GEOLOGIC REPORT ON SLEEPING BEAR DUNE NATIONAL LAKESHORE

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INTRODUCTION

This report is arranged in four sections which deal with, respectively, the bedrock, glacial, lake, and dune geology of the park. In each section discussions of the geologic history of certain features will be included in the belief that by doing so a better perspective can be gained of the feature importance. These discussions will introduce each section. Recommendations concerning various aspects of the park's geology compose the remainder of each section.

Very little mention of North Manitou Island will be made in the report. This is not because the island necessarily lacks valuable, geologic features, but, rather, because access to the island was refused by the chairman of the board of trustees that regulates North Manitou. Thus, only the most superficial observations can be made concerning the island.

BEDROCK GEOLOGY

Introduction

