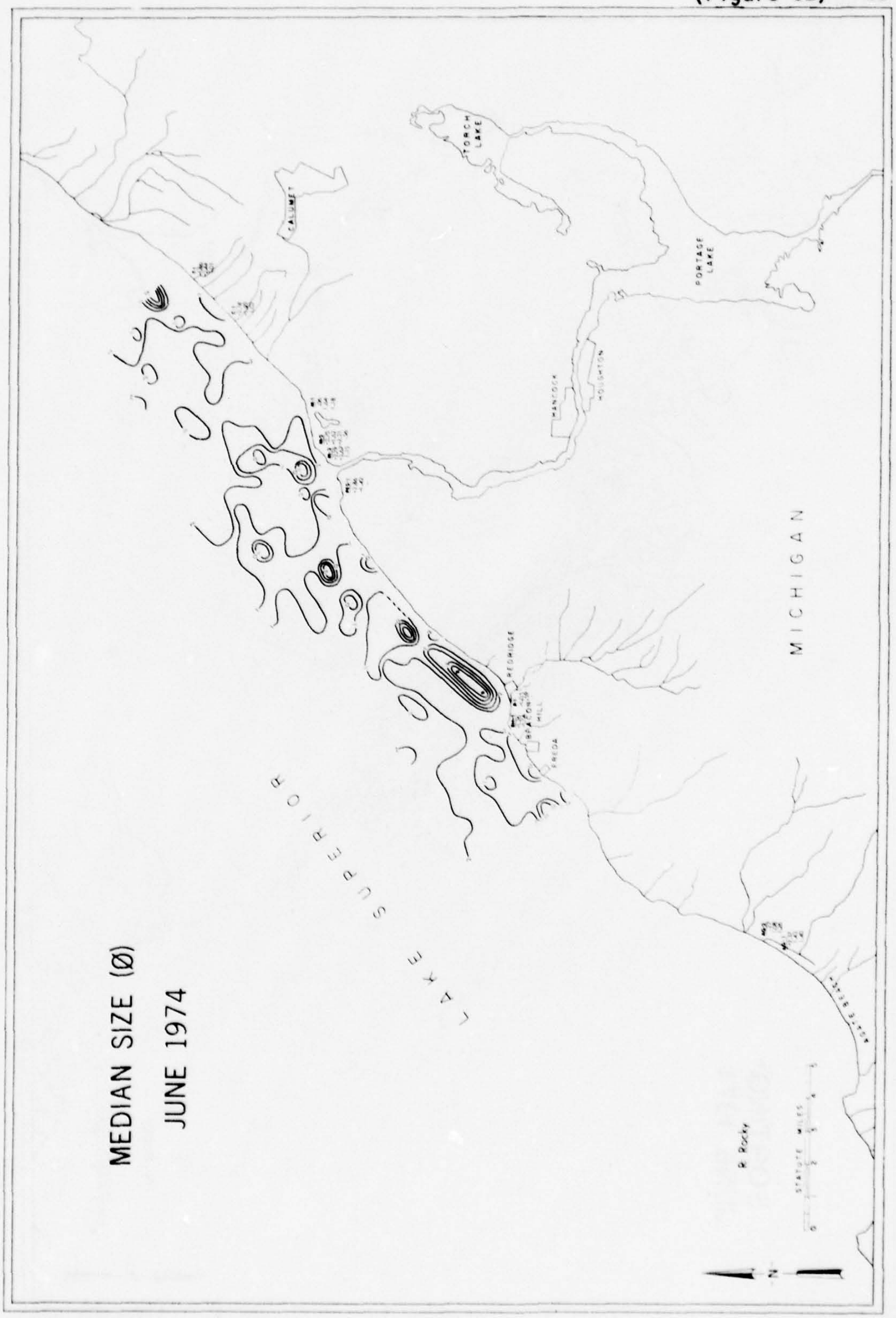
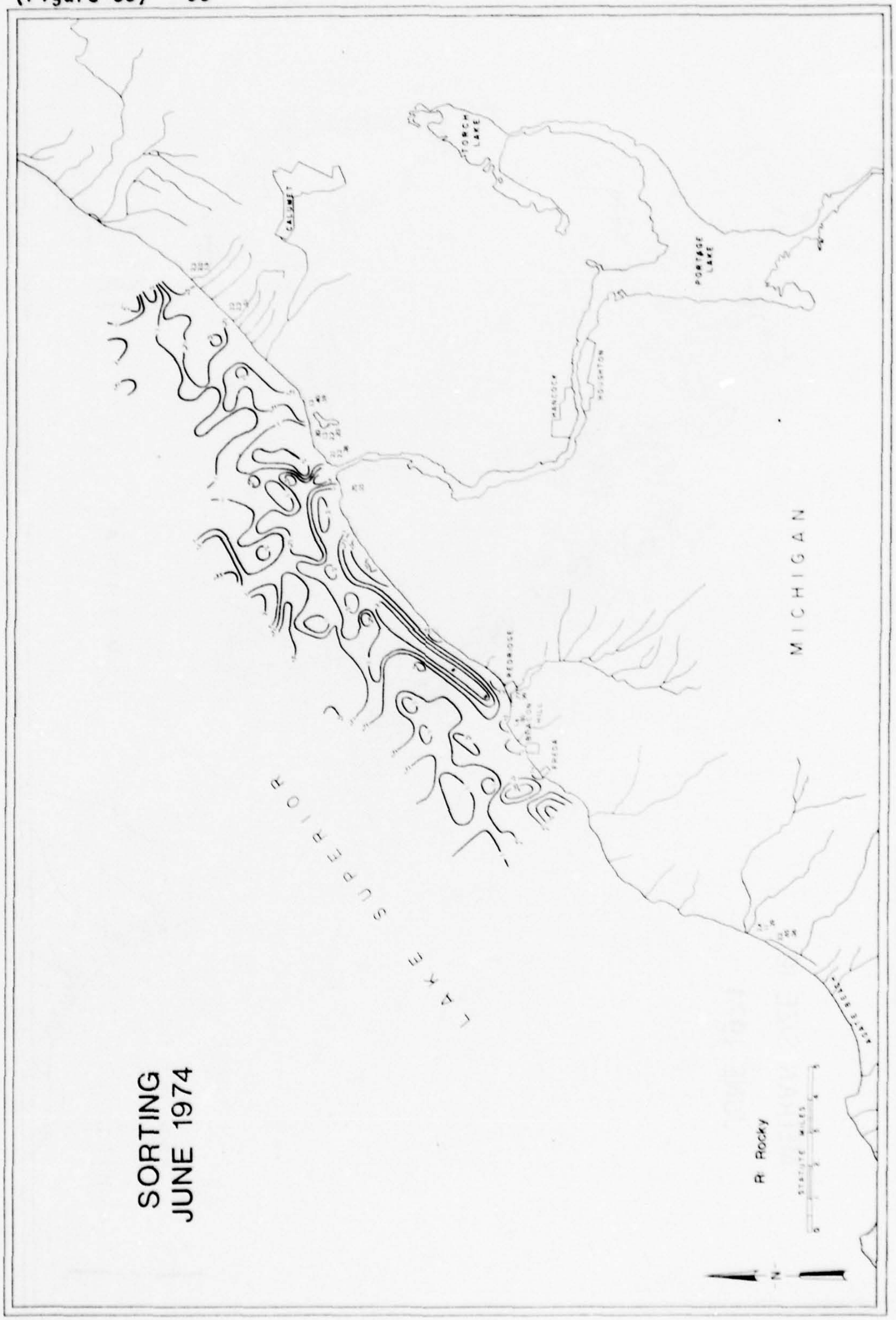
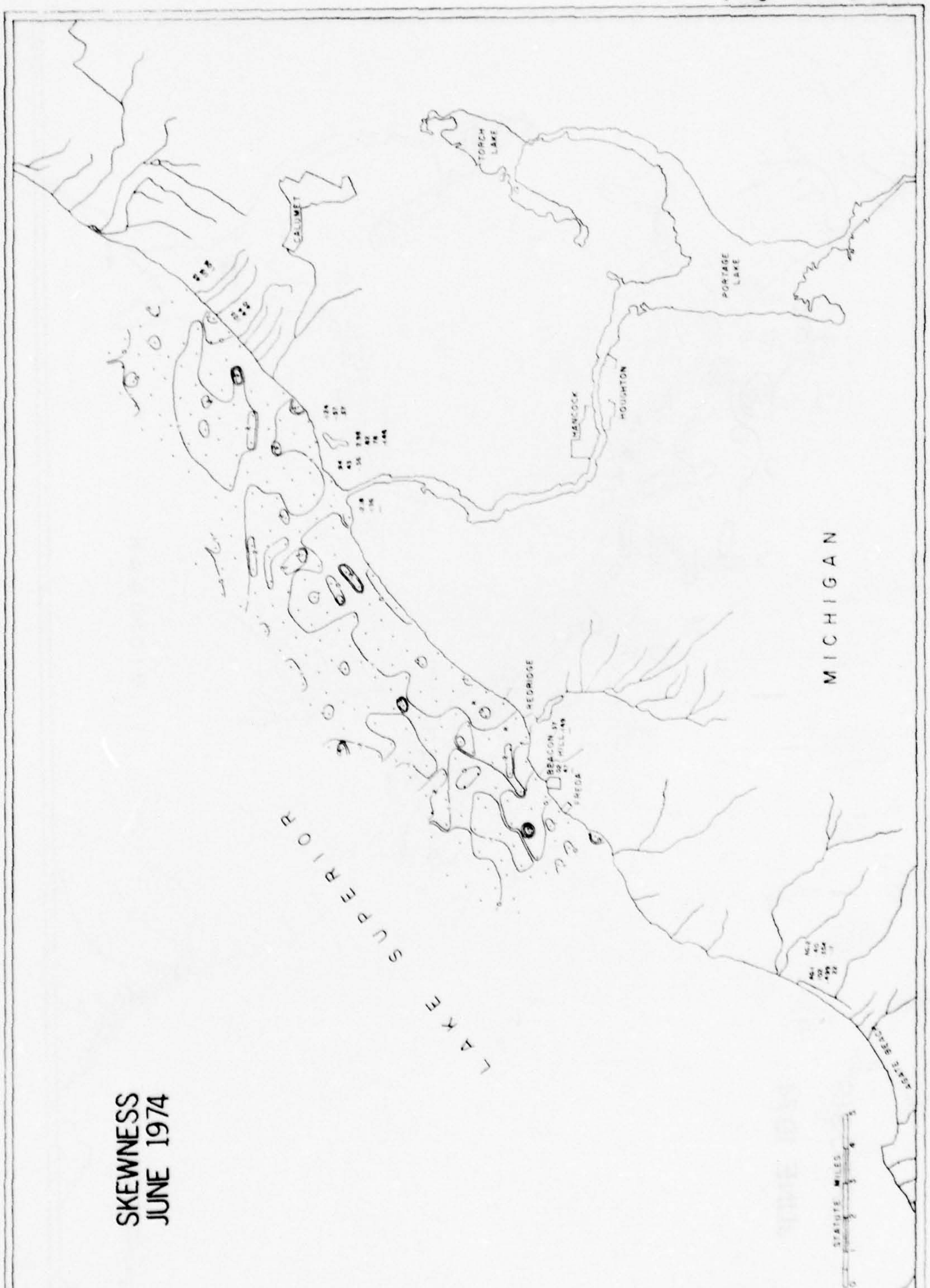
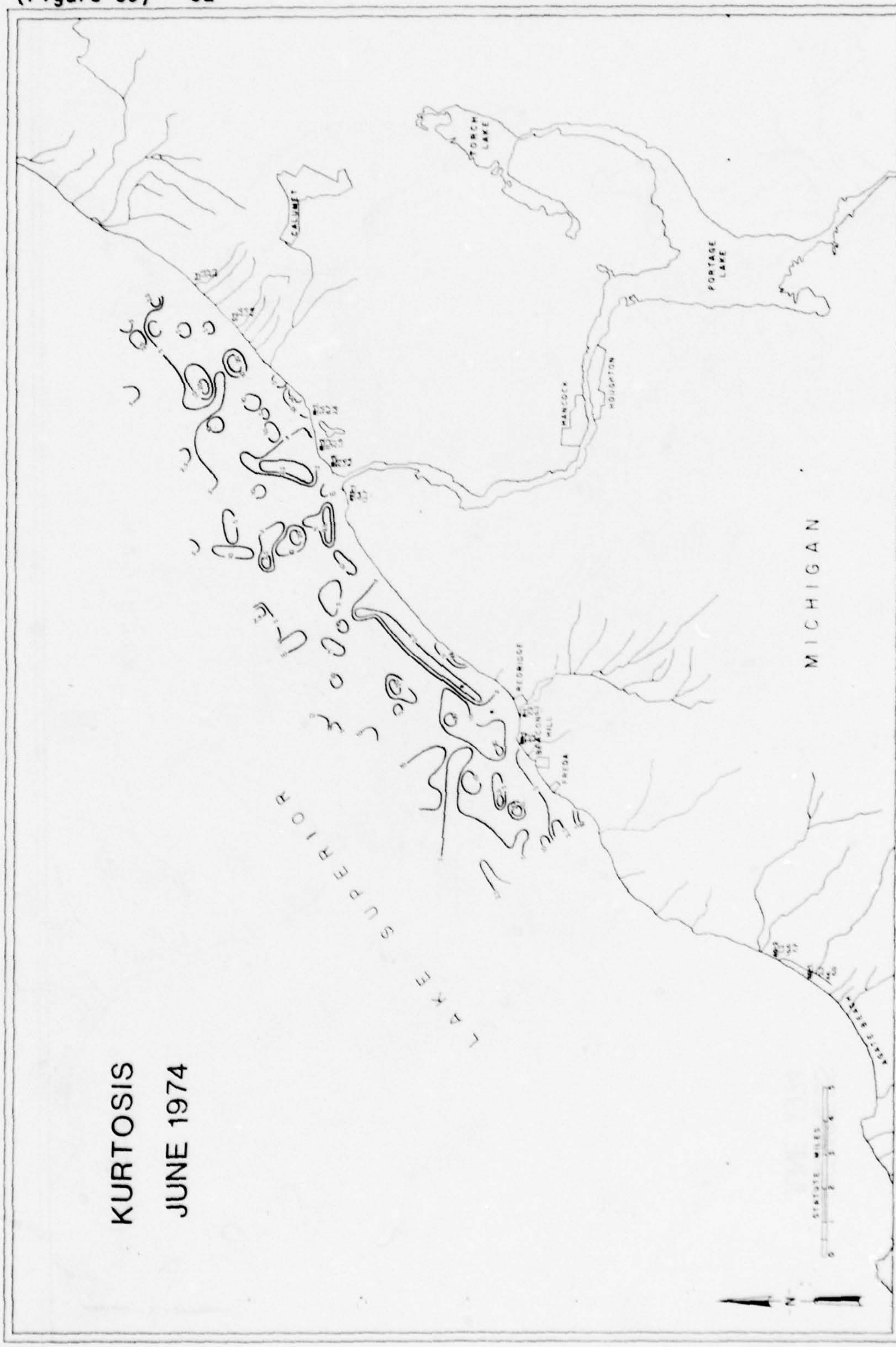

MEAN GRAIN SIZE (Ø)
JUNE 1974
LAKE SUPERIOR
MICHIGAN
TORCH LAKE
PORTAGE LAKE
CALUMET
HANCOCK
HOUGHTON
REDRIDGE
BEACON HILL
FREDA
STATUTE MILES
N

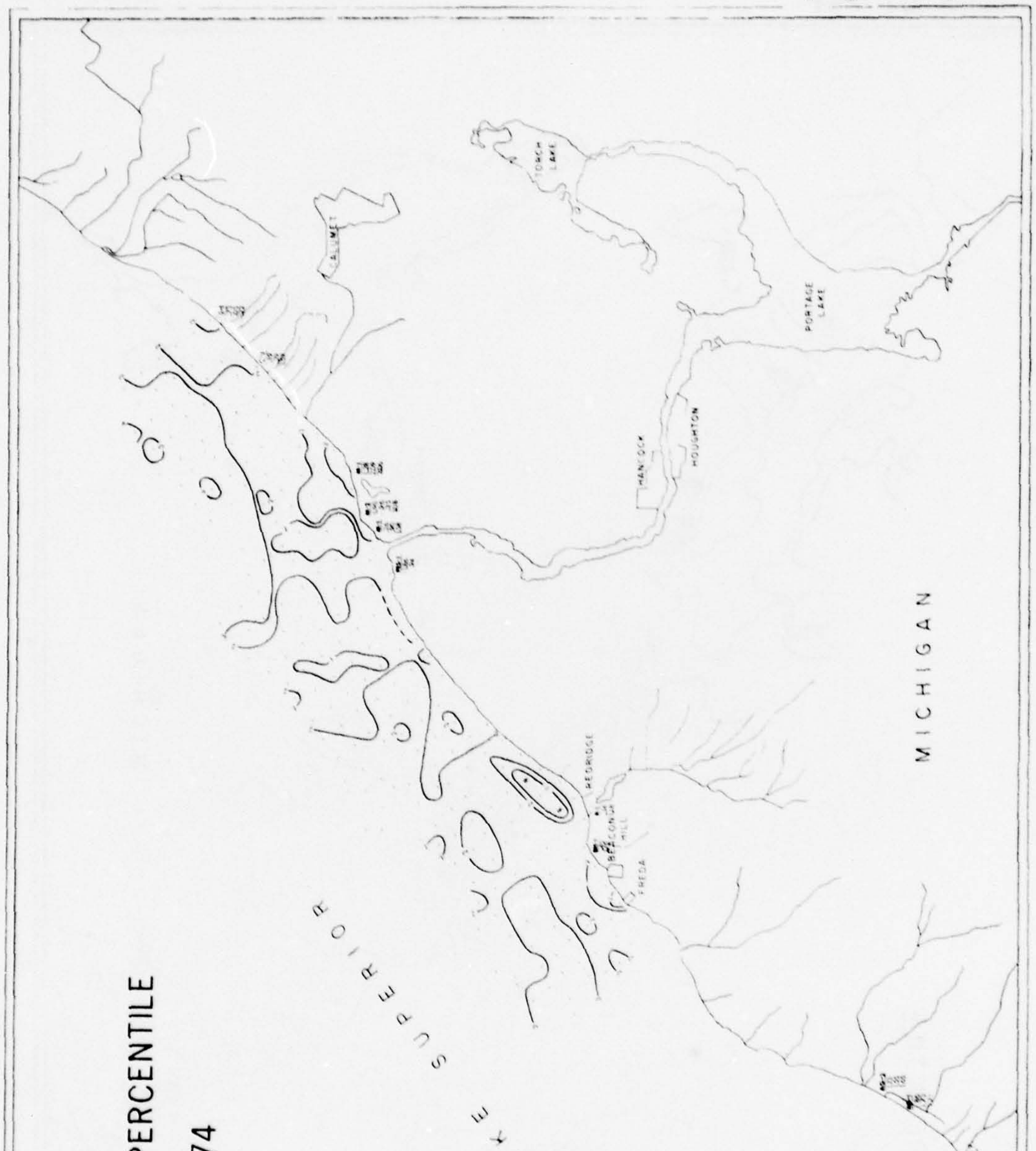

MEDIAN SIZE (Ø)
JUNE 1974
LAKE SUPERIOR
MICHIGAN
TORCH LAKE
PORTAGE LAKE
CALUMET
HANCOCK
HOUGHTON
REDRIDGE
FREDA
STATUTE MILES
N

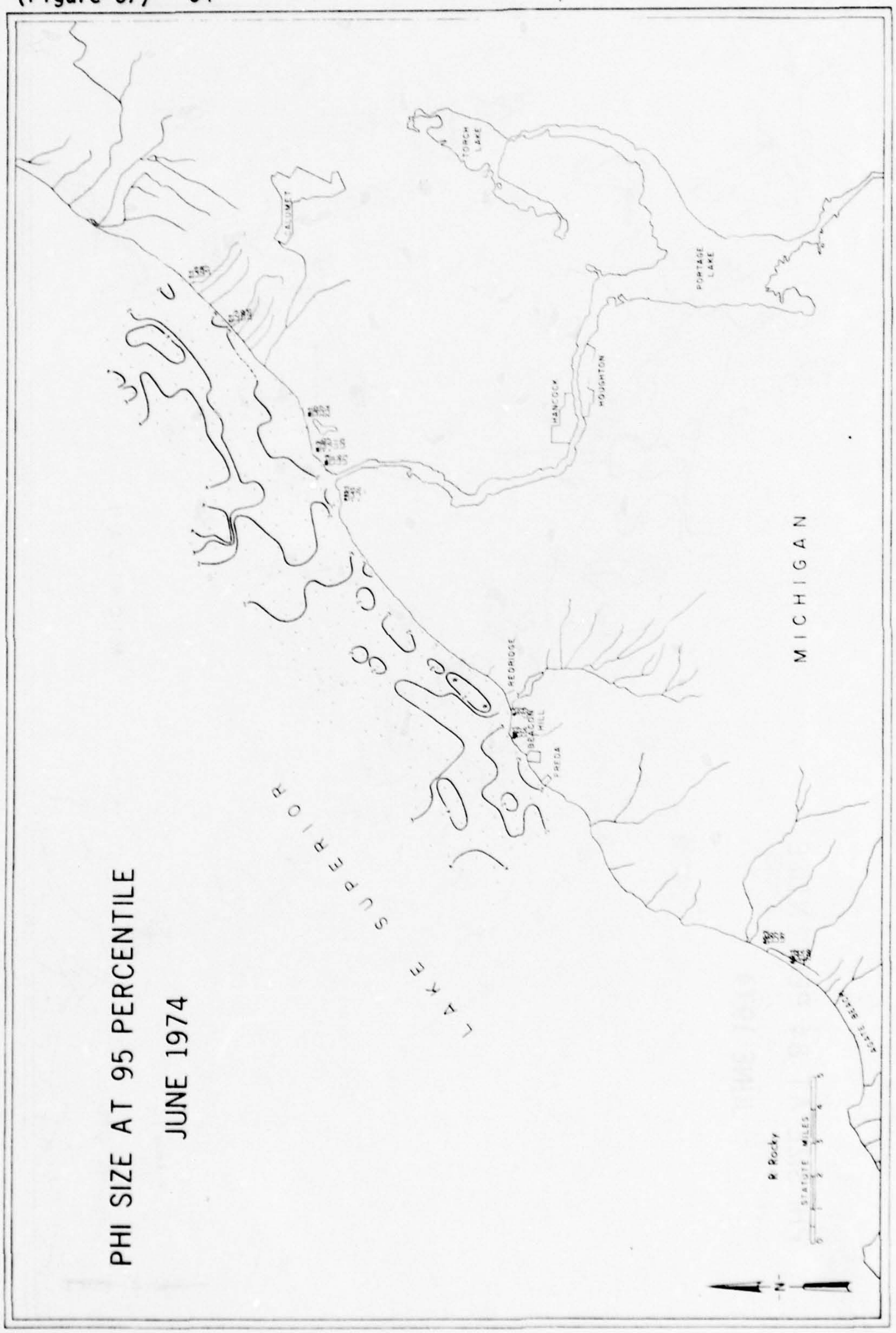

SORTING
JUNE 1974
LAKE SUPERIOR
MICHIGAN
CALUMET
TORCH LAKE
PORTAGE LAKE
HANCOCK
HOUGHTON
REDRIDGE
R: Rocky
STATUTE MILES


SKEWNESS
JUNE 1974
LAKE SUPERIOR
MICHIGAN
CALUMET
TORCH LAKE
PORTAGE LAKE
HANCOCK
HOUGHTON
REDRIDGE
FREDA
STATUTE MILES

(Figure 35) 62


KURTOSIS
JUNE 1974
LAKE SUPERIOR
MICHIGAN
CALUMET
TORCH LAKE
PORTAGE LAKE
HANCOCK
HOUGHTON
REDRIDGE
FREDA
STATUTE MILES


PHI SIZE AT 84 PERCENTILE
JUNE 1974
LAKE SUPERIOR
MICHIGAN
TORCH LAKE
PORTAGE LAKE
CALUMET
HANCOCK
HOUGHTON
REDRIDGE
BEACON HILL
FREDA
R Rocky
STATUTE MILES
N


PHI SIZE AT 95 PERCENTILE
JUNE 1974
LAKE SUPERIOR
MICHIGAN
TORCH LAKE
PORTAGE LAKE
HANCOCK
HOUGHTON
CALUMET
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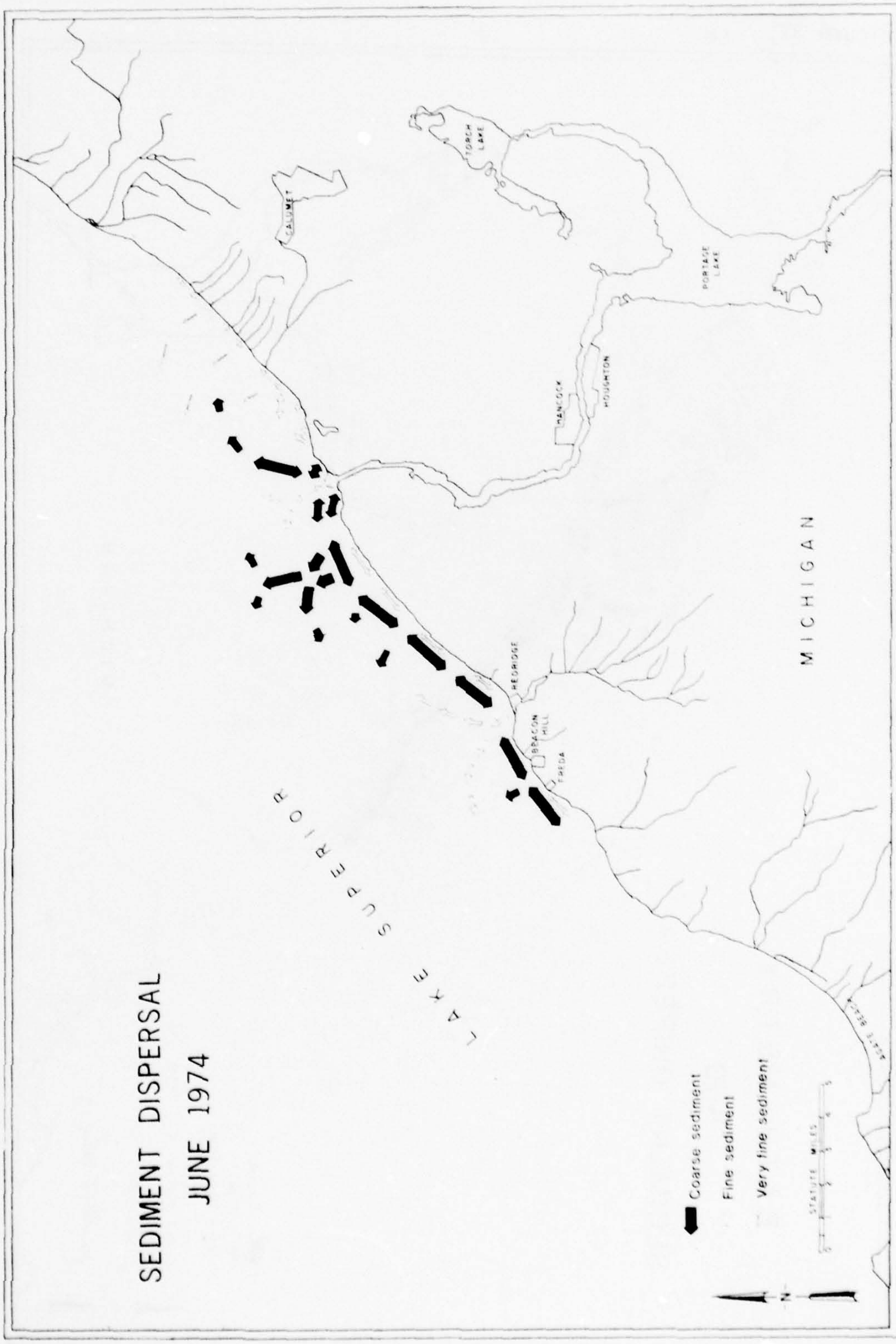
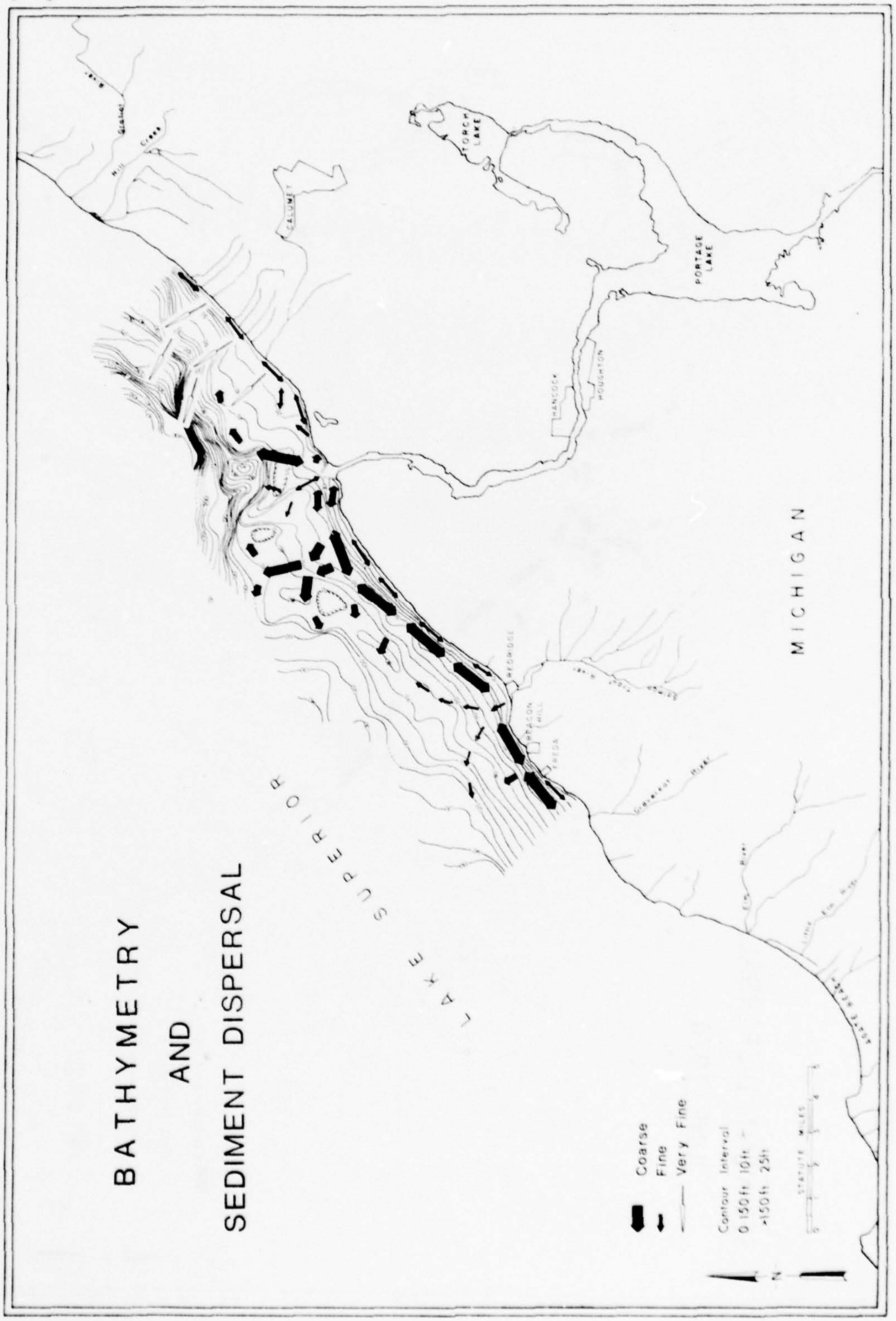
FREDA
STATUTE MILES
N


SEDIMENT DISPERSAL
JUNE 1974
LAKE SUPERIOR
MICHIGAN
Coarse sediment
Fine sediment
Very fine sediment
STATUTE MILES
CALUMET
TORCH LAKE
PORTAGE LAKE
HANCOCK
HOUGHTON
REDRIDGE
BEACON HILL
FREDA


BATHYMETRY
AND
SEDIMENT DISPERSAL
Coarse
Fine
Very Fine
Contour Interval
0-150ft 10ft
>150ft 25ft
STATUTE MILES
LAKE SUPERIOR
MICHIGAN
CALUMET
TORCH LAKE
PORTAGE LAKE
HANCOCK
HOUGHTON
REDRIDGE
BEACON HILL
FREDA

E. Sediment Entering the Waterway

The primary source of the sediment going into the Portage Entry is material (from the littoral zone) which settles in the calmer water within the breakwaters. The calculated volume of at least 87,670 cubic yards moved in the littoral zone at the adjacent McLain State Park for four of the eight ice-free months of 1973 matches well with the 88,430 cubic yards dredged from the Keweenaw Upper Entry that year (U.S. Army Corps of Engineers, St. Paul District, written communication). The total yearly littoral transport may be two or three times that calculated by Balsillie. Some material would bypass the Waterway, and some would move directly offshore. Petrographic studies of several samples shown that the percentage of lithic fragments in the Waterway sediment may range from 15 to 45%, indicating that the stampsands are not the sole source of fine sediments swept into the Entry.

Predominantly quartz-rich material from the nearby dunes and beaches on the northeast side of the Entry and predominantly lithic sediment from the southwest side are carried into the Waterway by the wind, small streams, and sheetwash during heavy storms. Debris jostled from the banks by the propwash of boats moving through the Entry also contributes to the constant infilling which requires the presence of the U.S. Army Corps of Engineers.

Sediment may leave the Entry as well as arrive through it. The bathymetry, textural patterns, and lithic distribution indicate quartz-rich material leaving the mouth of the Waterway, Flow velocities can periodically reach values over one knot in the northwest direction, allowing the current to sweep some of the potential dredge spoil inside the Entry offshore.

F. Keweenaw Beach Profiles and Textural Parameters

All the beaches studied south of the Portage Entry increased in width from fall of 1973 to November, 1974 (Fig. 40-47 and Table 3). The Agate

Beach stations showed a tendency for accretion in June. Unfortunately, they were inaccessible in November, 1974 and any further conclusions are difficult to make. The width of the beach at Beacon Hill was greatest in June and returned almost to the fall of 1973 width by November, 1974. The wide beach at Portage Entry South increased over 50 feet during the study period. Logs and coarse debris covering the beach attest to the effectiveness of ice and storm waves (Plate 1). Movement of the stamp-sands is responsible for the accretion here and at Redridge.

North of the Entry there is a strong tendency for retreat. At the northernmost station in McLain State Park, severe erosion of the bluff resulted in the loss of the marker several times. There is abundant evidence of erosion along the stretch of shore from McLain State Park to Tamarack. In some areas, trees have toppled into the water as the ground around their roots was removed.

M-3, the station in McLain State Park just north of the Waterway entrance is the one exception. The increase in beach width throughout the study period may be due to the dredge spoil dumped in shallow waters nearby as part of the U.S. Army Corps of Engineers beach nourishment program.

Total beach width seems to correlate well with the width of the backshore, but not with foreshore width (Table 4). Changes in lithic percentage, quartz percentage, skewness, and kurtosis on the berms and foreshores of Keweenaw beaches are related. Mean grain size is correlated with phi size at the 84th and 95th percentiles on the berm, but not on the foreshore. Mean grain size of the berm is only slightly correlated with the mean grain size of the foreshore. The same is true for changes in the sorting of the berm when compared to that of the foreshore. Removal of

PLATE 1
Portage Entry South (PES-1)
Looking east at debris on the beach.

Table 4 - Correlation Coefficients - Keweenaw Beaches

1.	Backshore Width - total width	.980
2.	Foreshore Width - total width	.545
3.	Lithic % (Berm) - lithic % (foreshore)	.871
4.	Quartz % (Berm) - Quartz % (foreshore)	.878
5.	Quartz % - Lithic %	-.990
6.	Phi 84 (Berm) - Phi 84 (foreshore)	.962
7.	Skewness (Berm) - Skewness (foreshore)	.809
8.	Kurtosis (Berm) - Kurtosis (foreshore)	.812
9.	Mean Grain Size - Phi 84 at berm	.866
10.	Mean Grain Size - Phi 84 at foreshore	.529
11.	Mean Grain Size - Phi 95 at berm	.836
12.	Mean Grain Size - Phi 95 at foreshore	.406
13.	Phi 84 (berm) - Phi 84 (foreshore)	.962
14.	Phi 95 (berm) - Phi 95 (foreshore)	.935
15.	Mean Grain Size (berm) - Mean Grain Size (foreshore)	.424
16.	Sorting (berm) - Sorting (foreshore)	.628

fine material from the foreshore by wave action and sediment brought to the beaches by the littoral system are probably responsible for these trends.

In general the foreshores and berms of the Keweenaw beaches were coarser and more poorly sorted in June, 1974 than in fall of 1973 and in November, 1974 (Figures 50-58). Increased stream discharge, lower water level, smaller wave height, and possible current action at this time of year are among the factors involved.

Data presented by Balsillie (1972, 1973b) show that wave height increased from June through September at McLain State Park. The average wave height for June was 0.55 feet; for September, 2.1 feet - a 28 fold increase in energy delivered to the sediment.

The Agate Beach stations (Figures 50 and 51) show coarseness and poorer sorting of the foreshore relative to the berm and backshore. Texture of the backshore remained unchanged over the study period. The mean grain size at AG-1 was coarser in June, 1974 than in fall of 1973. In June sorting on the berm was slightly poorer and the phi size at the 84th percentile was coarser. At AG-2 the mean grain size and the phi size 84th percentile was coarser. At Ag-2 the mean grain size and the phi size at the 84th percentile are coarser on the foreshore and the sorting on the berm is poorer in June. Relative percentages of the lithic fragments to quartz remained unchanged at both stations. This suggests the addition of material to the beach in June affected the foreshore. Wave action is lower in June, hence the poorer sorting of the berm.

Lithic content and the texture of the berm and backshore at Redridge and Beacon Hill remained unchanged (Figures 52 and 53). Foreshore mean grain size and phi size at the 84th percentile grew progressively coarser with time at both stations, while the foreshore at Beacon Hill showed better sorting in fall of 1973. This indicates that fine material being removed from the foreshore at Redridge and from the beaches at Freda is supplying the beach at Beacon Hill.

The station just south of the Portage Entry is coarser, has a coarser phi size at the 84th percentile, and is better sorted on the backshore and the berm in June, 1974 (Figure 54). The increased lithic percentage on the berm in June and the greater accretion from fall of 1973 to June, 1974 are related. The addition of lithic fragments to the beach, which is primarily composed of lithic fragments, would tend to increase the sorting. The foreshore was coarser in June than in November, 1973 and November, 1974; approximately equally sorted in fall of 1973 and June, 1974; and most poorly sorted in November, 1974, when there were less lithics on the berm. The berm was high and steep-faced in November, 1974, suggesting that wave action removes lithic material from the berm or brings more non-lithic material to the berm from offshore at this time. Replenishment of this material in June would be slower due to the lower wave heights. Wind action may be more important during the summer months.

The station northeast of the breakwater in McLain State Park shows a different pattern (Figure 55). The berm and foreshore were coarsest and poorly sorted in June, 1974 and slightly finer and better sorted in November, 1974. However, they were still coarser than they were in fall of 1973. The sorting of the foreshore in November, 1974 about equalled that in fall of 1973. The berm was more poorly sorted in November, 1974 than in fall of 1973.

This may be the result of the dredge spoil being dumped offshore of McLain State Park. The berm and foreshore show an increased lithic percentage by November, 1974. The backshore is coarser, has a coarser phi size at the 84th percentile by November, 1974. This may be due to progressive wind and wave sorting of the nourishment material with time, or the addition of finer material from the back of the beach.

At the next station in McLain State Park (M-2) there was more lithics on the foreshore in June, 1974 than in fall of 1973 (Figure 56). The percentages are about equal on the berm. Mean grain size, sorting and phi size at the 84th percentile are about equal on the berm and backshore, but the foreshore is coarser, has a coarser phi size at the 84th percentile, and is better sorted in June. The increase in lithic fragments and the better sorting in June may be due to the beach nourishment program. The stake was removed between June and November, 1974 and a new position had to be established.

The foreshore at Calumet (Figure 47) was coarsest and had a coarser phi size at the 84th percentile in June, 1974, and was coarser in November, 1974 than in fall of 1973. Lithic percentages and sorting in June, 1974 about equaled that in fall of 1973, and the fall of 1974 foreshore was the best sorted and lowest in lithic content. The greater erosion rate from June, 1974 to November, 1974 may be responsible. The berm and backshore show the poorest sorting in June, and sorting in November, 1974 was poorer than in fall of 1973. Mean grain size and the phi size at the 84th percentile remained unchanged on the backshore.

At Tamarack (Figure 58) the foreshore has the greatest percentage of lithics, best sorting, and coarsest phi size at the 84th percentile in fall of 1973, and a lower percentage of lithics, poorer sorting, and coarser phi 84 in June than in fall of 1974. The mean grain size of the berm is coarsest in June and about equal in fall of 1973 and November, 1974.

Lithic percentage remains constant and the fall of 1973 profile shows better sorting and a coarser phi size at the 84th percentile than in June or November, 1974. The backshore was coarsest and most poorly sorted in June, 1974. Fall of 1973 petrology indicates a greater percentage of quartz in the backshore region. Removal of material from the backshore between fall of 1973 and June, 1974 may explain the low lithic percentage and poorer sorting of the foreshore and berm in June. The period from fall of 1973 to June, 1974 show the greatest amount of retreat of the beach.

Understanding of the variations in textural parameters in the Keweenaw area is difficult due to the complexity of the natural system, the lack of a control station, the movement of the easily-eroded stampsands from Redridge and Freda, and the effect of the shallow water dumping of dredge spoil off McLain State Park. The beaches are generally coarser and more poorly sorted in June, than in November and the foreshores are coarser than the berms and backshores. Finer material from the shallow water dumping seems to have some effect on the texture of the berms and backshores of the beaches north of the Waterway entrance.

G. Possible Effects of Ice on the Shoreline

The effect of ice on a shoreline can be both beneficial and destructive. The ice may form a barrier which shields the shore from storm waves, which break harmlessly on this ice "foot". The pressure and weight of the ice against and on top of the shoreline may cause parts of the shore to collapse into the lake, where the debris is carried off by waves.

The tremendous amount of ice which builds up against the Keweenaw shoreline makes this an important factor. Ice thickness measurements were made at Redridge, Beacon Hill, and the two northernmost stations in McLain State Park in February, 1975. These are shown with the beach profiles of these stations (Figures 42, 43, 46, 47). Thickness measurements were not taken at McLain 2, but the mark visible on the Lake Survey wave pole at the back of the beach was fifteen feet. There were two distinct ice ridges developed on the beach at Redridge: one on the foreshore and one four hundred and fifty yards offshore from the marker. Snow and ice on the shore at the northernmost station in McLain State Park (M-1) is shown in Plate 2. The same area four months earlier is shown in Plate 3.

Another factor to consider besides ice damage to the shoreline is the amount of sediment from the beach and offshore that is frozen into the ice. At Redridge and Beacon Hill the bottom sediments appeared to have been thrown onto the ice during periods of high winds and waves, and then were covered with ice and snow. This results in layers containing large quantities of sediment, ranging in size from fine silt and sand to cobbles one foot in diameter at Beacon Hill. The volume of ice samples taken on this survey was measured by immersing the samples in cold water and measuring the volume displaced, and then weighing the amount of sediment left after melting the ice and evaporating off the water. The results are shown in Table 5. The range of values reflect the variability within a given ice sample. The locations of these samples are also shown on the beach profiles. Using an estimated total volume of ice based on the Redridge profile, and an estimated sediment content derived from the ice content measurements, the total volume of sediment contained in the ice at Redridge is 500-2500 tons. At best this is a rough estimate, but it is evident that a substantial amount is trapped in the ice. What happens during ice breakup and melting is difficult to say.

PLATE 2

McLain State Park (M-1)
February 22, 1975

PLATE 3

McLain State Park (M-1)
November 16, 1974

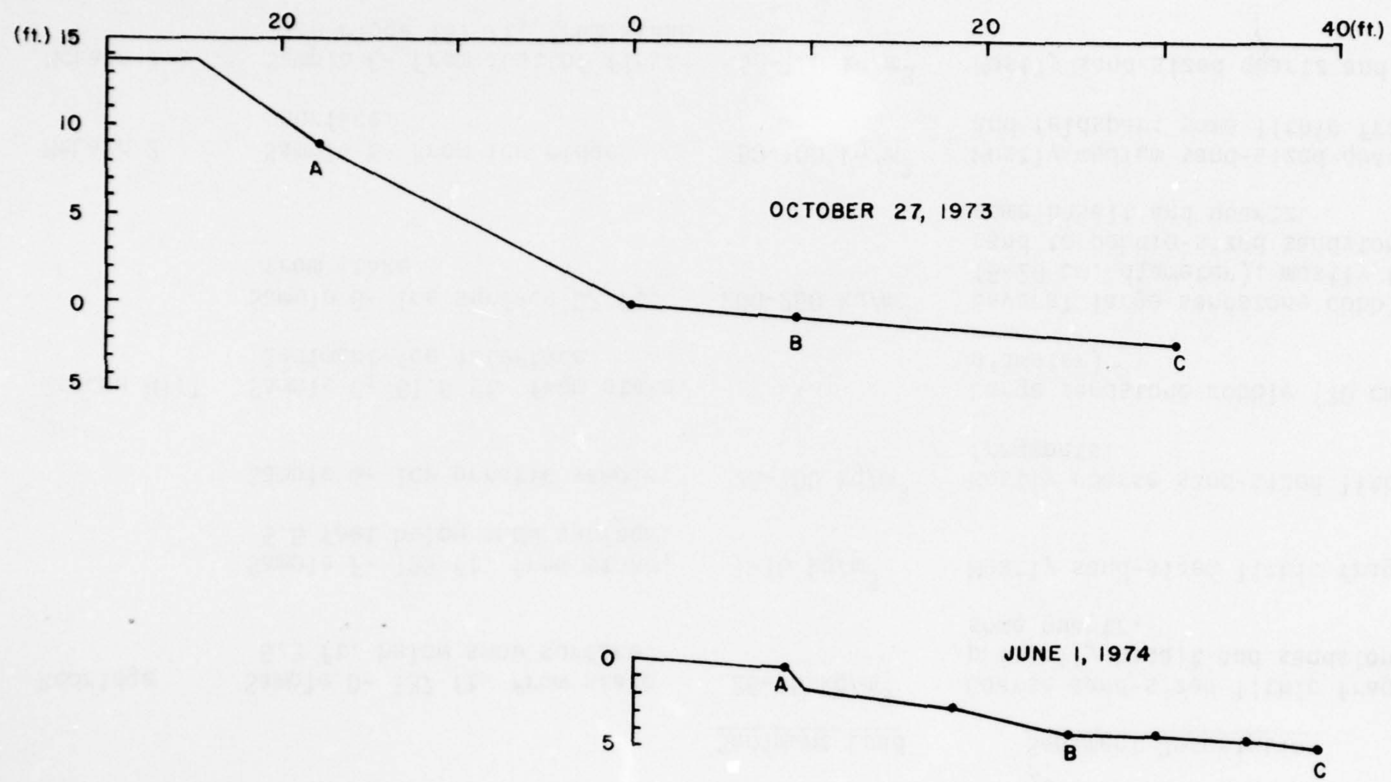
Table 5

Keweenaw Ice Content February 22, 1975

		Sediment Load	Sediment Description
Redridge	Sample D- 137 ft. from stake 5.3 ft. below snow surface.	25-75 kg/m^3	Coarse sand-sized lithic fragments, primarily basalt and sandstone; some quartz.
	Sample F- 199 ft. from stake, 5.5 feet below snow surface.	1-10 kg/m^3	Mostly sand-sized lithic fragments.
	Sample G- Ice erratic sample.	25-100 kg/m^3	Mostly coarse sand-sized lithic fragments.
Beacon Hill	Sample C- 61.5 ft. from stake. Sediment-ice interface.	---	Large sandstone cobble (30 cm. diameter)
	Sample G- Ice surface 82 ft. from stake.	200-250 kg/m^3	Several large sandstone cobbles (5-20 cm. diameter); mostly fine sand to pebble-sized sandstone, some basalt and quartz.
McLain 2	Sample E- From ice ridge surface.	50-100 kg/m^3	Mostly medium sand-sized quartz and feldspar; some lithic fragments.
McLain 1	Sample C- From foot of first ice ridge 151 ft. from stake	50-100 kg/m^3	Mostly sand-sized quartz and feldspar.

Note: Estimated total ice sediment load at Redridge 500-2500 tons.

AGATE BEACH I (AG-I)



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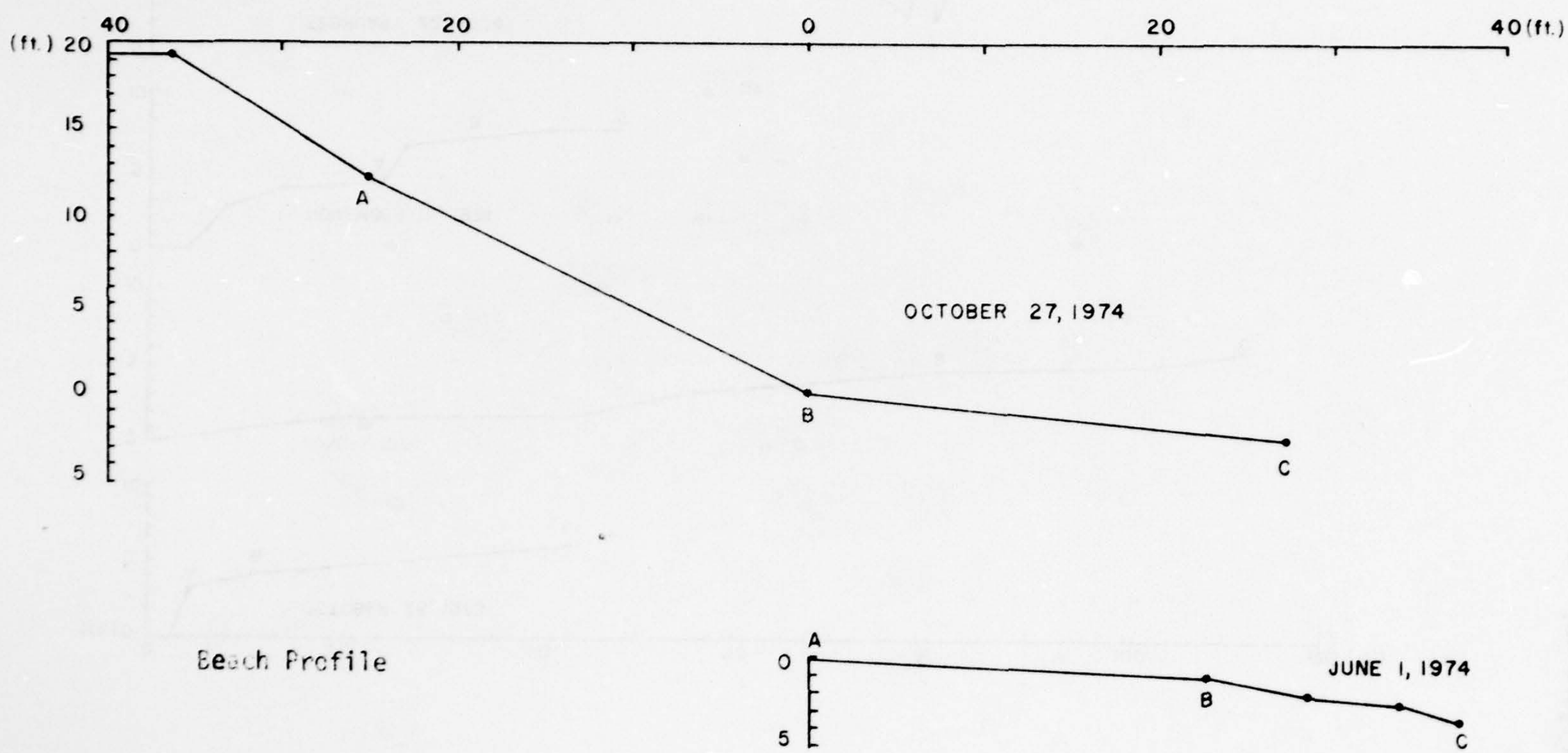
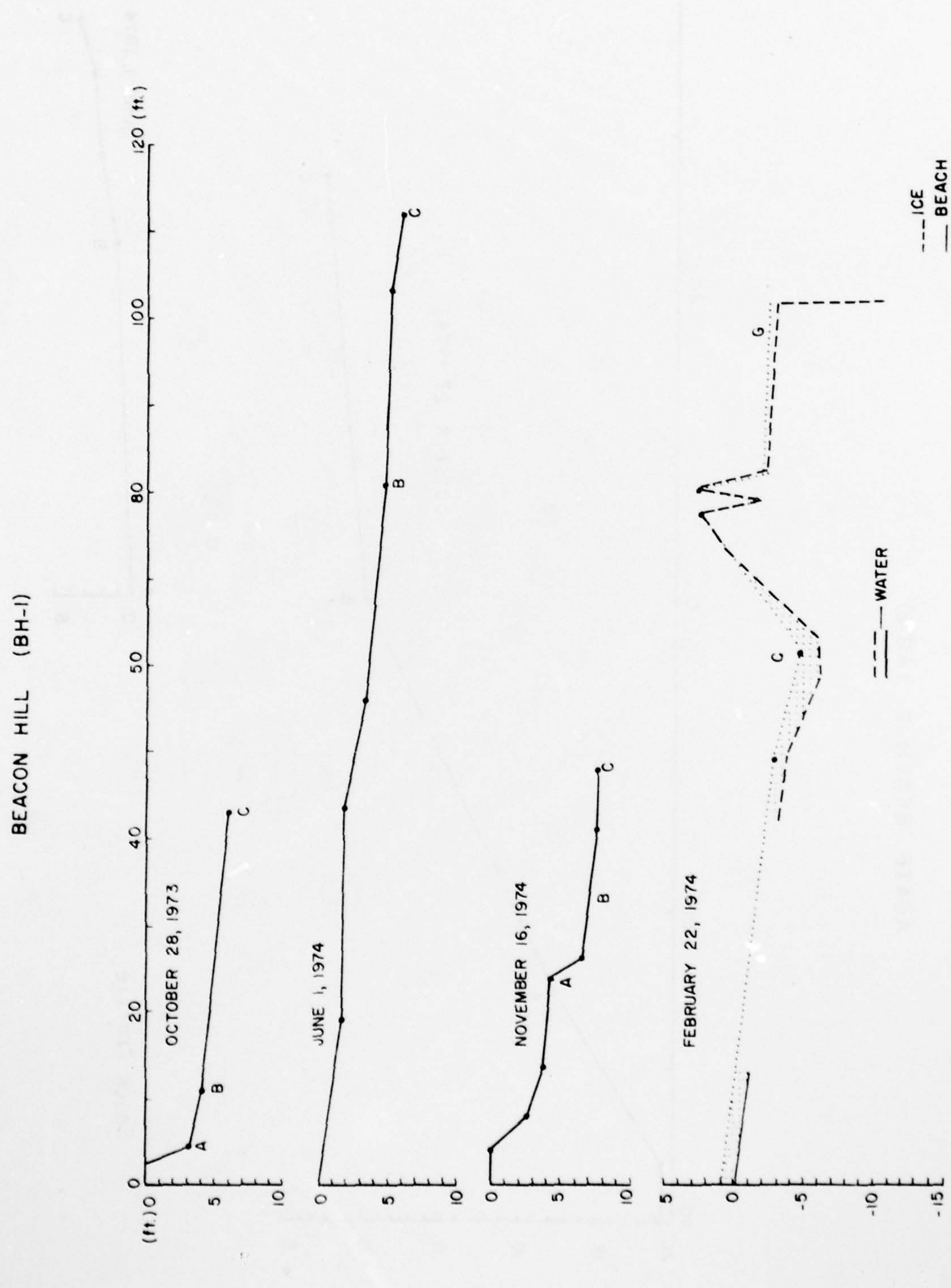
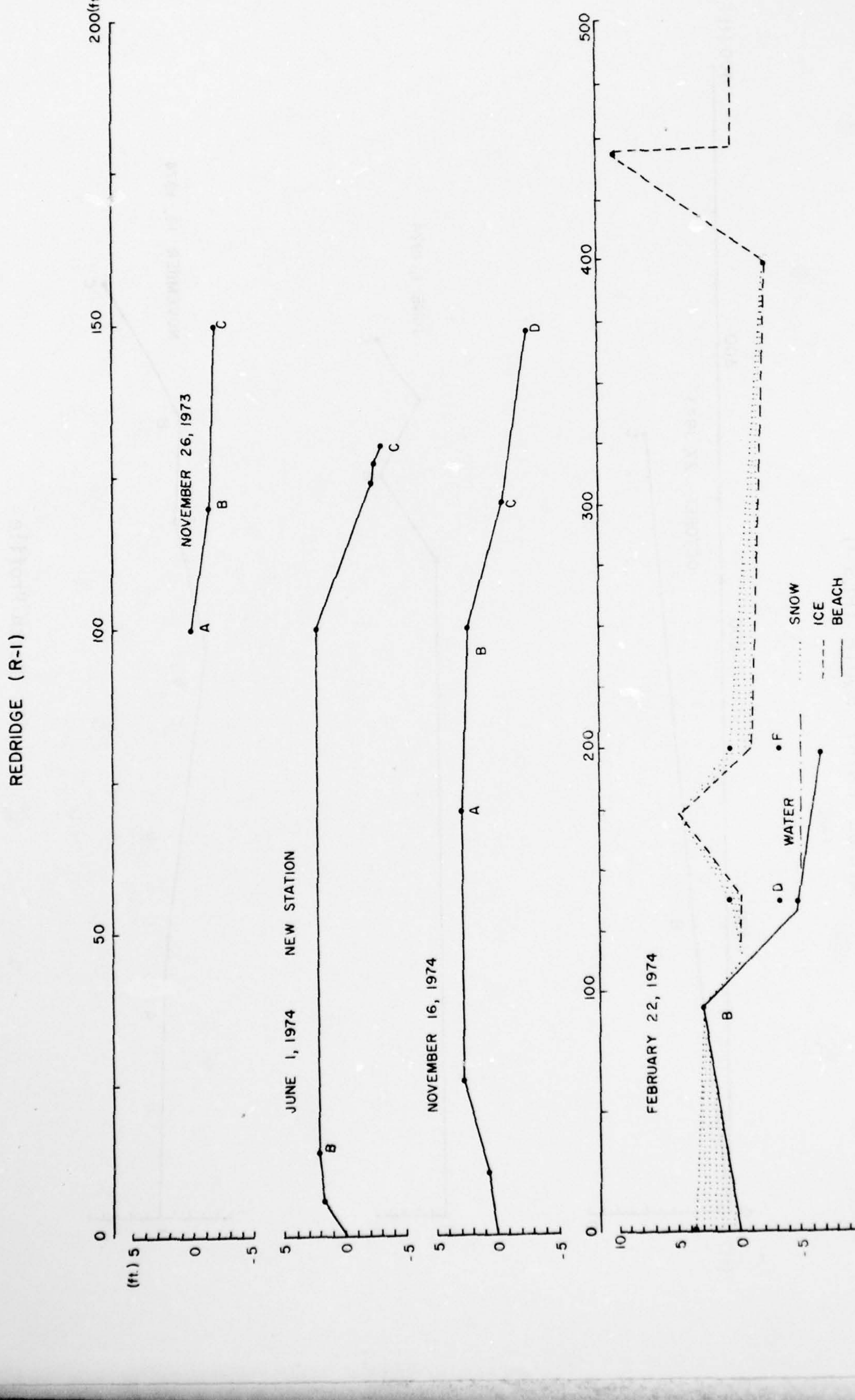


Beach Profile



Beach Profile



Beach Profile

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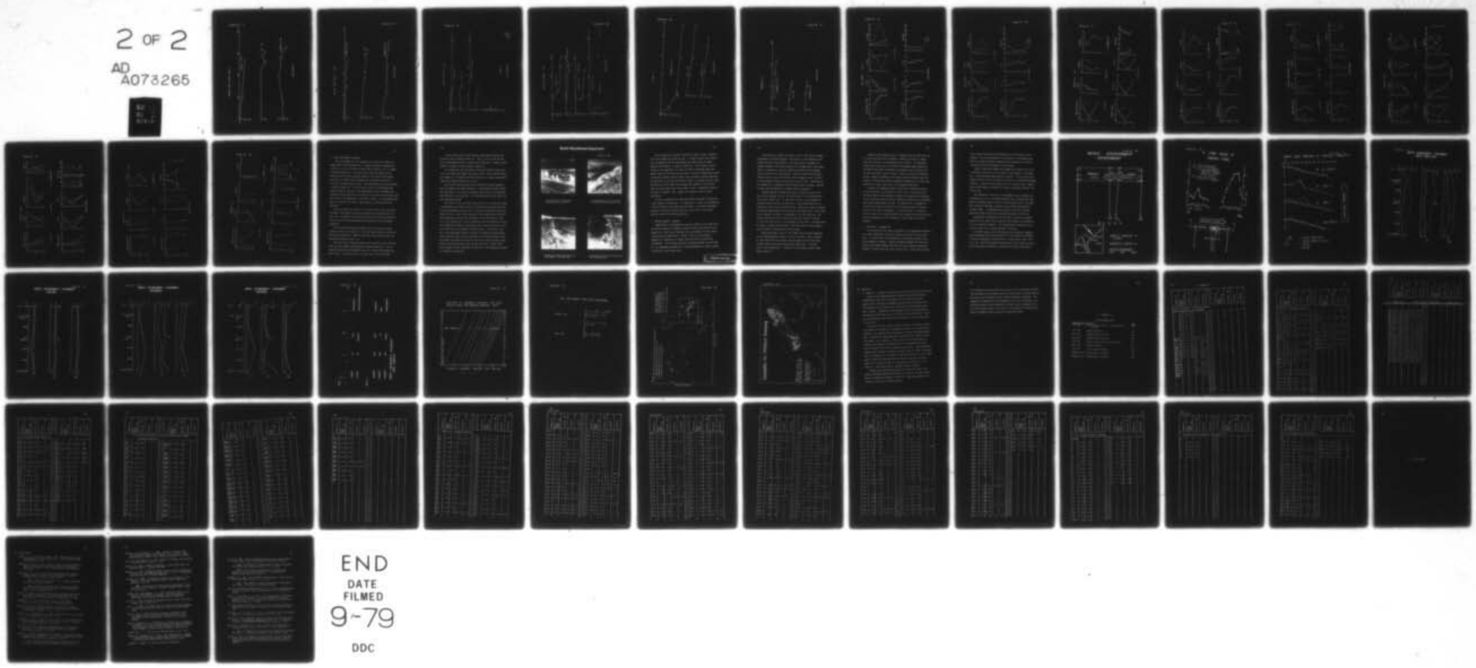

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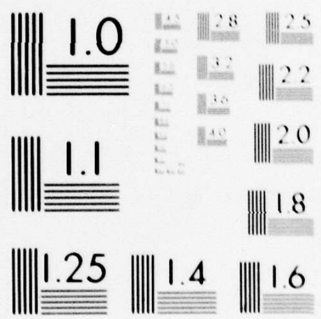
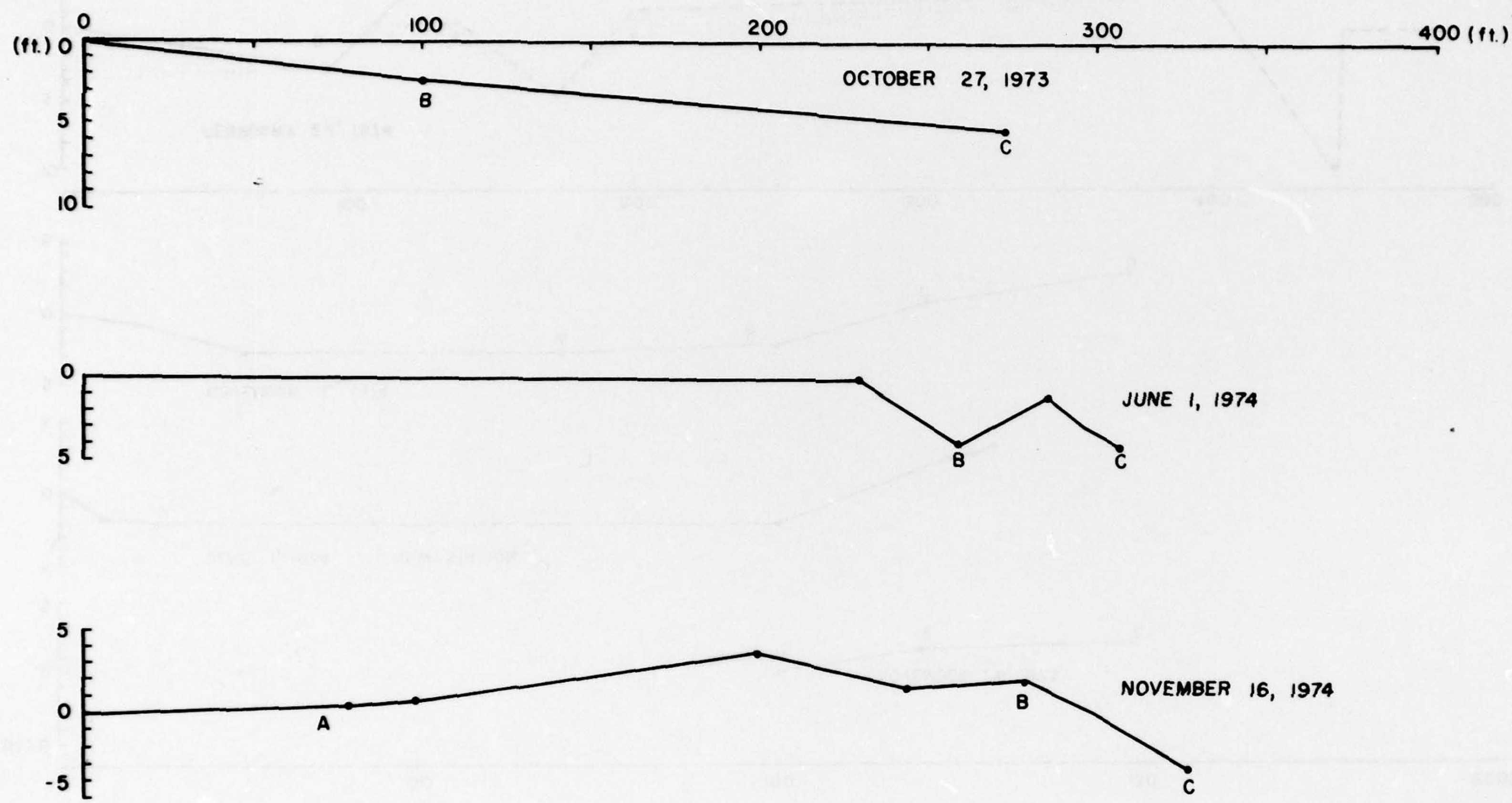


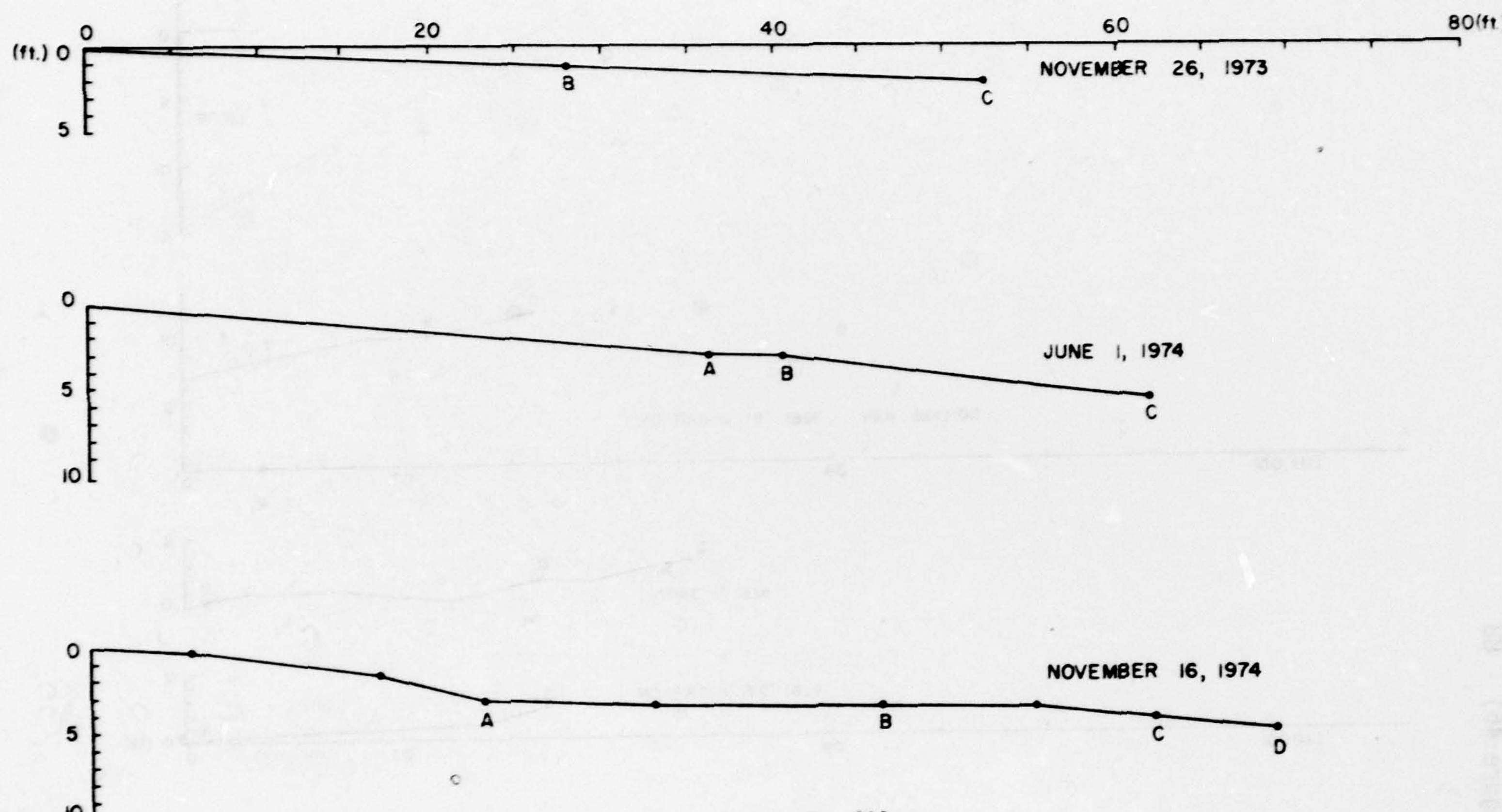
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

PORTAGE ENTRY SOUTH (PES-1)

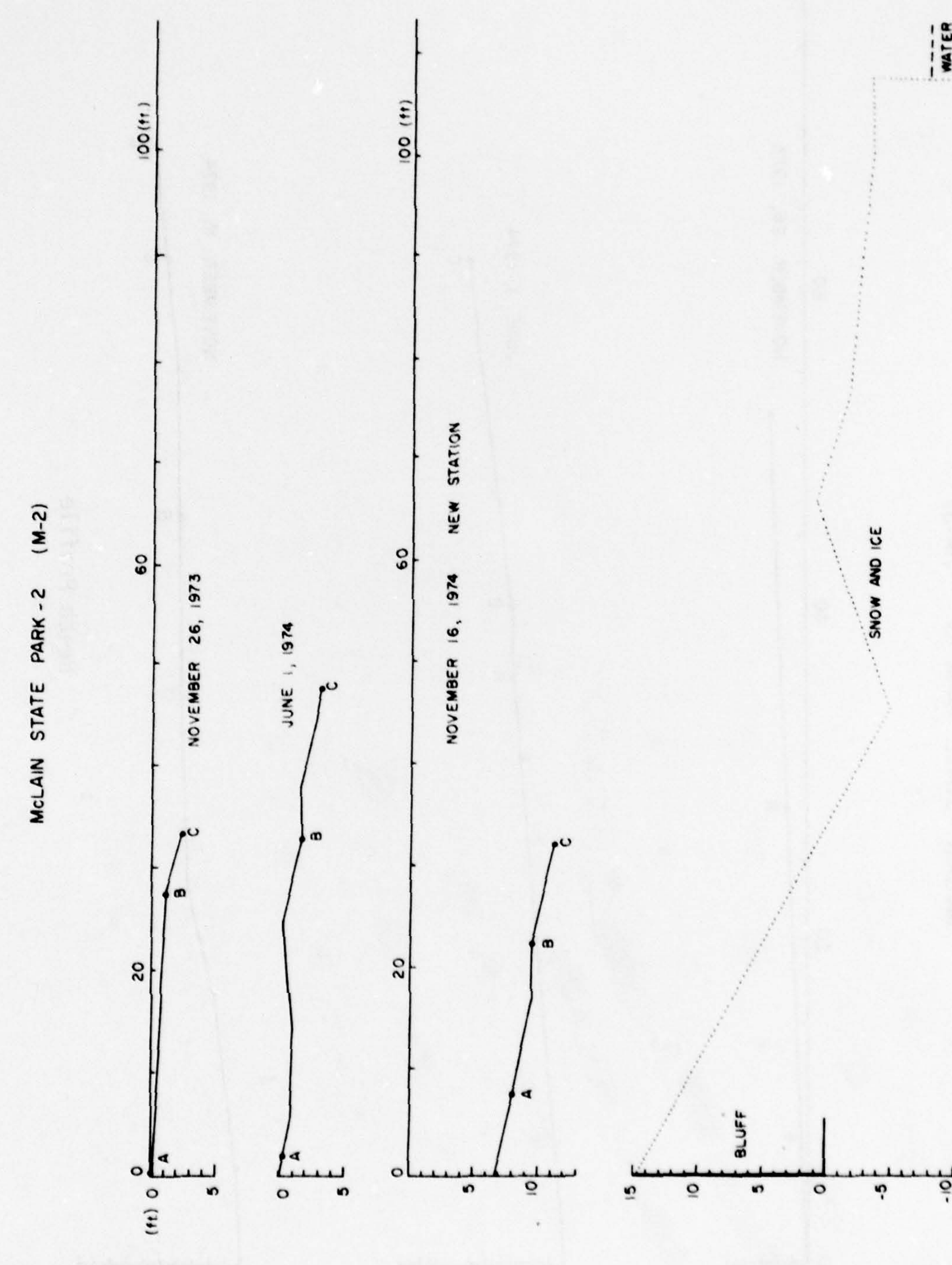


Beach Profile

McLAIN STATE PARK 3 (M-3)

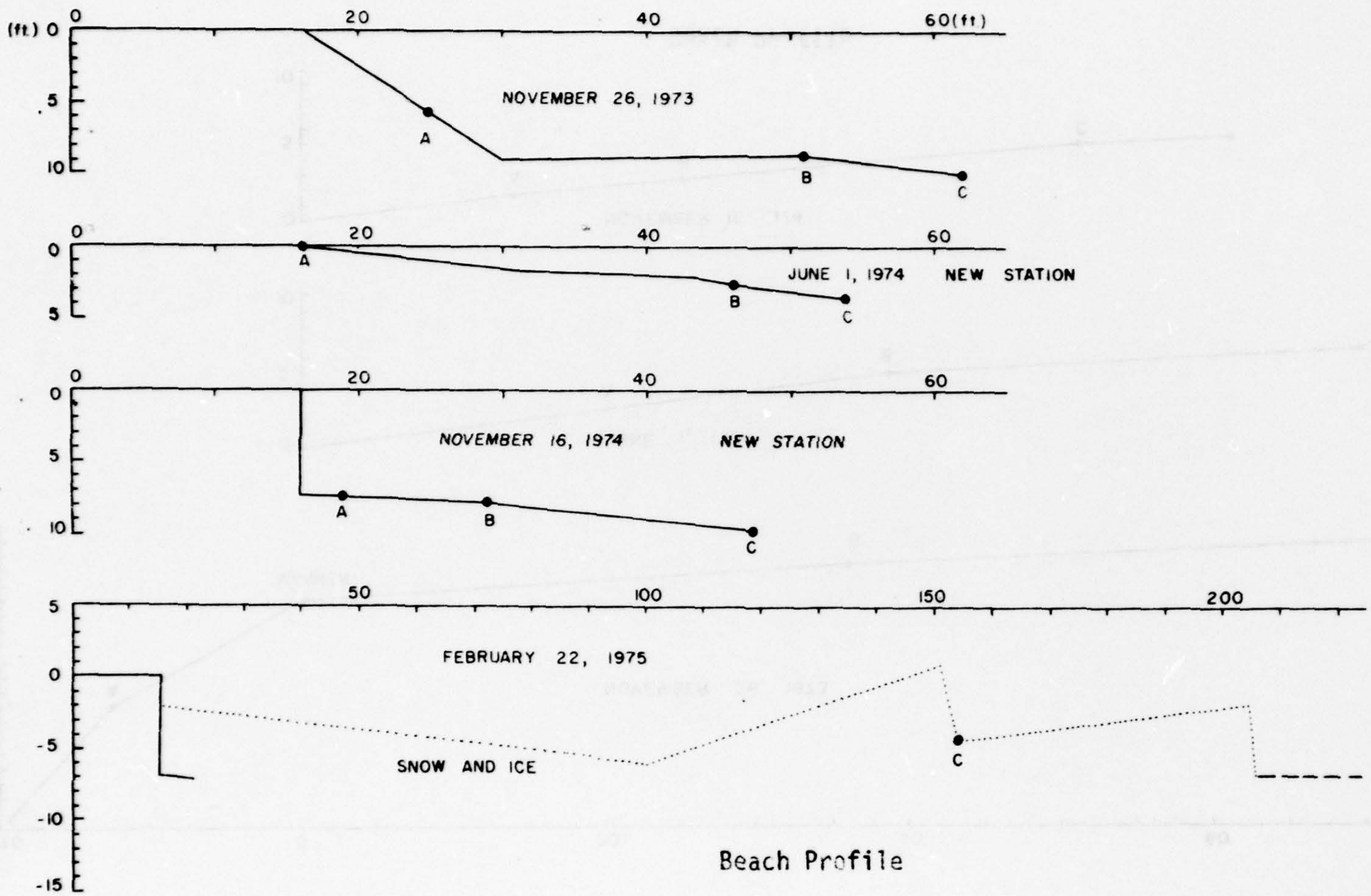


Beach Profile

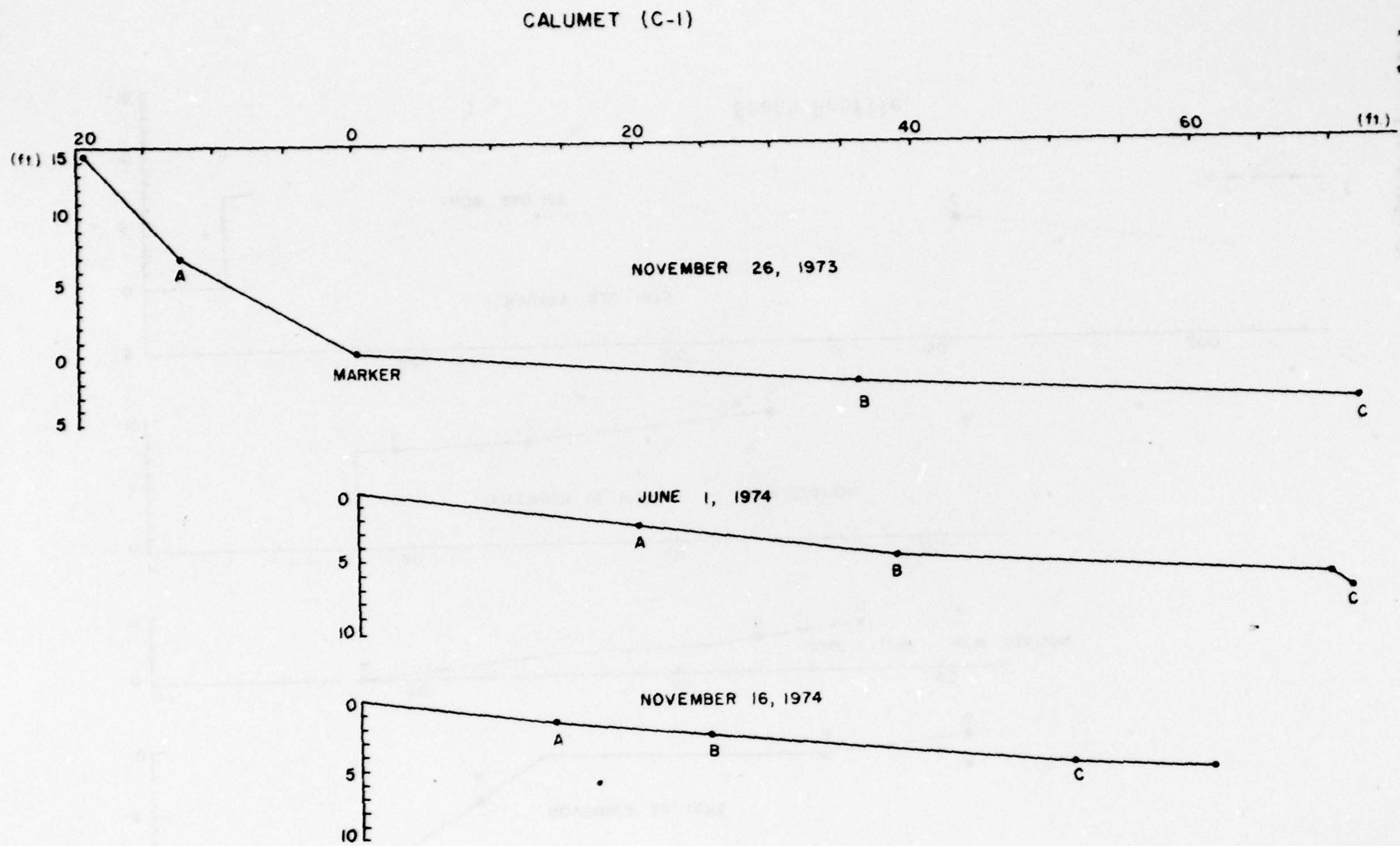


Beach Profile

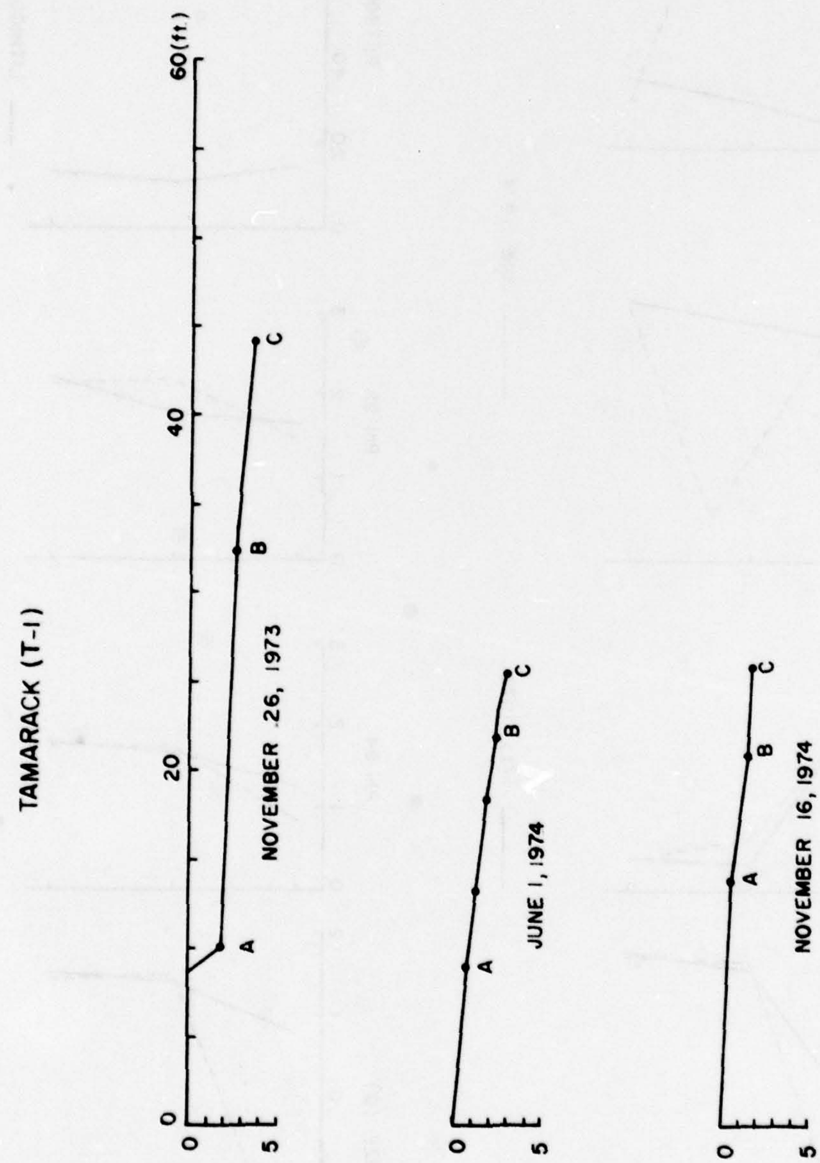
McLAIN STATE PARK -1 (M-1)



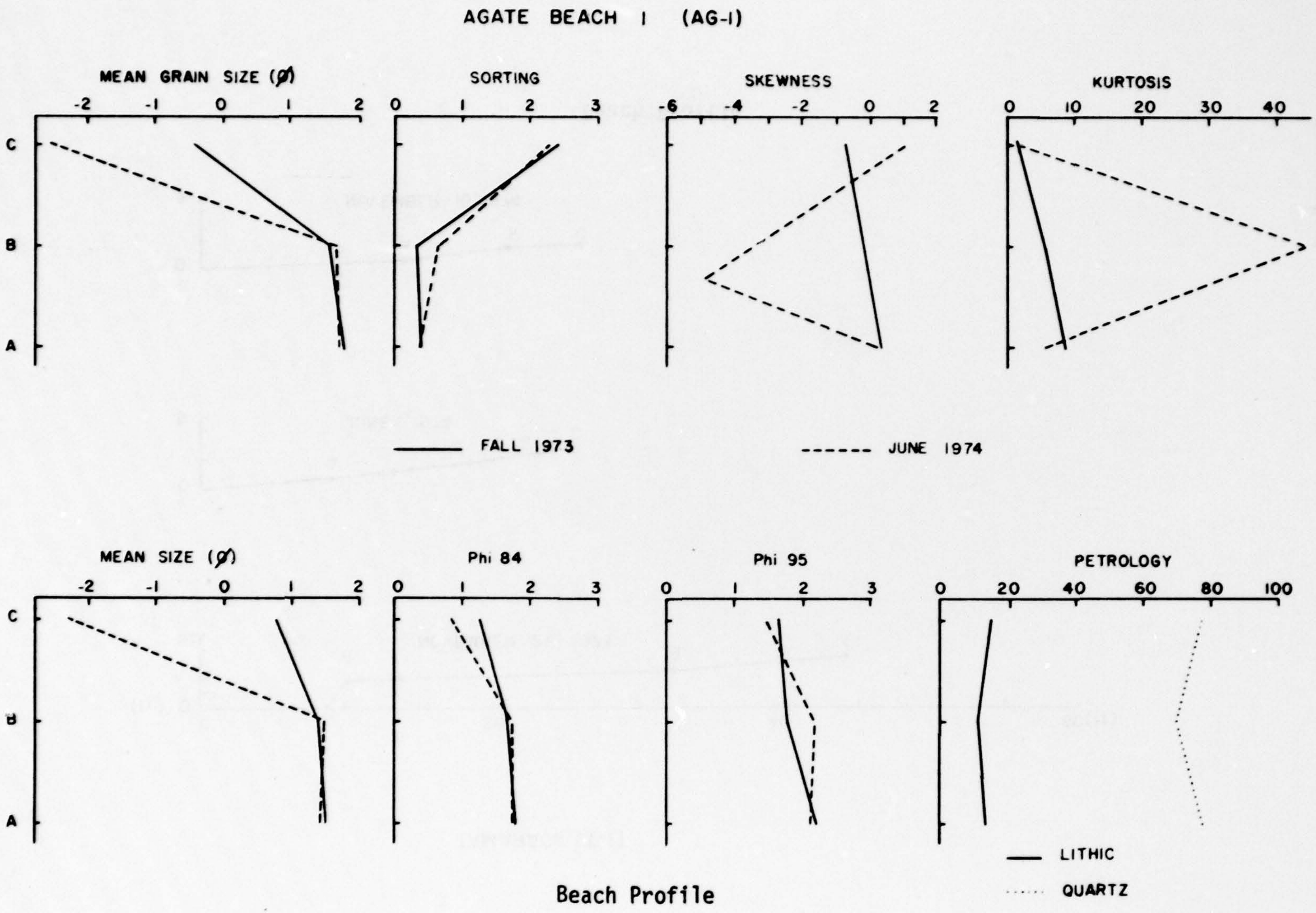
Beach Profile

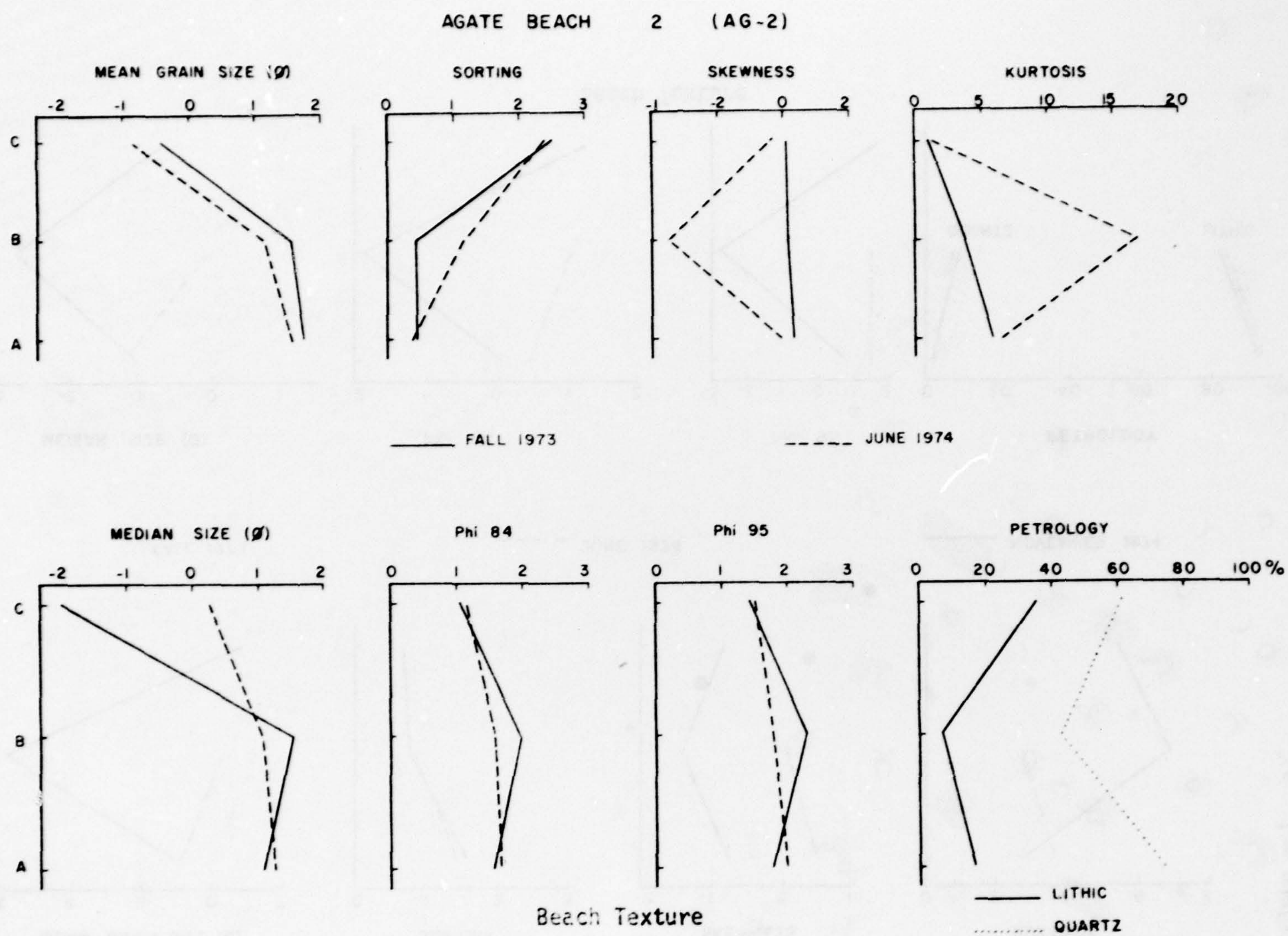


Beach Profile

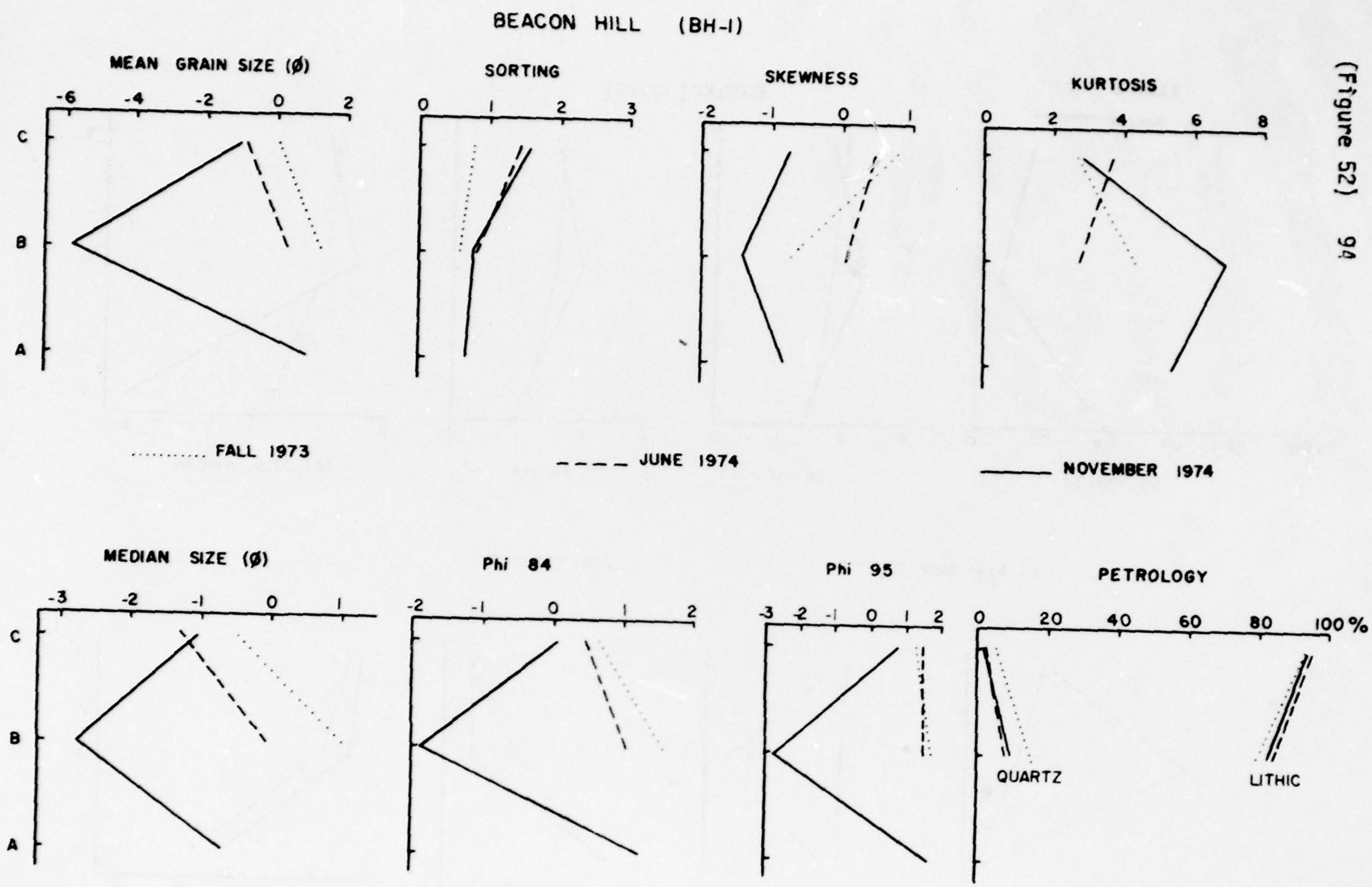


Beach Profile

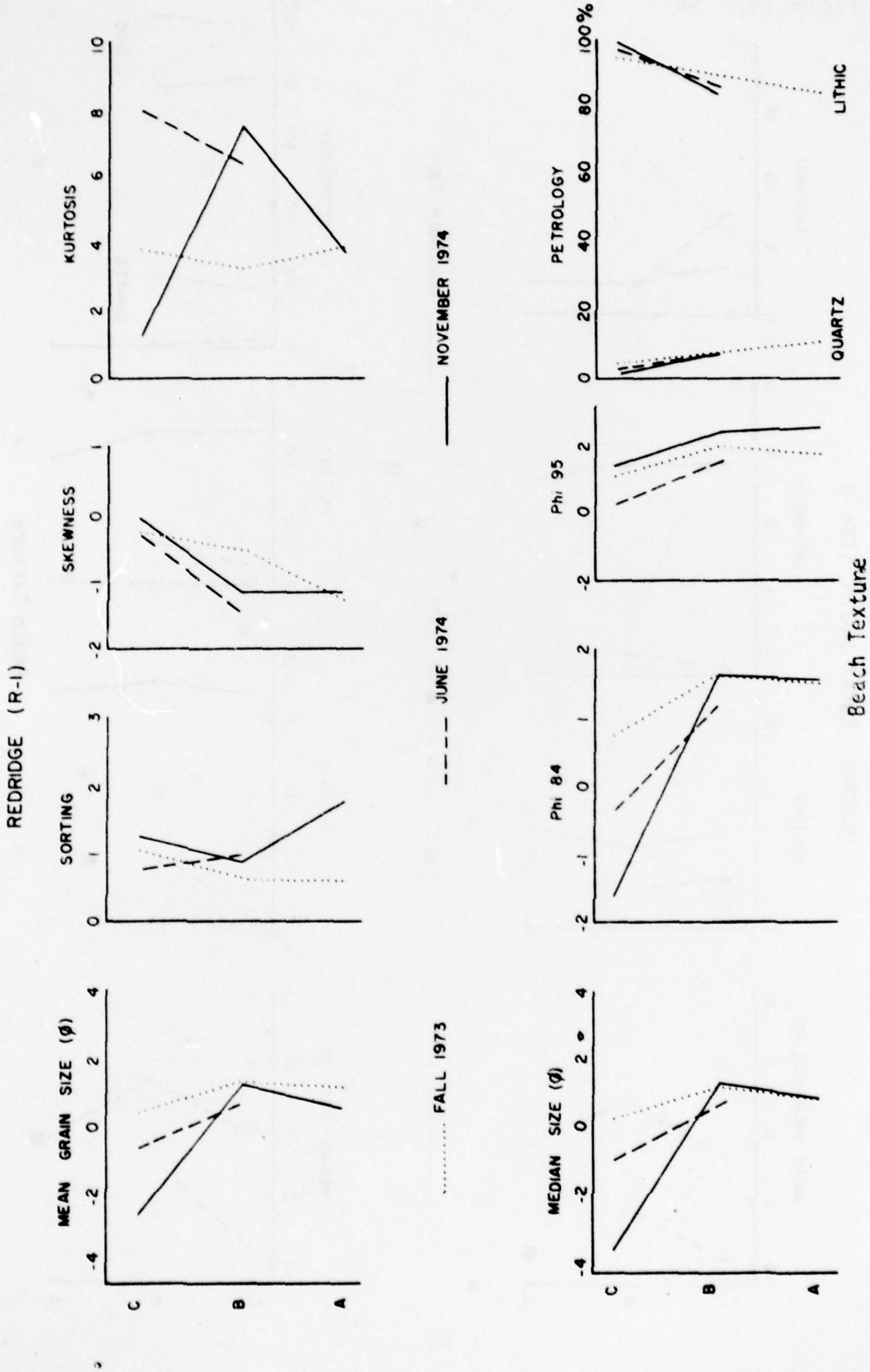

AGATE BEACH I (AG-I)
MEAN GRAIN SIZE (Ø)
SORTING
SKEWNESS
KURTOSIS
C
B
A
FALL 1973
JUNE 1974
MEAN SIZE (Ø)
Phi 84
Phi 95
PETROLOGY
LITHIC
QUARTZ
Beach Profile

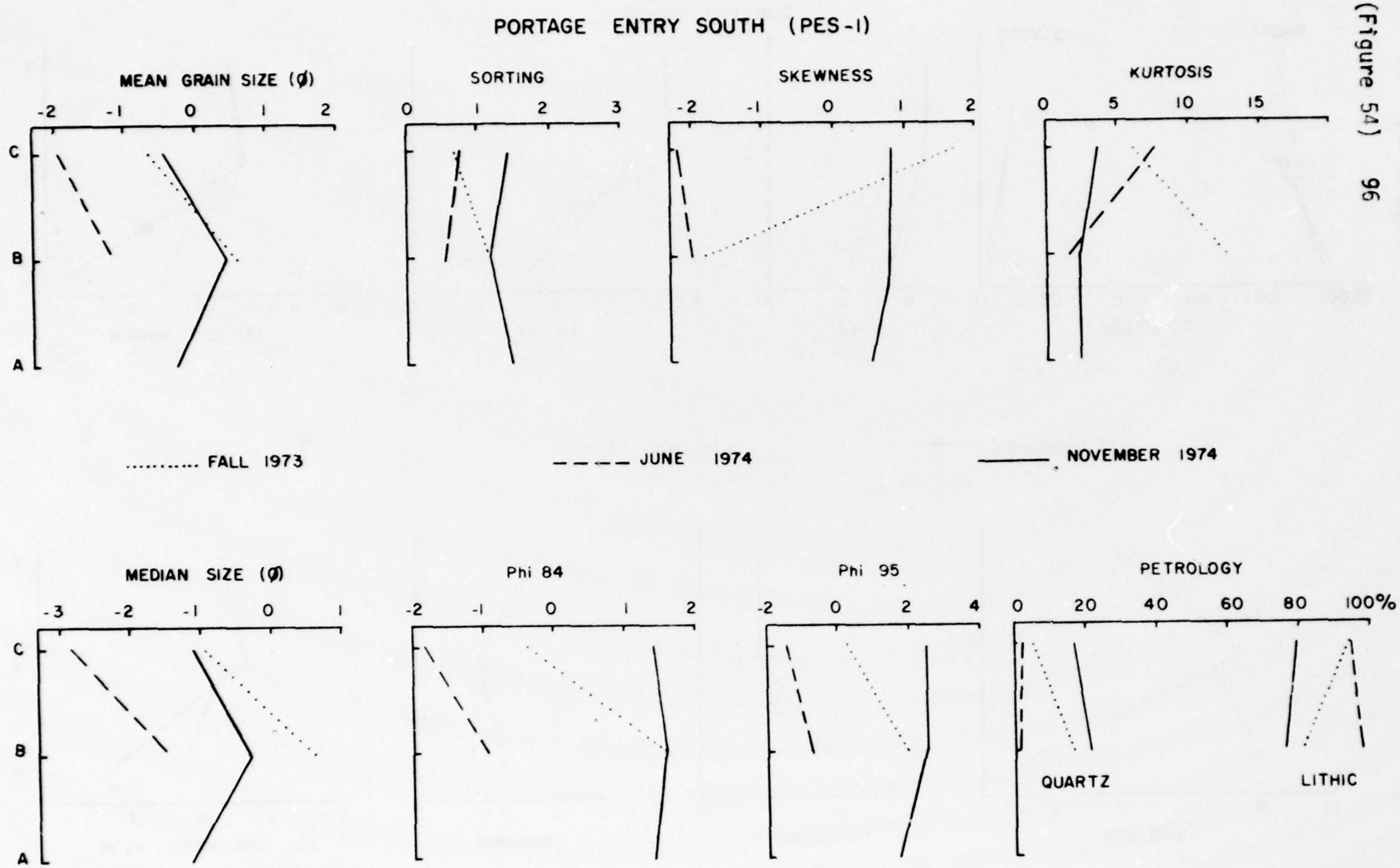


Beach Texture



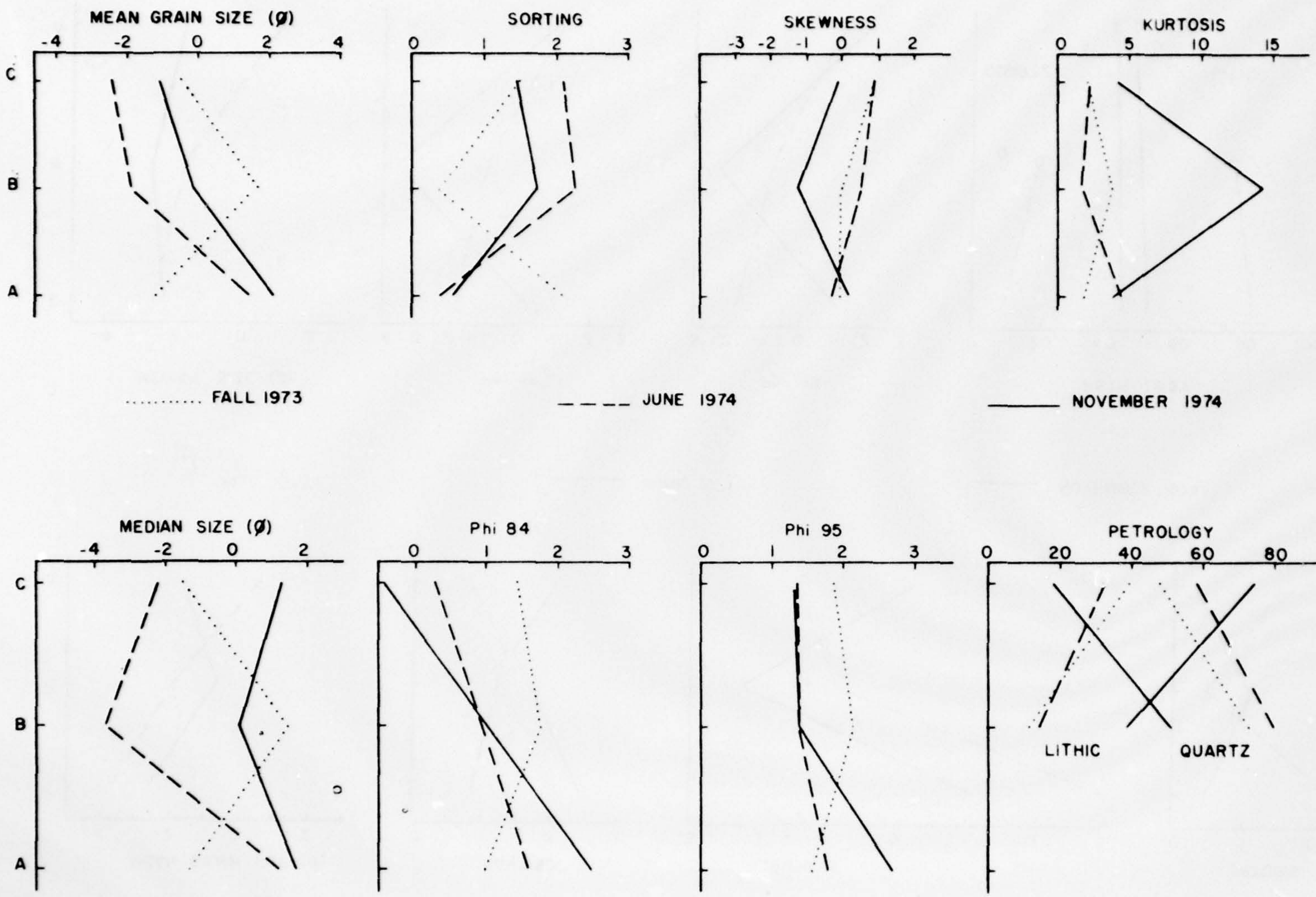
Beach Texture


REDRIDGE (R-1)
MEAN GRAIN SIZE (Ø)
SORTING
SKEWNESS
KURTOSIS
FALL 1973
JUNE 1974
NOVEMBER 1974
MEDIAN SIZE (Ø)
Phi 84
Phi 95
PETROLOGY
100%
LITHIC
QUARTZ
C
B
A
Beach Texture

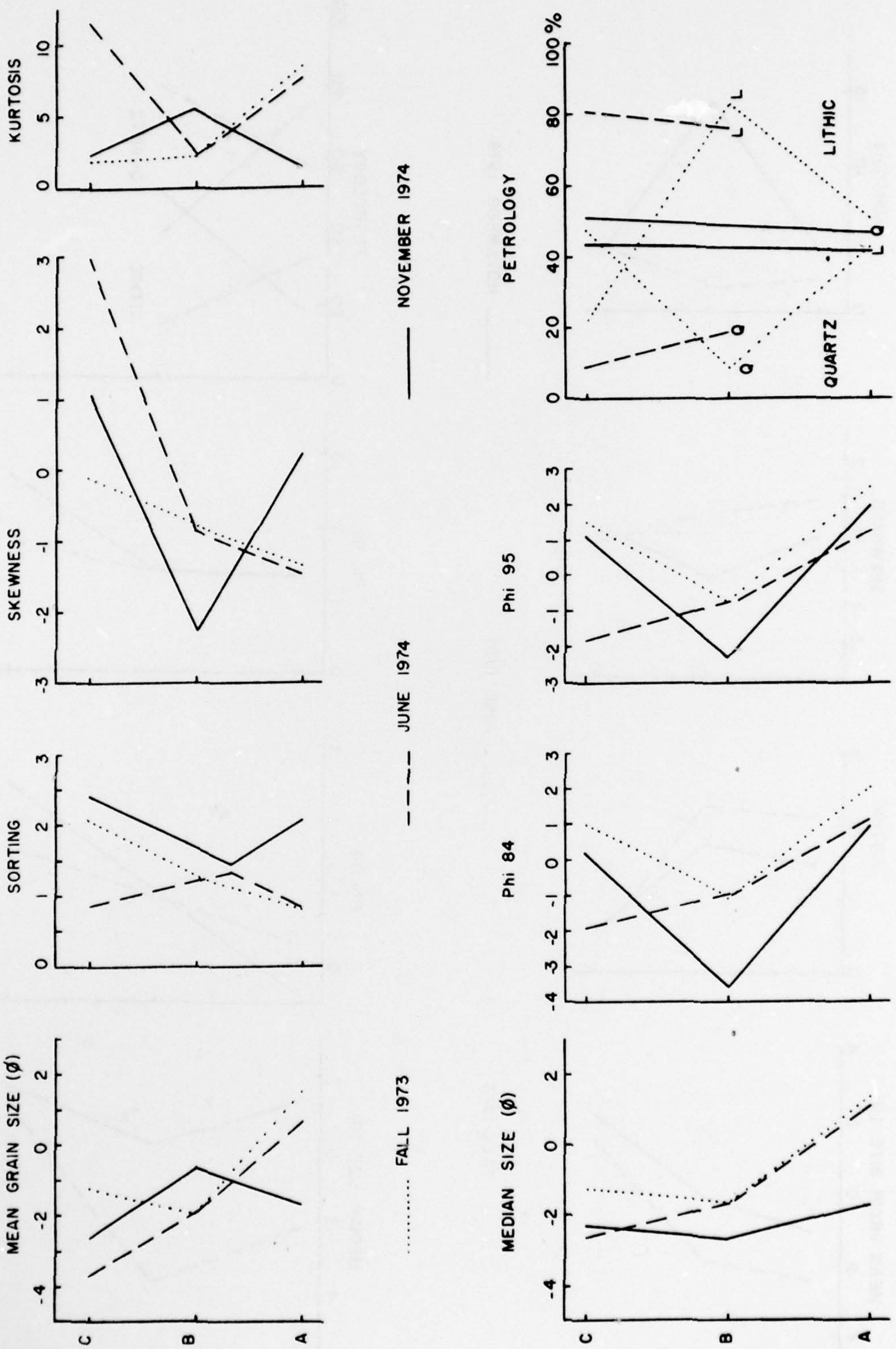


Beach Texture

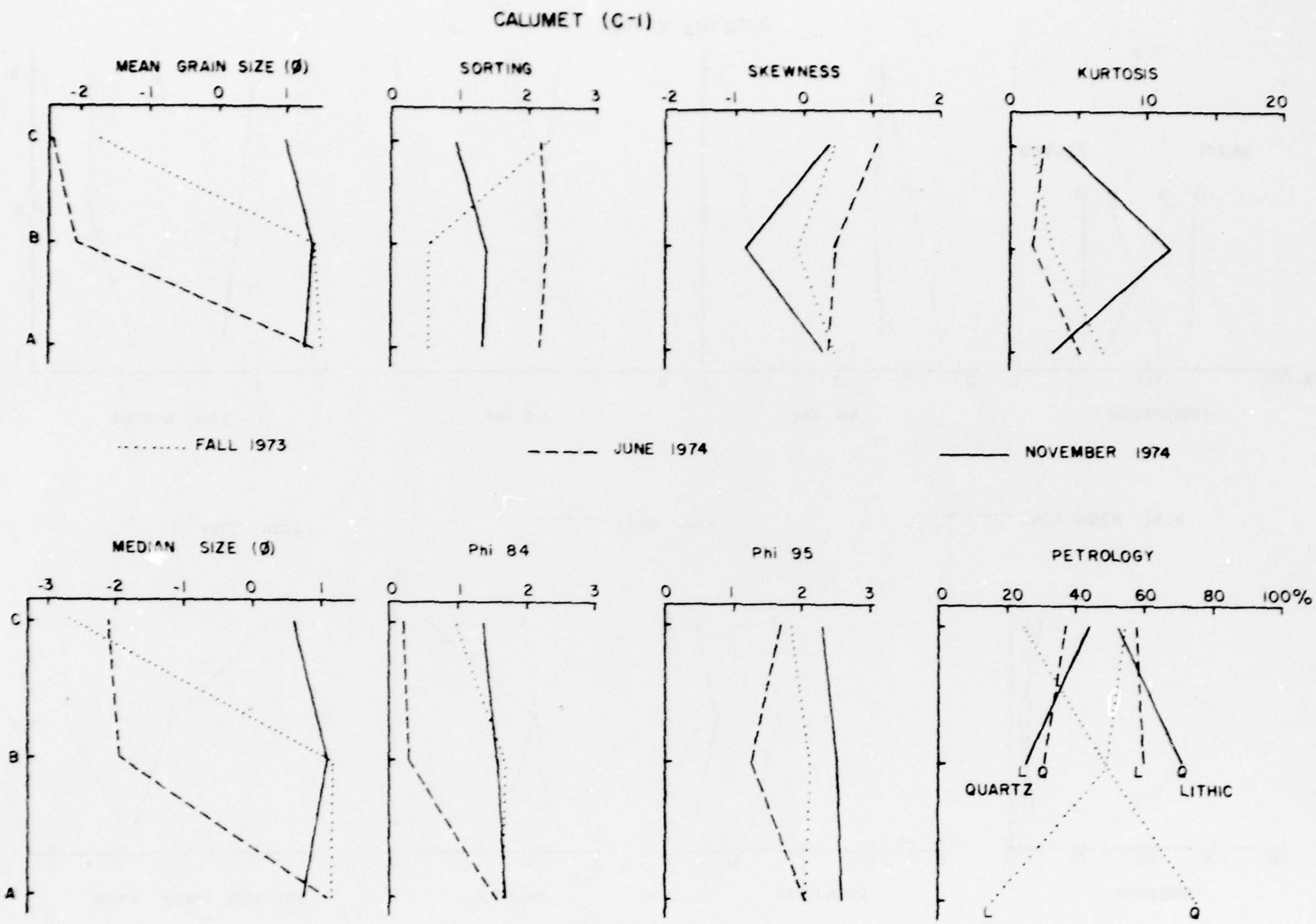
McLAIN 3 (M-3)



Beach Texture

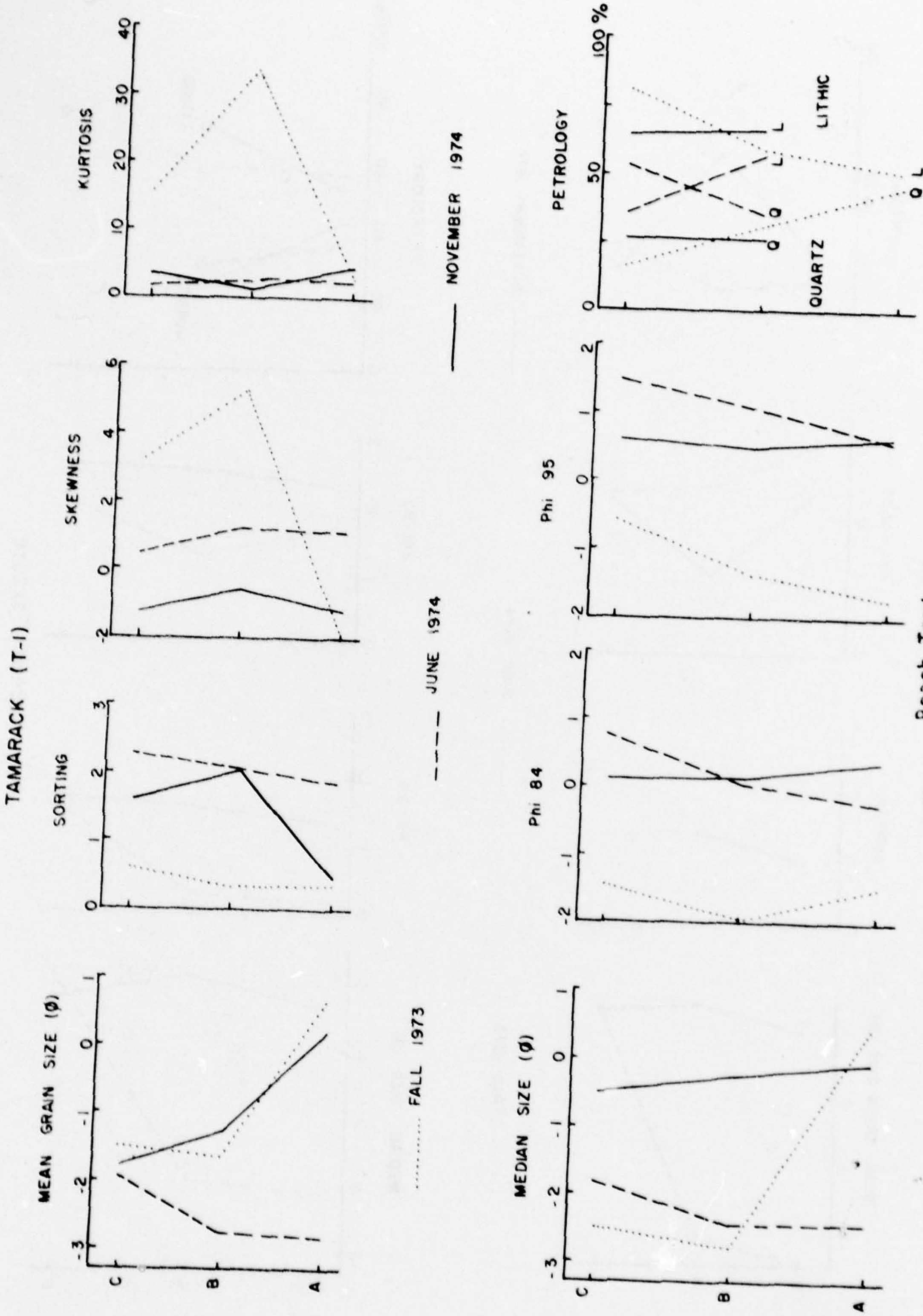


Beach Texture



Beach Texture

TAMARACK (T-1)



Beach Texture

H. Beach Nourishment Experiment

Beach nourishment has been suggested as a method for disposal of dredge spoil in the Keweenaw area. A beach nourishment experiment was carried out in the first week of June, 1974 to find out if it is indeed a workable alternative. One cubic yard of spoil was dumped in the swash zone of the beach at McLain State Park and profiles and samples were taken on either side and through the spoil sample following a preliminary pre-nourishment survey. The experimental set-up and location is shown in Figure 59. S1 and S2 refer to the first and second spoil samples placed on the beach. The photographs in Plate 4 document the setting up of the experiment, the removal of the spoil by wave action, and the results of the experiment at the end of the day. The experiment shows that it is possible to create a sandy beach on an otherwise gravelly foreshore.

Figure 60 shows the increase in fine sand on each side of the spoil. The beach in the downdrift direction received a considerable portion of fine sand. The updrift side also received some fine sand from the spoil. By the next day fine sand percentages had returned to pre-nourishment conditions.

Profiles taken during the experiment show the progressive disappearance of the spoil (Figure 61). The first spoil sample was leveled in approximately five hours. When the beach was visited the next day, the second spoil sample was also gone.

Mean grain sizes of samples taken along the profiles show a decrease after the spoil samples were placed on the beach (Figure 62). This is especially evident on the downdrift side and in the profile through the spoil sample. The lowest part of the swash zone is least affected.

Sorting values show a slight tendency toward poorer sorting, but generally remain constant (Figure 63). There is also a shift of skewness to more negative values in most cases (Figure 64). Kurtosis values appear to increase in some instances (Figure 65).

This agrees well with the nature of the spoil samples (Figure 66): finer, more negatively skewed, and larger kurtosis values than the beach were dumped on. The addition of finer material to a coarser beach would explain the slight difference in sorting.

The fact that sorting values remain relatively constant suggests that the energy of the beach processes is high enough to rapidly remove the dredge spoil. The textural parameters show a return to pre-nourishment conditions by the next day. Profiling indicates that the spoil had been completely removed.

The results of the experiment indicate that it is possible to create a sandy beach on an otherwise gravelly foreshore using dredge spoil from the Keweenaw Waterway, but only for a limited time before wind and waves remove the spoil. Berg (1965) noted that fine-grained material used to nourish beaches on Presque Isle Peninsula, on the south shore of Lake Erie, Erie, Pennsylvania, was more compatible with the conditions in the zone immediately offshore of the beaches than in the zones which are subject to the forces associated with breaking waves. The relative fineness of the nourishment material resulted in substantial portions being removed from the beach foreshore and deposited in nearby offshore areas. Berg (1965) also noted that erosion rates from the beach foreshore slope appear to correlate directly with the mean lake level. DuBois (1973) also assigned a similar importance to lake level in the seasonal variation of a beach on Lake Michigan.

Beach Nourishment Experiment

1. Unloading sacks of dredge spoil.
McLain State Park June 1974

2. Suspended sediment in the surf zone
during beach nourishment experiment.

3. Looking updrift(SW) from dredge spoil.
Note pebbles in the swash zone.

4. Looking downdrift(NE) from dredge spoil.
Note sandy swash zone.

Using the empirical equation of Balsillie (1973a) yields a transport rate of only 4000 cubic yards per year. (A figure allowing easy calculation of transport rate when wave height and breaker angle are known, based on this equation, is shown in Figure 67). This transport rate for the day of the experiment is at least an order of magnitude lower than normal littoral drift rates for this beach. Removal of dredge spoil placed on the beach during periods of higher waves and greater energy conditions at other times of the year would be more rapid. As compared to June, 1974, the decrease in the effect of the dredge spoil dumped in 12-14 feet of water off McLain State Park in the summer of 1974 - subsequently shown on the beach in November, 1974, suggests the temporary nature of beach nourishment.

It must be noted that the beach nourishment experiment involved only a small amount of dredge spoil. If enough spoil is used, the vulnerability of the shore during late summer may be reduced. The present nourishment program is effectively maintaining only a small part of the eroding shoreline north of the Waterway entrance.

I. Offshore Dumping: Keweenaw

Modification of the bathymetry caused by dredging in the Upper Entry and offshore dumping is probably a temporal effect, particularly at the dredge site. Infilling of the Upper Entry by sediment from the littoral zone returns the Upper Entry to "normal" status at least biyearly. Dredging is a retardant on a system trying to attain an equilibrium distribution. The fact that the Corps is dumping sediment into the lake is, in a bathymetric perspective, a simple enhancement of natural process occurring on a much larger scale.

The petrology of samples collected in fall of 1973 from the dredge- and dumpsites (Figure 68) suggests that quartz is more abundant at the dredge site than at the dumpsite. This may be due to a greater percentage of quartz in the finer portions of the dredge spoil, which would remain in suspension or would be selectively removed from the dredge spoil by wave action at the dumpsite. One spoil sample from the Upper Entrance taken in June, 1974 was 45% lithic fragments, which is similar to the percentage found at the dumpsite in fall of 1973. Variability in the composition of sediments within the Upper Entry is evident. Sorting by flow within the Waterway is probably partly responsible.

Offshore dumping of dredge spoil that is texturally coarser than the existing sediment inhibits the establishment of an equilibrium profile in the littoral zone. If the spoil is finer it will probably be dispersed rapidly by wave and wind action. Wave characteristics, as a function of season, play an important role. Because wave energy increases through the summer months in the vicinity of the Upper Entry, so do rapidity of dispersal and depth of disturbance of the spoil material. The sediment dispersal pattern (Figure 39) shows that sediment in depths of less than fifty feet will be influenced by wave action. The observation of ripples in depths below 50 feet in the area (Berkson, 1974) suggests that the depth of dispersal may be even greater.

Observations made on June 3, 1974 suggest that turbidity generated by the dredging-dumping process is of short duration. After a dumping of spoil about 150 yards offshore near the beach at McLain State Park, a turbid plume was observed moving slowly toward land. Five hours later it was indiscernable. Turbidity is not uncommon nearshore under normal conditions.

Material from the Upper Entry is introduced into the lake from time to time by the flow from the Waterway. Offshore dispersal of dredge spoil from the entry is an extension of this process. The geological changes which take place in the area of the Keweenaw Upper Entrance at the hands of the Corps of Engineers are probably short in duration and of minor importance in most instances. With the exception of dredging itself, changes in bathymetry, the redistribution of textural types and minerals, the turbidity, and the changing of bedforms are all being done naturally on a much larger scale in the Keweenaw study area.

Selection of a dumpsite depends on the rate of dispersal desired. The most desirable site geologically would be one in which both spoil and bottom material have equivalent textural and compositional characteristics, insuring that the substrate and degree of mobility of the sediment would remain approximately the same. One possibility is northwest of the Upper Entry where the outflow from the Waterway naturally deposits sediments from within the Waterway. The spoil material is texturally similar to much of the studied offshore area between McLain State Park and Calumet, although the lithic percentage is much greater in the spoil sediments.

J. Conclusions: Keweenaw Area

The activities of the Corps of Engineers in the Keweenaw area seem to be a simple enhancement of natural processes occurring on a much larger scale. The Upper Entry of the Waterway has obstructed the normal longshore movement of sediment. Dumping of material dredged from the Entryway puts the trapped sediment back into the natural system provided the sediment is placed within the zone of wave action. Some of this material may be used to nourish the eroding beaches to the northeast of the Waterway. This erosion appears to be due partly to the Waterway and partly to natural conditions intensified by the nature of the sandy lake beds on the shore northwest of the Waterway.

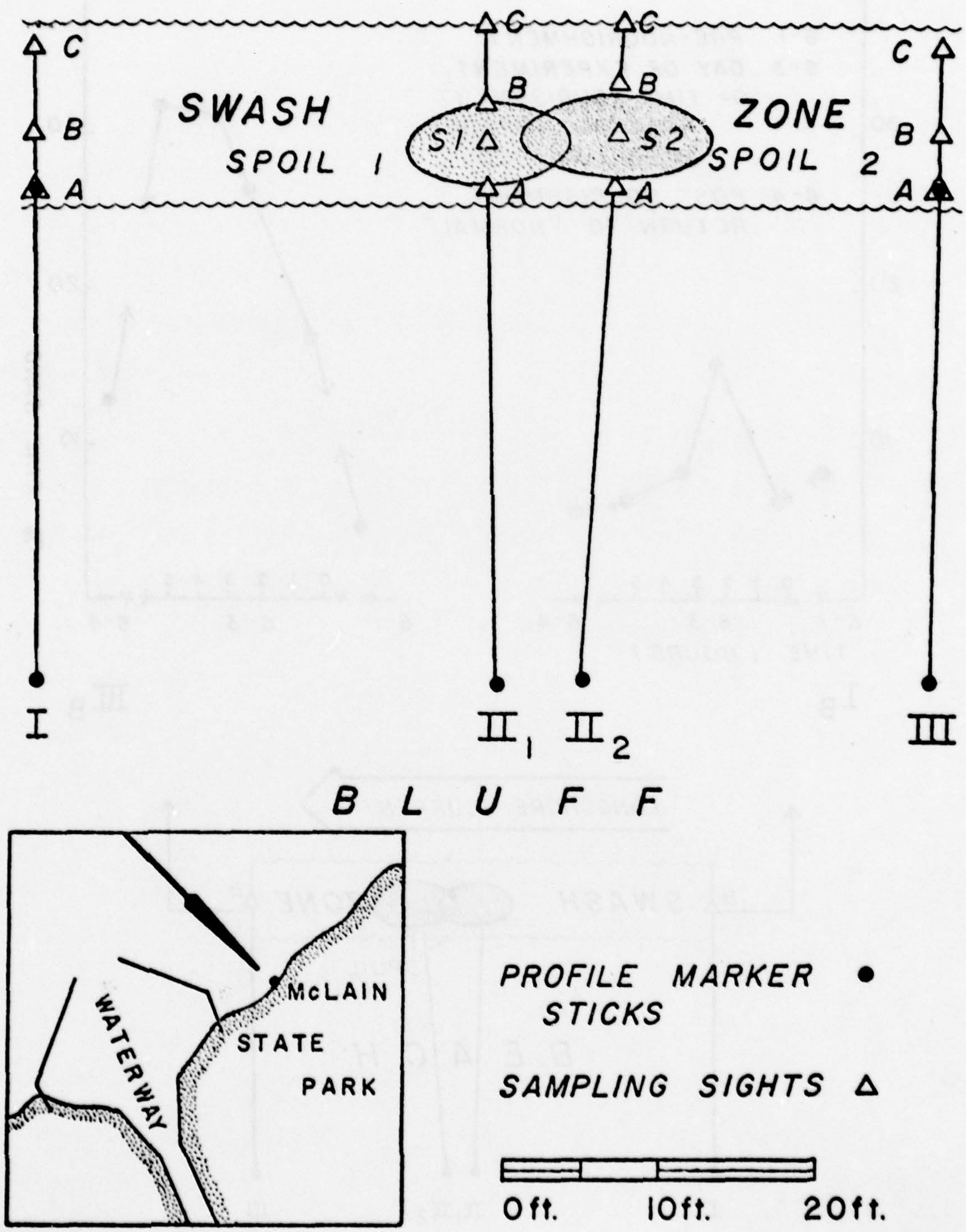
However, beach nourishment using dredge spoil appears to be only a temporary solution due to the fineness of the sediment in the Waterway. Continued renourishment would be required. This may be possible because the infilling of the Upper Entry requires continued maintainence dredging. Suitable offshore dumpsites exist in several areas, notably where outflow deposits sediment from within the Waterway offshore from time to time.

The influence of "red clay" in the Keweenaw area is probably not significant, as it is in the Duluth-Superior area, although clay lake beds are indicated along the shore from the southern part of the study area to north of Redridge, according to the surface geology map of Leverett (1929). An undetermined percentage of the finer sediment entering the Upper Entry may be derived from erosion of this clay.

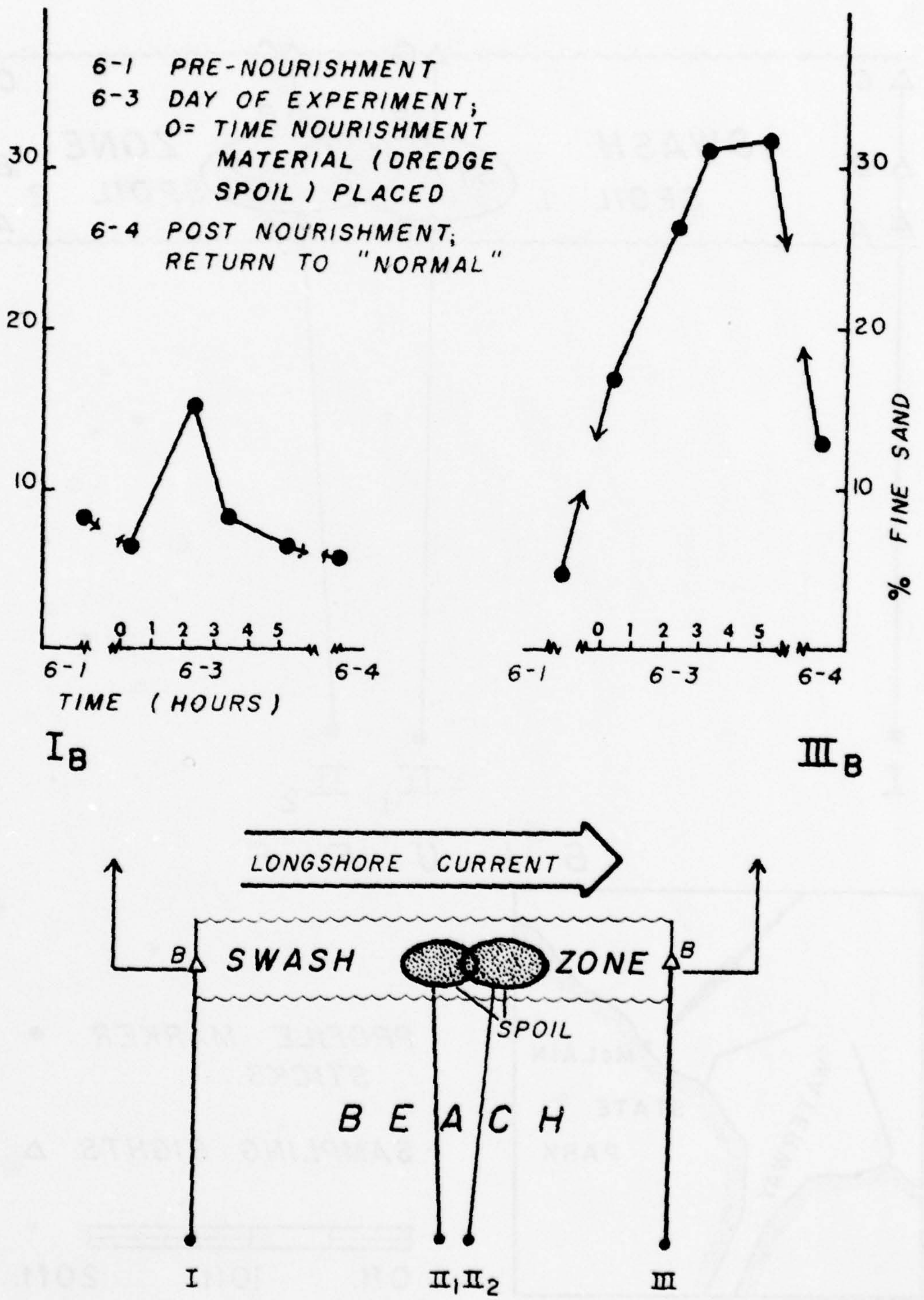
Examination of petrographic thin sections of samples of dredged material from the Upper Entry showed that the sediment was composed of 15 to 45% stampsand fragments. The Freda/Redridge stampsands are not the sole source of fine grained sediment in the area.

In the MTU report, part of the shallow water turbidity frequently observed between Freda and the North Entry is attributed to "grinding of the soft stampsands on the beach and in shallow water" (MKU, 1975, p. 51, 52). Within the methods and objectives of this study, we had no way of evaluating the effects or importance of particle comminution.

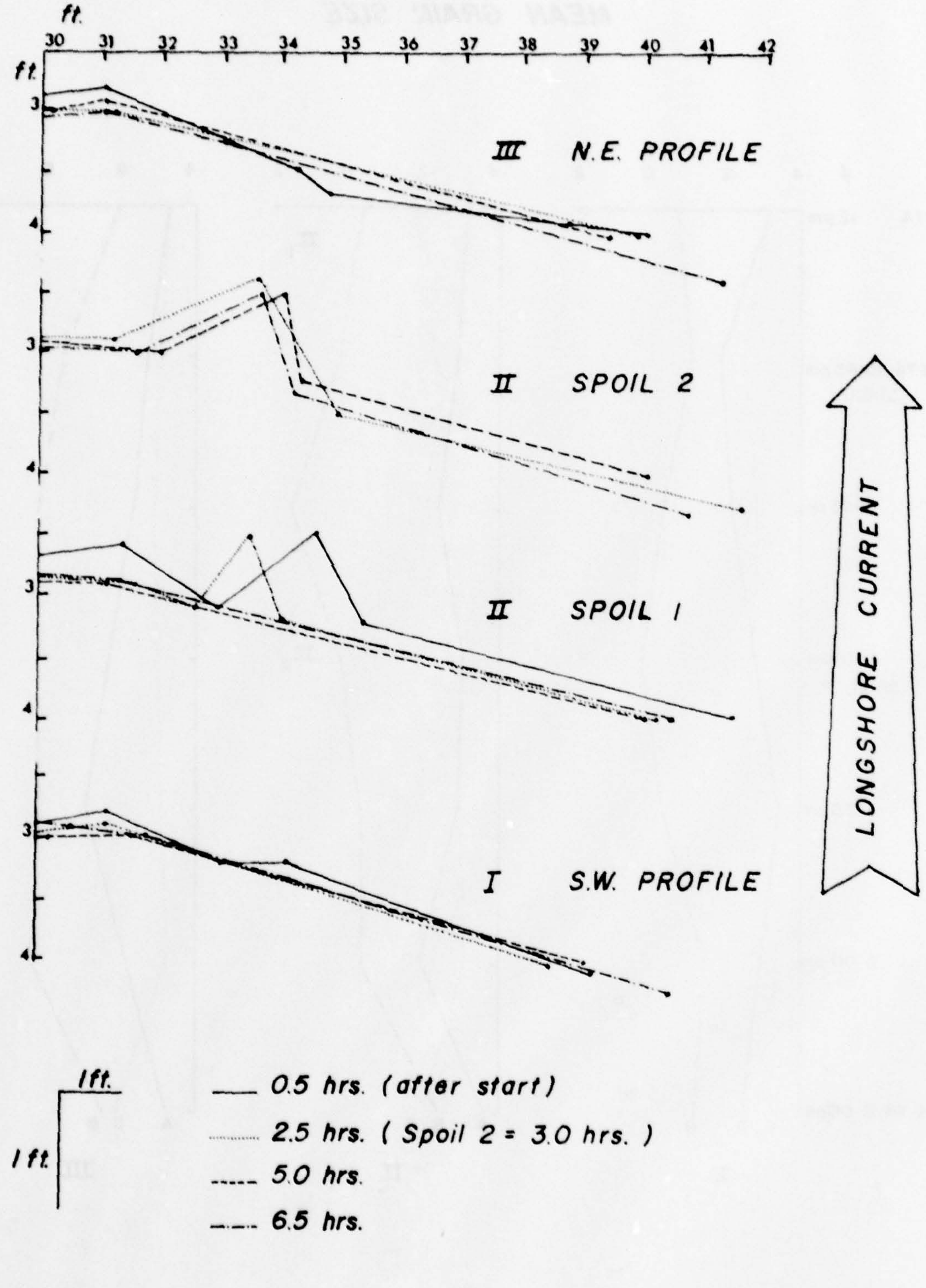
BEACH NOURISHMENT EXPERIMENT



% FINE SAND IN SWASH ZONE

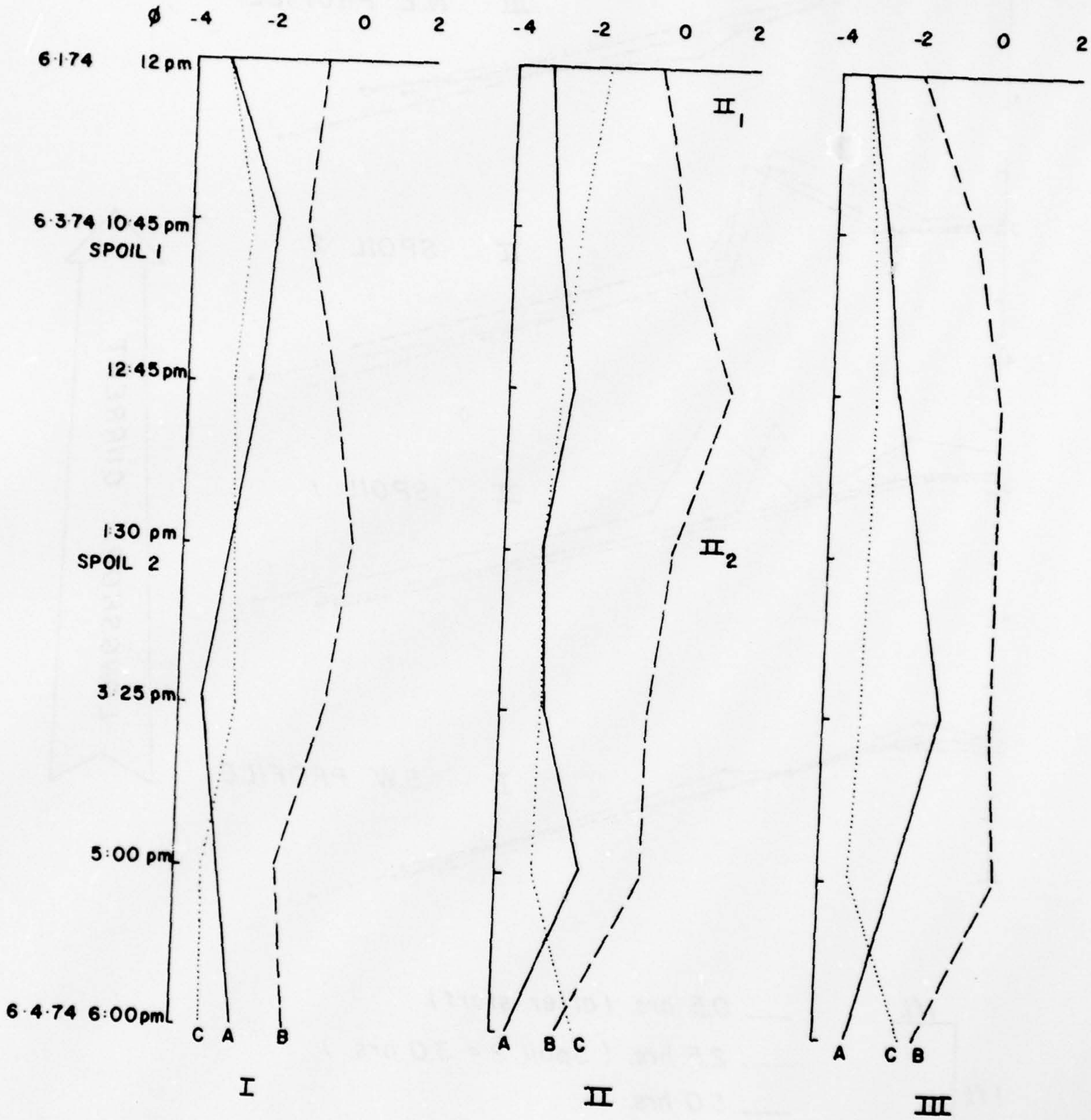


SWASH ZONE PORTIONS OF PROFILES (Taken 6-3)

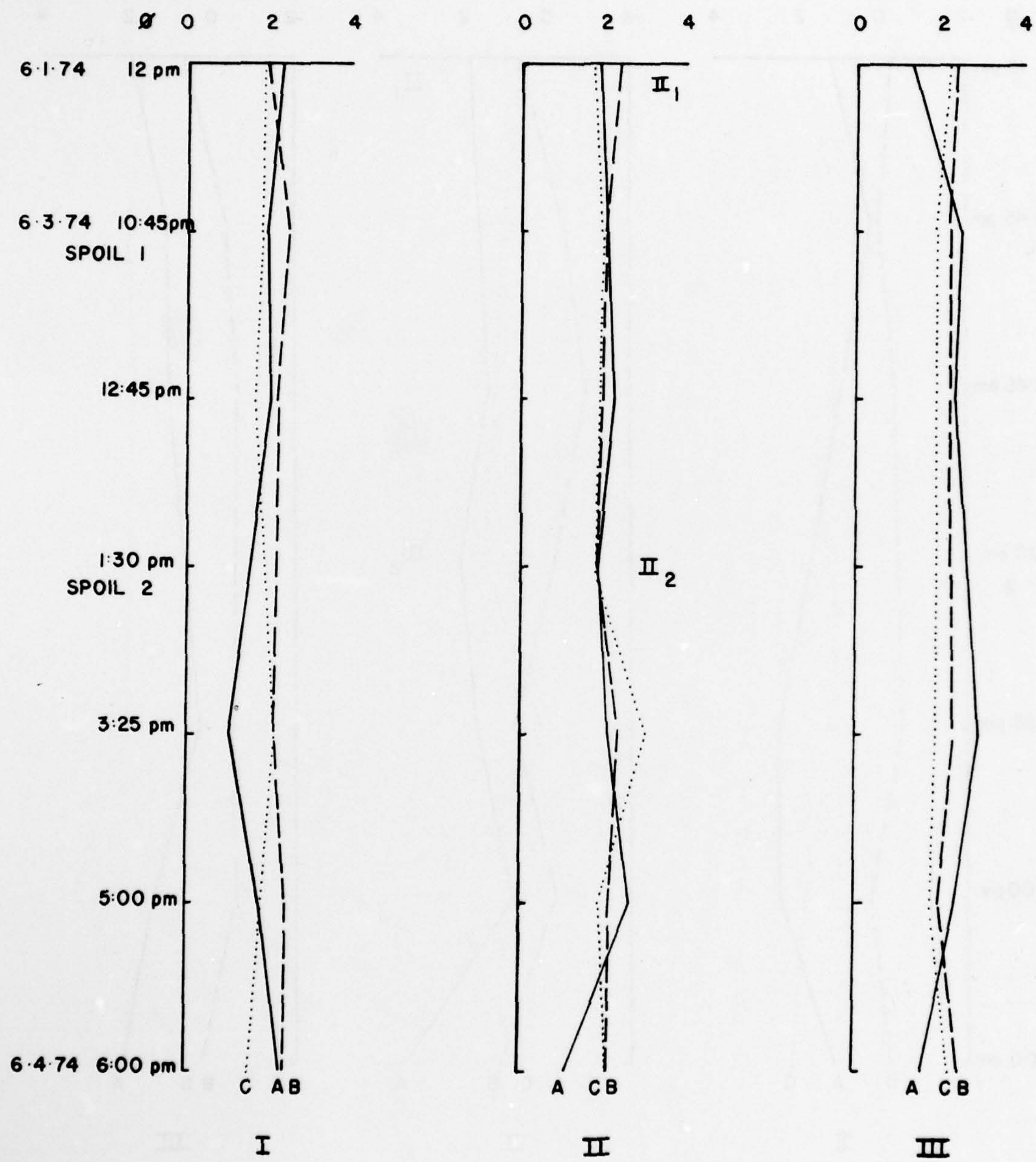


(Figure 62) 112

BEACH NOURISHMENT EXPERIMENT
MEAN GRAIN SIZE

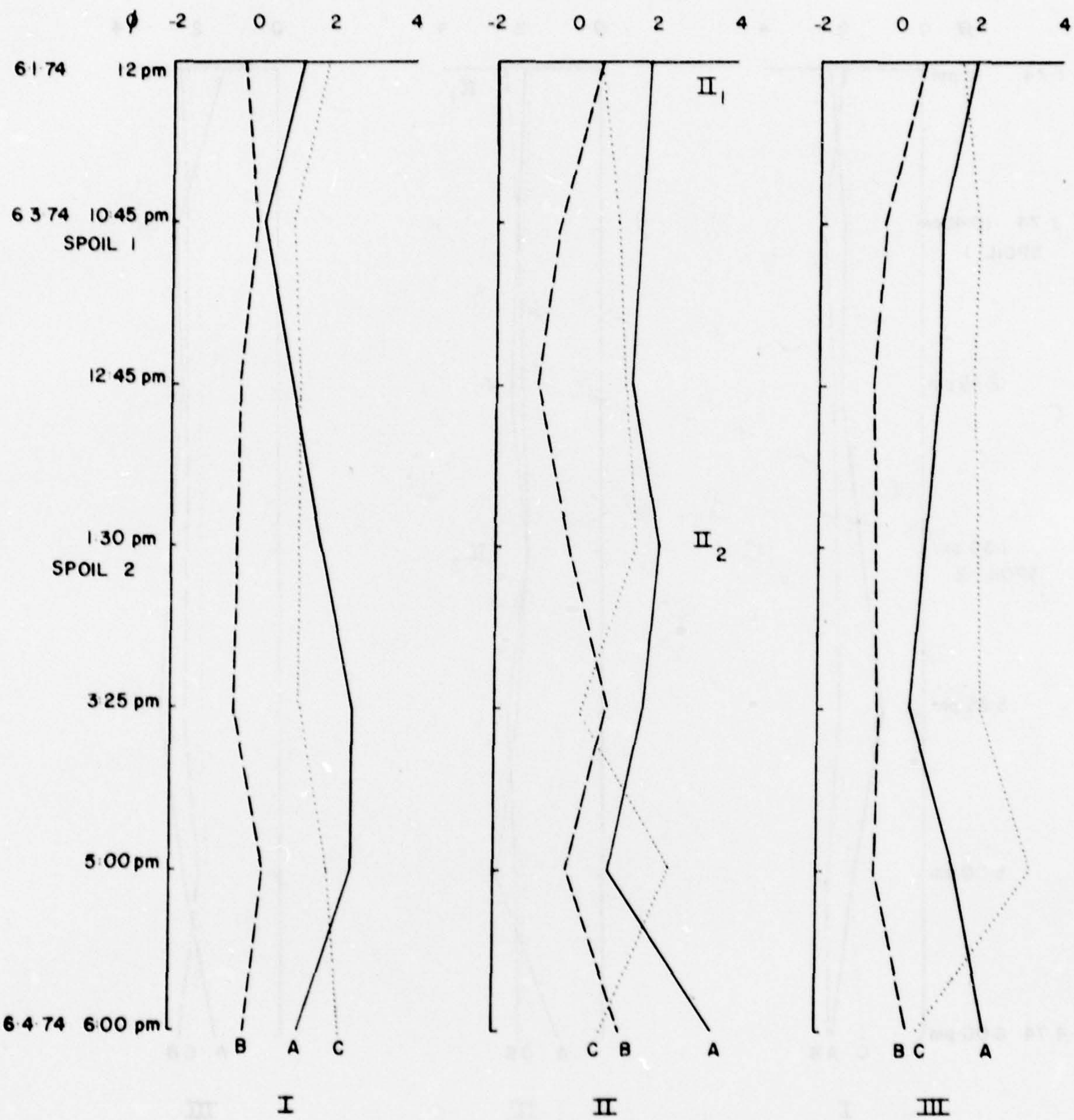


BEACH NOURISHMENT EXPERIMENT
SORTING

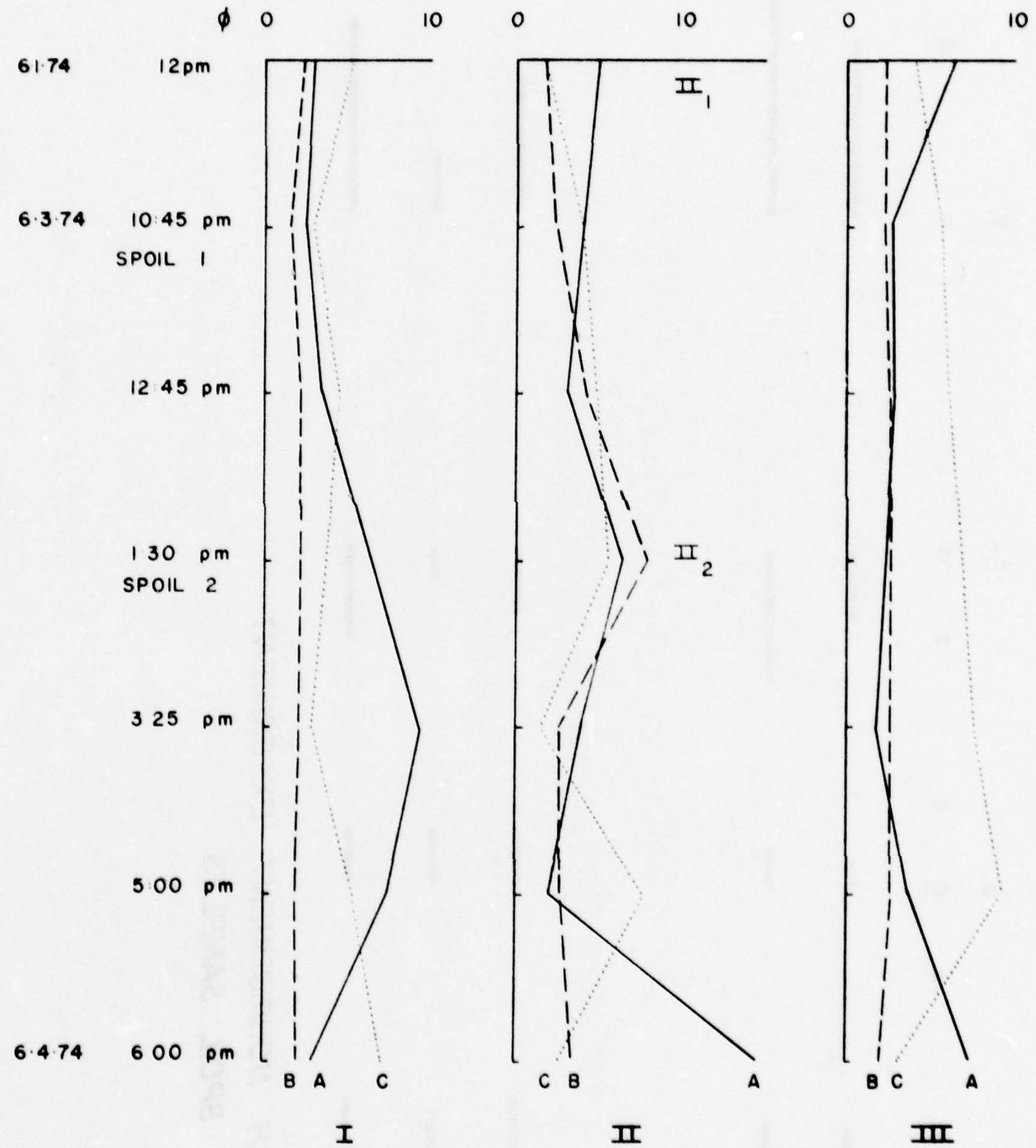


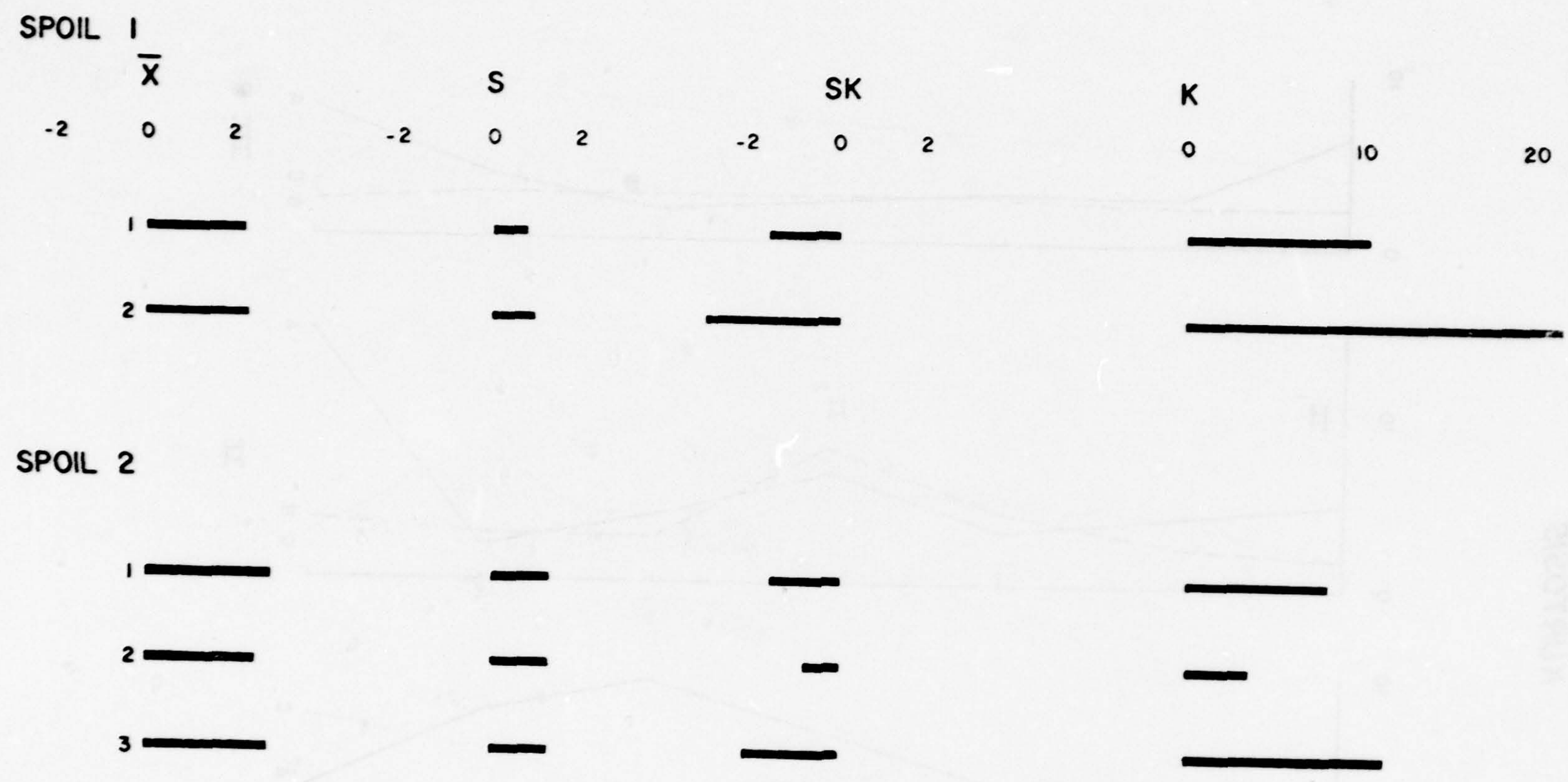
(Figure 64) 114

BEACH NOURISHMENT EXPERIMENT
SKEWNESS



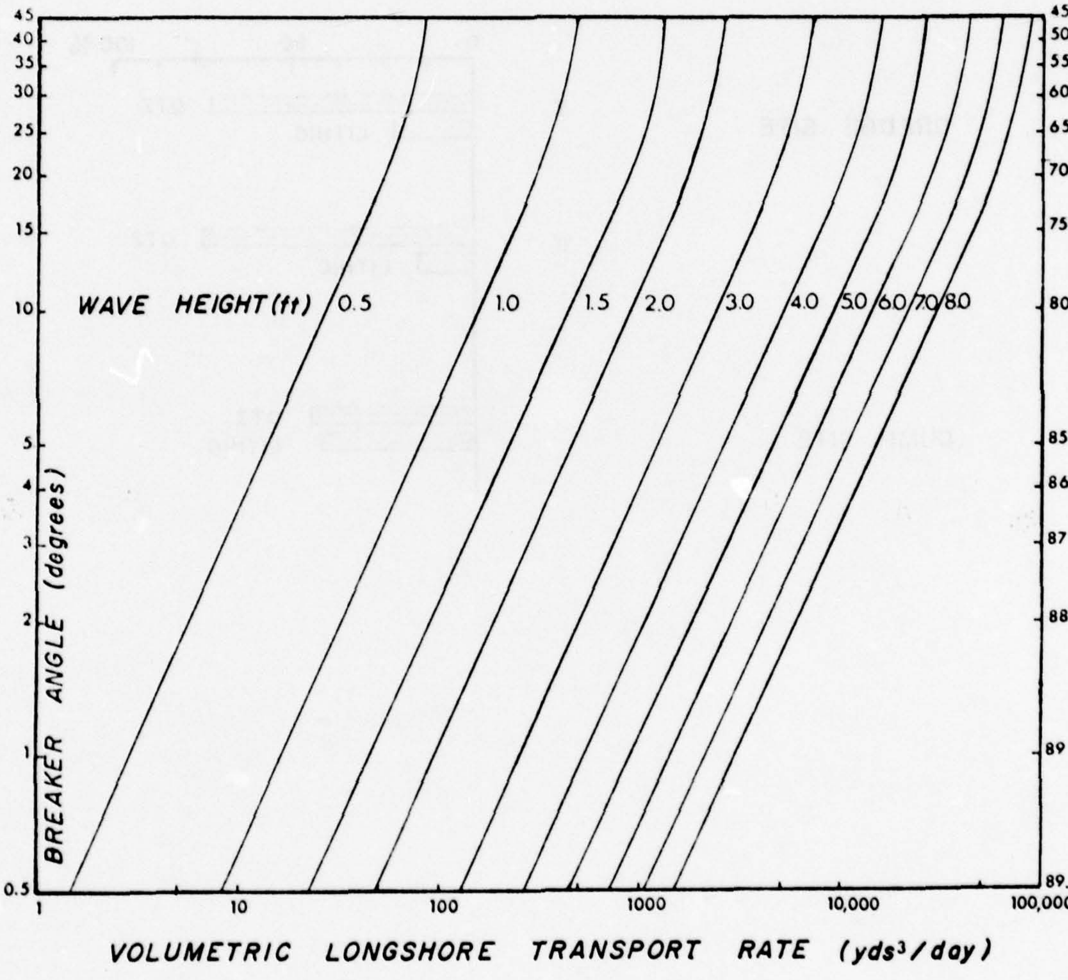
BEACH NOURISHMENT EXPERIMENT
KURTOSIS





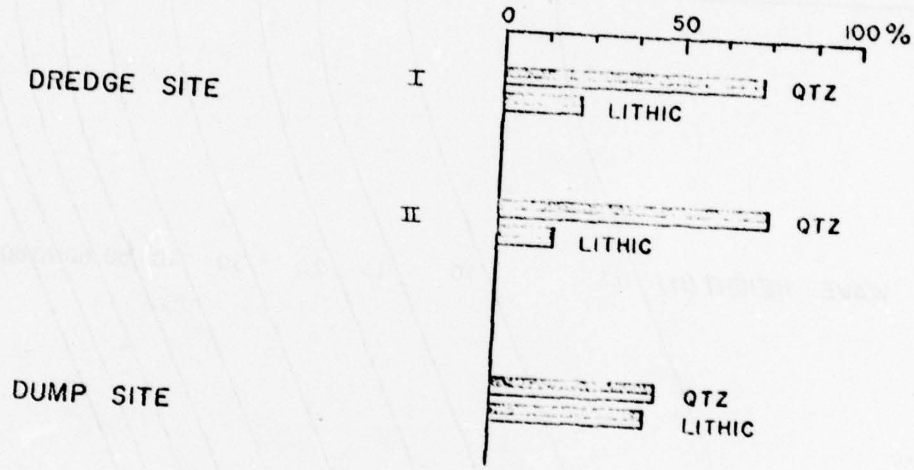
BEACH NOURISHMENT EXPERIMENT
SPOIL SAMPLES

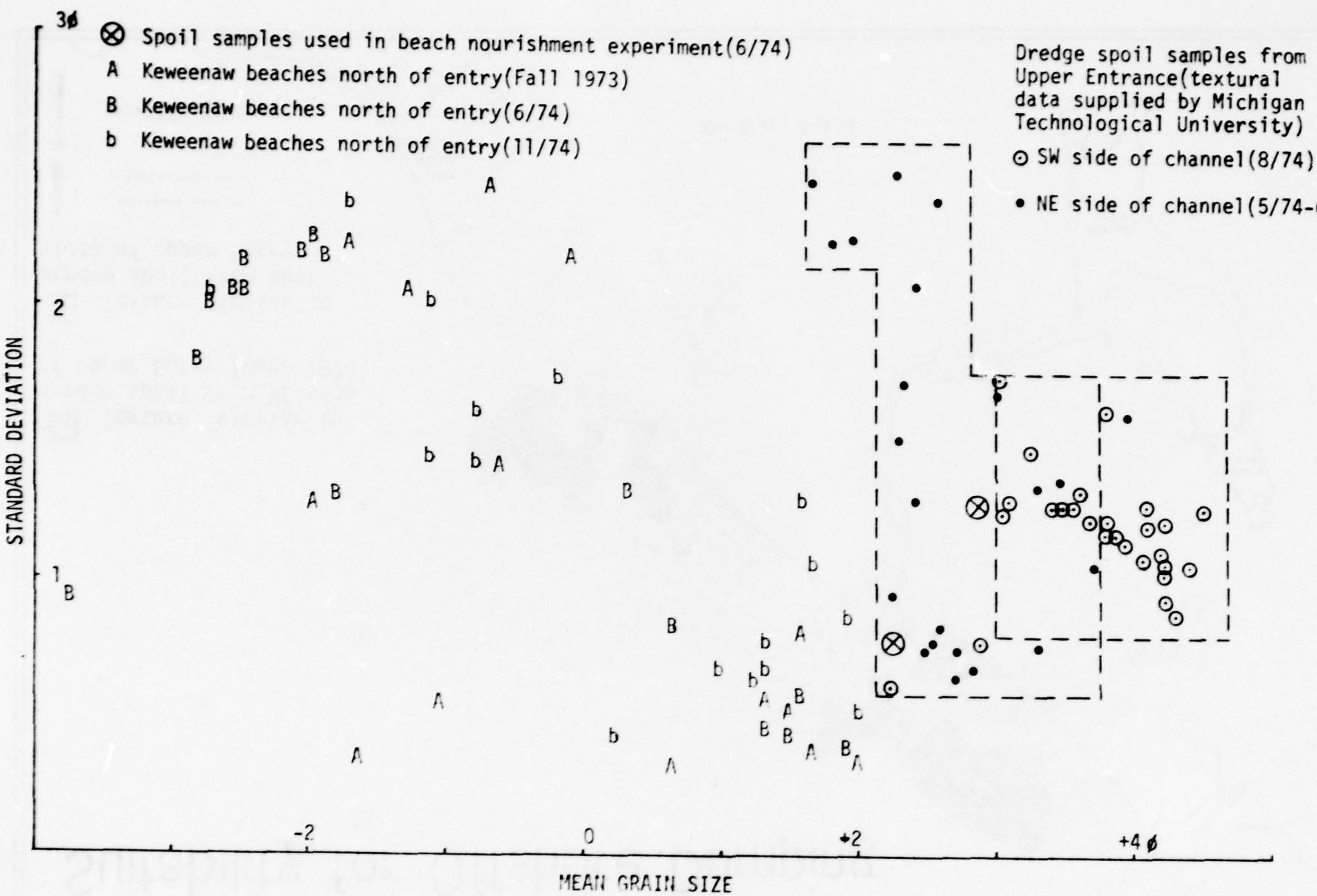
PREDICTION OF LONGSHORE TRANSPORT RATE USING BREAKER HEIGHT AND BREAKER–SHORELINE ANGLE



Based on [illegible]

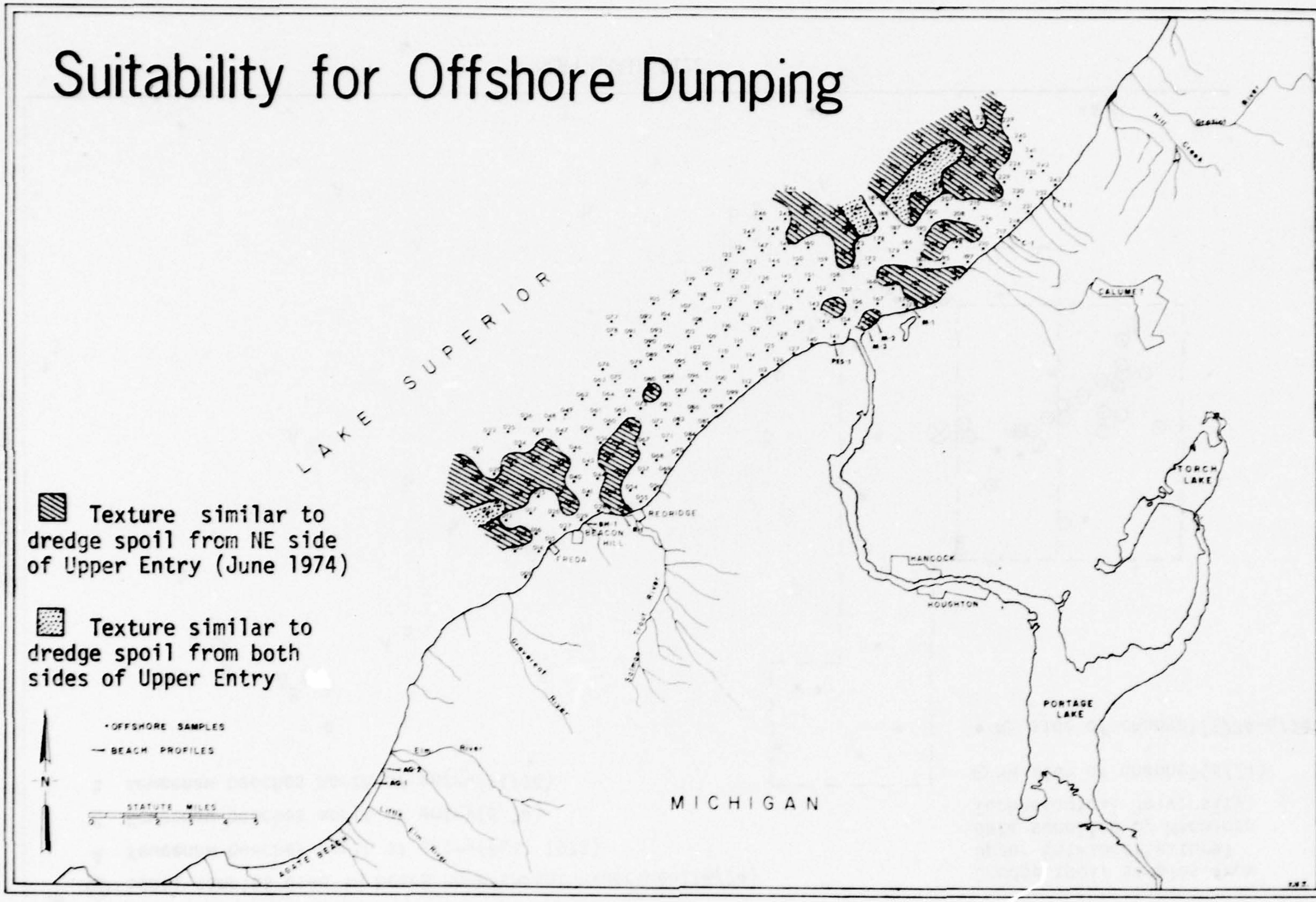
FALL 1973 QUARTZ AND LITHIC PERCENTAGES





Spoil samples used in beach nourishment experiment(6/74)
A Keweenaw beaches north of entry(Fall 1973)
B Keweenaw beaches north of entry(6/74)
b Keweenaw beaches north of entry(11/74)
Dredge spoil samples from Upper Entrance(textural data supplied by Michigan Technological University)
SW side of channel(8/74)
NE side of channel(5/74-6/74)
STANDARD DEVIATION
3ϕ
2
1
MEAN GRAIN SIZE
-2
0
+2
+4 ϕ

(Figure 69)


Suitability for Offshore Dumping
Texture similar to dredge spoil from NE side of Upper Entry (June 1974)
Texture similar to dredge spoil from both sides of Upper Entry
•OFFSHORE SAMPLES
→ BEACH PROFILES
N
STATUTE MILES
LAKE SUPERIOR
MICHIGAN
CALUMET
TORCH LAKE
HANCOCK
HOUGHTON
PORTAGE LAKE
REDRIDGE
BEACON HILL
FREDA
Gratiot River
Mill Creek
Elm River
Little Elm River
Graveraet River
Salmon Trout River
AGATE BEACH

III. References

A. Appendix 1: Sediment Data Supplied by Michigan Technological University

Studies of the Keweenaw Waterway sediments conducted by Michigan Technological University in the summer of 1974 show that the spoil samples used in the beach nourishment experiment were representative of the sediment on the northeast side of the Upper Entranceway where they were collected. Sediments on the southwest side of the channel tend to be texturally finer than those on the northeast side (Figure 69). Michigan Tech researchers have found that the material in the Lily Pond area is even finer.

Figure 69 shows the relative textural fineness of the Upper Entranceway sediments as compared to the Keweenaw beaches north of the Waterway entrance. This supports the conclusions of the beach nourishment experiment. Michigan Tech researchers have learned that the clogging of nets with leaves, logs, branches, clinkers, and other extraneous debris is causing local commercial fishermen to avoid the deepwater area northeast of the entry near the old offshore disposal area. These researchers suggest that all manner of material is swept along the "shelf" from southwest to northeast until it plunges off the edge and comes to rest in deep water or along the slope (Michigan Technological University Progress Report for 1-31 March to the U. S. Army Corps of Engineers, St. Paul District). This agrees with our sediment dispersal pattern.

Offshore areas with textures which fall within the range of the Upper Entranceway sediments indicated by the Michigan Tech data (within boxes in Figure 69) are shown in Figure 70. These sites appear to be texturally suitable for offshore dumping.

It is interesting to note that the mean grain size of the samples collected from the beach on the southwest side of the Upper Entry is coarser than the mean grain size of samples of beach sediment collected at Redridge. This suggests that comminution of the stampsands may not be as important as the selective sorting of the fine-grained fractions from the stampsand piles. This fine-grained sediment is the result of the mechanical crushing of the basaltic fragments during processing to remove the copper.

B. Appendix II

SELECTED SAMPLE DATA

B. Appendix II

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics		Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
Fall 1973 DULUTH - SUPERIOR HARBOR, BEACH, DUMPSITE, AND OFFSHORE										
A	.46	1.46	-	-						
B	2.32	.53	-	-						
C	2.54	.57	-	-						
D	2.62	.73	-	-						
E	2.44	.57	-	-						
F	2.82	.60	-	-						
G	2.21	.56	-	-						
H	1.73	.64	-	-						
J	2.38	.54	-	-						
W-P Beach	.64	.68	68.6	7.9						
WP2-5	2.10	.45	77.7	11.4						
WP2-12	2.27	.56	71	8.0						
Dump-site	2.40	1.42	67	14						
S-2 14X-73	2.05	.84	67	6.6						
III-1 16X-73	2.52	.92	69.3	18.0						
IV-2 16X-73	2.91	1.02	60	20.9						
IX 16X-73	1.97	.98	77	10.4						
VII 16X-73	-	-	53.7	5.6						
VIIIA 16X-73	-	-	71	14.6						
S-1 14X-73	-	-	75	12.3						
S-3 15X-73	-	-	71.3	6.7						
S-22 14X-73	-	-	67.7	12.3						
Dump-site	-	-	67	18.0						

FALL 1973 Keweenaw Offshore

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
LS A-				
4-1	1.96	.43	76.7	17.3
4-2	1.96	.42	-	-
10-1	2.65	.59	74.9	14.1
20-1	1.66	.56	86	10
20-2	1.71	.58	-	-
30-1	1.93	.70	80.7	16.7
A-30-2	1.85	.69	-	-
LS D-4-1	1.48	.52	51.8	29.3
LS D-4-2	1.54	.59	-	-
LS R-				
4-2	2.17	.56	12.2	52.8
9-1	2.49	.70	8	67
9-2	2.46	.70	-	-
20-1	2.53	.61	76.9	15.5
30-1	1.52	.92	69.7	21.3
30-2	1.50	.94	-	-
LS B-8-1	2.52	.86	72.7	20.0
LS B-8-2	2.62	.91	-	-
LS P-				
4-2	3.37	.64	59.2	21.4
10-1	2.73	.57	56.3	31.6
10-2	2.68	.64	-	-
15-1	1.00	1.95	76.3	7.6
19-2	1.91	.95	-	-
19-1	2.23	.49	45.5	25.9

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
LS P				
23-1	1.73	.60	61.7	25.3
LS T				
2-1	2.11	.41	76.7	18.7
2-2	2.01	.40	-	-
29-1	1.80	.78	76.7	15.3
29-2	1.90	.73	-	-
LS C 20-1	.80	.91	60.7	31.7
LS X 19-1	1.01	.69	63.1	29.2
LS X 19-2	1.16	.62	-	-

FALL 1973 KEWEEWAW BEACH PROFILING FALL 1973

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics	Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
AG-1-A	1.73	0.37	77.3	13.0					
AG-1-B	1.55	0.31	69.1	10.3					
AG-1-C	-0.41	2.39	77.3	12.7					
AG-2-A	1.35	0.42	74.0	16.0					
AG-2-B	1.77	0.42	42.9	6.3					
AG-2-C	-1.48	2.49	61.6	32.8					
BH-1A-B	1.19	0.48	-	-					
BH-1-B	1.25	0.58	15.1	79.1					
BH-1-C	0.01	0.78	5.6	42.9					
R-1-A	1.06	0.66	10.0	24.7					
R-1-B	1.22	0.65	6.7	20.9					
R-1-C	0.39	0.60	4.3	50.8					
RT	0.16	1.86	1.7	96.0					
PES-1B	0.60	1.13	16.0	81.6					
PES-1C	-0.64	0.67	4.3	94.6					
M-3-B	1.64	0.39	73.3	11.7					
M-3-C	-0.54	1.48	47.9	44.0					
M-2-A	1.60	0.81	48.0	21.3					
M-2-B	-1.92	1.30	8.7	82.6					
M-2-C	-1.21	2.08	43.7	51.0					
M-1-A	1.96	0.41	82.7	8.1					
M-1-B	-0.77	2.46	46.3	44.6					
M-1-C	-0.06	2.36	40.1	56.3					
C-1-A	1.43	0.51	75.0	26.6					
C-1-B	1.37	0.58	48.2	49.8					
C-1-C	-1.75	2.25	25.0	66.3					
T-1-A	0.67	0.38	45.9	50.2					
T-1-B	-1.66	0.37	31.7	59.6					
T-1-C	-1.50	0.57	16.8	80.5					

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics	Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
6-74 KEWEENAW BEACH PROFILING									
6-74 TIA	-2.41	1.89	-	-	6-74 PES-1B	-1.42	.55	0.7	98
6-71 TIB	-2.44	2.03	35.3	56.3	6-74 PES 1C	-2.86	.75	2	96
6-74 TIC	-1.86	2.26	53.3	36	6-74 RR-B	.59	.99	6.3	85.7
6-74 Ca-A	1.02	.51	-	-	6-74 rrC	-1.03	.77	2	96.3
5-74 CA-B	-1.92	2.22	31.3	59.3	6-74 BH-B	-.04	.80	7	83.7
5-74 Ca-C	-2.18	2.18	36.3	57.7	6-74 BH B1?	1.05	.51	-	-
6-74 M1A	1.18	.59	-	-	6-74 BH-C	-1.26	1.42	-	-
6-74 M1B	1.64	.40	-	-	6-74 Ag2-A	1.26	.39	-	-
6-74 M1C	.06	1.32	-	-	6-74 Ag2 B	1.08	1.12	-	-
A5-74 M2-A?	.56	.83	-	-	6-74 Ay2-C	.27	2.40	-	-
BS 74 M2-B	-2.21	2.15	-	-	6-74 AG1A	1.40	.36	-	-
M-2-B 2of2?	-1.62	1.31	19	76	6-74 AG1B	1.43	.65	-	-
CS-74 M-2-C?	-2.75	.82	10	80.7	6-74 AG1C	-2.37	2.28	-	-
S74 M3A	1.15	.38	-	-					
S-74 M3B	-3.67	2.23	79.7	14					
S-74 M-3C	-2.19	2.09	58.7	32.7					

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics		Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
6-74 BEACH NOURISHMENT EXPERIMENT McLain State Park KEWEENAW PENINSULA										
S74 BNA	1.07	2.34	-	-		BNP I B6-74	-1.17	2.46	-	-
S-74 BNB	-2.00	2.38	-	-		6-74 C	-1.98	1.83	-	-
S-74 BNC	-2.49	1.78	-	-		6-74 BNP IIA	-2.90	1.90	-	-
S-74 BND	-.64	2.05	-	-		6-74 BNP II A-B	2.20	.95	-	-
S-74 BNE	-2.47	2.22	-	-		6-74 BNP II-B	.20	1.98	-	-
S-74 BNF	-.63	2,57	-	-		6-74 BNP II-C	-2.39	1.72	-	-
S-74 BNG	-2.07	2.08	-	-		6-74 BNP III-A	-2.48	2.38	-	-
S-74 BNH	-3.07	1.80	-	-		6-74 BNP III-B	-.41	2.14	-	-
S74 BNI	-.50	2.28	-	-		6-74 BNP III-C	-3.04	1.85	-	-
S-74 BNJ	-1.73	2.49	-	-		6-74 BNP I-2-A	-2.82	1.63	-	-
S-74 BNK	.31	2.04	-	-		BNP I2-B	-.39	2.13	-	-
G-74 BNL	-2.54	2.17	-	-		BNP I2-C	-2.27	1.97	-	-
S-74 BNM	-3.30	1.34	-	-		6-74 BNP II2-A	-2.54	2.19	-	-
S-74 BNN	-1.98	2.30	-	-		6-74 BNP II2A-B	2.37	.54	-	-
S-74 BNO	-2.80	2.15	-	-		6-74 BNP II2-B	1.44	1.78	-	-
6-74 BNP IA	-2.51	1.79	-	-		6-74 BNP III2-A	-2.40	2.36	-	-

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
6-74 BNP III2B	.16	2.19	-	-
6-74 BNP III2C	-2.95	1.81	-	-
BNP II Spoil 2A	-3.11	1.79	-	-
BNP II Spoil 2-A-B	2.47	1.53	-	-
BNP II Spoil 2B	.20	1.82	-	-
BNP II Spoil 2C	-3.13	1.32	-	-
BNP I3-A	-2.60	2.05	-	-
6-74 BNP I3-B	-.33	2.03	-	-
6-74 BNP I3-C	-3.53	1.10	-	-
BNP II3-A Spoil-1	-2.59	2.21	-	-
BNP II3-B Spoil-1	-.44	1.97	-	-
BNP II3-C Spoil-1	-.71	2.33	-	-
BNP II3-A Spoil-2	-2.83	2.15	-	-
BNP II3A-B Spoil-2	2.62	1.12	-	-
BNP II3-B Spoil-2	-1.71	2.27	-	-
BNP II3-C Spoil-2	-1.07	3.00	-	-
BNP III3 A	-1.27	2.93	-	-
BNP III3 B	.19	2.26	-	-
BNP III3 C	-3.04	1.81	-	-
BNP I4-A	-3.03	1.78	-	-
6-74 BNP I4-B	-1.49	2.35	-	-
6-74 BNP I4-C	-3.26	1.73	-	-
6-74 BNP II4-A	-1.87	2.80	-	-
BNP Sp 1 II4-B	-.35	1.90	-	-
BNP Sp 1 II4-C	-2.62	2.14	-	-
BNP Sp 2 II4-A	-1.94	2.56	-	-
BNP Sp 2 II4	2.68	1.11	-	-
BNP Sp 2 II4-B	-.40	2.13	-	-
BNP Sp 2 II4-C	-3.11	1.96	-	-
BNP III4 A	-2.68	2.24	-	-
BNP III4 B	.22	2.12	-	-
BNP III4 C	-3.30	1.78	-	-
BNP I5-A	-3.27	1.58	-	-
BNP I5-B	-1.18	2.28	-	-
BNP I5-C	-2.53	2.20	-	-
BNP II5 A	-3.62	1.17	-	-

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics	Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
BNP II5-B	-2.40	2.16	-	-					
BNP II5-C	-2.04	2.18	-	-					
BNP III5 A	-3.26	1.60	-	-					
BNP III5 B	-1.50	2.86	-	-					
BNP III5 C	-1.82	2.21	-	-					
BNP Sp.2 1	2.81	1.28	38.5	43.0					
BNP Sp.2 2	2.56	1.29	41.0	42.5					
BNP Sp.2 3	2.88	1.32	-	-					
BNP Sp.1 1	2.24	.79	-	-					
BNP Sp.1 3	2.32	.96	-	-					

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics	Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
JUNE 1974 KEWEENAW OFFSHORE									
CE 001	2.48	.55	20.0	66.5	CE 018	2.72	.68	-	-
CE 002	-.94	2.98	52.0	35.5	CE 019	2.61	.86	-	-
CE 003	2.75	.59	-	-	CE 020	1.92	.99	-	-
CE 004	2.39	.59	78.5	5.5	CE 021	1.90	.94	-	-
CE 005	2.87	.82	-	-	CE 022	2.02	.78	79.0	7.0
CE 006	2.70	1.03	-	-	CE 023	2.63	1.20	-	-
CE 007	2.86	1.20	76.3	10.3	CE 024	2.93	.85	71.5	11.5
CE 008	2.11	1.09	-	-	CE 025	.93	1.28	-	-
CE 009	2.60	1.11	78.5	7.0	CE 026	1.83	.51	86.0	6.0
CE 010	2.42	1.02	-	-	CE 027	.82	.61	5.0	86.6
CE 011	2.88	.73	-	-	CE 028	2.30	.41	11.7	75.3
CE 012	2.00	.68	-	-	CE 029	1.06	.91	7.5	86.0
CE 013	2.22	.75	-	-	CE 030	2.46	.63	64.7	24.3
CE 014	2.07	.62	-	-	CE 031	2.29	.68	-	-
CE 015	-.69	1.77	3.0	90.7	CE 032	2.72	.82	-	-
CE 016	1.94	.88	-	-	CE 033	2.62	1.14	-	-
CE 017	1.75	.07	76.7	10.0	CE 034	2.06	.88	79.0	10.0

(continued)

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics		Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
035	-	-	-	-		058	2.44	.65	81	7
036	1.87	.63	-	-		059	2.36	.87	-	-
037	1.73	.66	79.0	13.0		060	.86	.92	83.7	9
038	2.73	1.06	-	-		061	1.43	.54	-	-
039	2.85	.68	-	-		062	1.67	.60	-	-
040	2.55	.53	77.0	6.5		063	1.27	.62	-	-
041	2.00	.71	83.0	0.7		064	1.54	.59	-	-
042	2.61	.64	10.3	70.3		065	.84	1.10	-	-
043	2.62	.76	56.7	29.3		066	2.38	.68	-	-
044	2.36	.59	-	-		067	2.00	.58	-	-
045	1.97	.50	-	-		068	-	-	-	-
046	1.71	.81	-	-		069	1.79	.54	14	76.3
047	2.11	.69	-	-		070	1.91	.70	15	78
048	1.62	.60	-	-		071	-.27	2.35	46	48
049	2.21	.77	72.0	13.0		072	2.07	.49	77.5	4.5
050	1.20	1.06	-	-		073	2.44	.55	80.3	6.7
051	1.64	.80	-	-		074	1.56	.58	-	-
052	2.60	.77	73.0	8.3		075	1.44	.88	77.5	15
053	2.51	.63	68.3	12.3		076	1.96	.97	-	-
054	-	-	-	-		077	1.89	.70	79	11.5
055	1.88	.48	8.3	80.7		078	2.00	.50	-	-
056	1.75	.62	11.5	82.0		079	2.00	.65	-	-
057	-2.43	2.29	28.0	68.7		080	.99	1.09	-	-

(continued)

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics	Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
081	2.37	.63	-	-	104	1.93	.53	84	9.0
082	2.15	.62	-	-	105	1.96	.52	-	-
083	.38	2.42	50.7	42.7	106	1.83	.46	-	-
084	2.46	.46	-	-	107	1.96	.52	-	-
085	1.59	.59	-	-	108	.22	1.62	53.5	35
086	-1.90	2.88	-	-	109	1.57	.79	-	-
087	1.06	1.06	74.5	14.5	110	-.62	2.91	-	-
088	.24	1.24	-	-	111	1.89	1.02	-	-
089	2.09	.74	-	-	112	1.41	.48	40.7	52.7
090	2.02	.60	75	11.5	113	.25	.00	-	-
091	1.85	.58	-	-	114	1.72	.63	-	-
092	1.95	.52	-	-	115	1.11	1.58	72.7	18.7
093	1.90	.57	-	-	116	1.90	.77	-	-
094	-	-	-	-	117	1.09	.95	-	-
095	2.01	.94	84	9.3	118	1.26	.88	-	-
096	1.11	.82	-	-	119	1.90	.36	81	7.7
097	-.14	2.81	-	-	120	.53	1.88	-	-
098	-	-	23.5	62.5	121	1.51	.46	-	-
099	-	-	-	-	122	.88	.60	-	-
100	-.08	2.21	54	41	123	1.23	.76	-	-
101	1.75	.67	-	-	124	-2.92	2.18	-	-
102	.48	1.60	-	-	125	1.47	.62	75.3	19
103	1.96	.61	-	-	126	1.98	.44	49	37.5

(continued)

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics		Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
127	-	-	-	-		150	1.24	.59	74.5	15
128	.94	1.07	74.5	15.5		151	1.29	.66	-	-
129	1.17	.57	73.3	33		152	1.53	1.10	-	-
130	.12	1.30	-	-		153	2.22	.71	76	8.5
131	.46	.65	46	43		154	1.87	.52	59.5	23.5
132	.52	1.01	-	-		155	2.78	1.04	49.5	30
133	-.12	2.81	-	-		156	-1.50	2.69	-	-
134	1.14	.90	34	51.5		157	2.10	.42	-	-
135	.35	.94	-	-		158	1.41	1.64	76	12.5
136	.82	.75	-	-		159	1.21	.78	-	-
137	1.44	.56	-	-		160	.84	1.27	-	-
138	1.56	.72	-	-		161	2.69	1.06	66.7	23
139	-.29	2.02	50	44.3		162	2.28	1.17	-	-
140	-	-	-	-		163	2.87	1.09	-	-
141	1.84	1.44	39	48.5		164	2.42	.61	82.3	11
142	-.64	2.05	17.5	73.5		165	1.17	.78	-	-
143	1.29	.67	-	-		166	-.03	2.24	47	41.5
144	1.69	.69	73.5	15		167	1.41	1.06	78.3	15.3
145	.96	1.05	-	-		168	2.09	1.28	-	-
146	-1.26	2.31	-	-		169	-	-	-	-
147	.54	1.01	-	-		170	1.91	1.63	-	-
148	-	-	-	-		171	2.62	.54	64.5	19
149	.96	.99	-	-		172	-.92	2.32	-	-

(continued)

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
173	1.04	1.01	-	-
174	2.77	.72	-	-
175	2.47	.92	69	15
176	3.01	1.14	-	-
177	3.06	.84	-	-
178	1.60	.79	-	-
179	1.47	.89	43	54
180	2.69	.76	52.7	29.3
181	2.79	.79	64.3	20
182	2.36	.70	63.7	12.7
183	3.38	.92	-	-
184	2.68	.74	-	-
185	2.57	.93	-	-
186	1.86	1.56	80	7.5
187	1.19	1.07	-	-
188	-	-	-	-
189	-	-	-	-
190	2.54	1.23	-	-
191	3.29	.95	69	10
192	2.83	.82	-	-
193	2.36	.53	-	-
194	2.46	.75	81.7	10.3
195	2.46	.51	74	10
196	2.64	.91	-	-
197	-	-	-	-
198	2.41	.49	-	-
199	2.27	.63	-	-
200	1.33	1.29	76	16.3
201	2.66	1.01	-	-
202	3.02	1.32	-	-
203	2.49	1.14	-	-
204	2.49	1.16	-	-
205	2.90	1.19	-	-
206	3.11	.82	-	-
207	2.73	.53	-	-
208	1.39	.87	-	-
209	2.02	.75	81	8
210	-	-	-	-
211	2.28	1.07	-	-
212	3.00	1.07	76.7	13
213	2.59	1.12	-	-
214	2.56	.63	-	-
215	1.96	.51	-	-
216	2.02	.42	-	-
217	1.01	1.07	59.3	26.7
218	.58	.53	-	-

(continued)

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics		Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
219	1.38	.74	-	-		243	1.77	.50	77.3	15
220	2.02	.62	-	-		244	1.78	1.00	-	-
221	2.66	.90	68	10.5		244B	2.15	1.03	-	-
222	2.27	1.10	-	-		245	1.65	.48	-	-
223	3.01	1.18	-	-		246	1.32	.36	76	6
224	2.00	.68	-	-		247	1.01	.34	-	-
225	2.61	1.64	76	12.3						
226	1.74	1.02	-	-						
227	2.25	1 08	-	-						
228	2.54	.90	-	-						
229	.91	.91	-	-						
230	1.40	.55	-	-						
231	.62	.73	-	-						
232	-	-	73.7	13						
233	-	-	-	-						
234	1.18	.61	82.3	11						
235	2.61	1.09	-	-						
236	.00	1.15	-	-						
237	1.86	2.53	-	-						
238	1.96	1.04	-	-						
239	1.61	.91	76	11						
240	1.57	.74	-	-						
241	-2.18	2.62	-	-						
242	1.09	.50	81	12.3						

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics		Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
7-74 DULUTH-SUPERIOR OFFSHORE										
CE-DS						21	2.93	1.07	-	-
1	1.85	.54	-	-		22	2.49	.89	-	-
2	3.92	.41	-	-		23	2.10	1.38	-	-
3	3.93	.54	-	-		24	2.12	.49	-	-
4	3.93	.74	-	-		25	2.02	.97	-	-
4B	2.66	.97	-	-		26	1.84	.93	-	-
5	3.86	.84	-	-		31	2.49	1.11	-	-
6	3.77	.66	-	-		32	1.62	.68	-	-
7	3.33	.62	-	-		33	1.94	.45	-	-
8	1.83	.68	-	-		H-1	2.09	1.35	-	-
9	1.78	.71	-	-		H-3	2.42	.72	-	-
10	3.38	1.15	-	-		H-4	2.50	.99	-	-
11	3.18	1.07	-	-		H-5	2.48	.88	-	-
12	3.18	.96	-	-						
13	3.70	.90	-	-						
14	3.42	1.11	-	-						
15	1.76	.79	-	-						
16	1.56	.63	-	-						
17	2.11	.64	-	-						
18	3.15	.97	-	-						
19	3.01	1.12	-	-						
20	3.79	1.08	-	-						
20B	3.05	1.11	-	-						

(continued)

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics		Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
OFFSHORE DULUTH-SUPERIOR September 1974										
CE										
19	2.97	1.25	-	-						
20	3.10	1.21	-	-						
21	3.00	1.22	-	-						
40	2.54	1.53	-	-						
41	2.80	1.42	-	-						

Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics	Sample no.	Mean Grain Size (Ø)	Sorting (Ø)	% Quartz	% Lithics
11-74 KEWEENAW BEACH PROFILING									
CE									
T1A	-.01	.45	-	-	R1-C	0.62	0.34	-	-
T1B	-.21	2.03	26	67	R1-D	-3.70	1.23	1	99
T1C	-.47	1.61	26.3	65.7	BH1-A	0.71	0.66	9	82
C1-A	.72	.79	-	-	BH1-B	-2.74	o.767	-	-
C1-B	1.10	.68	70.3	25	BH1-C	-1.01	1.54	2	94
C1-C	.68	.69	52.7	43.3					
M1-A	1.02	.60	-	-					
M1-B	1.48	1.09	-	-					
M1-C	1.44	1.24	-	-					
M2-A	-1.73	2.38	47	41					
M2-B	-2.61	1.42	-	-					
M2-C	-2.33	2.04	51.7	80.7					
M3-A	1.61	.53	-	-					
M3-B	.03	1.72	51.3	38.7					
M3-C	1.66	.86	-	-					
M3-D	-1.27	1.46	18.7	74.3					
PES1-A	-1.17	1.41	-	-					
PES1-B	-3.0	1.14	21.7	74.3					
PES1-C	-1.10	1.44	17	79.0					
R1-A	0.76	1.77	-	-					
R1-B	1.01	0.82	6.3	83.7					

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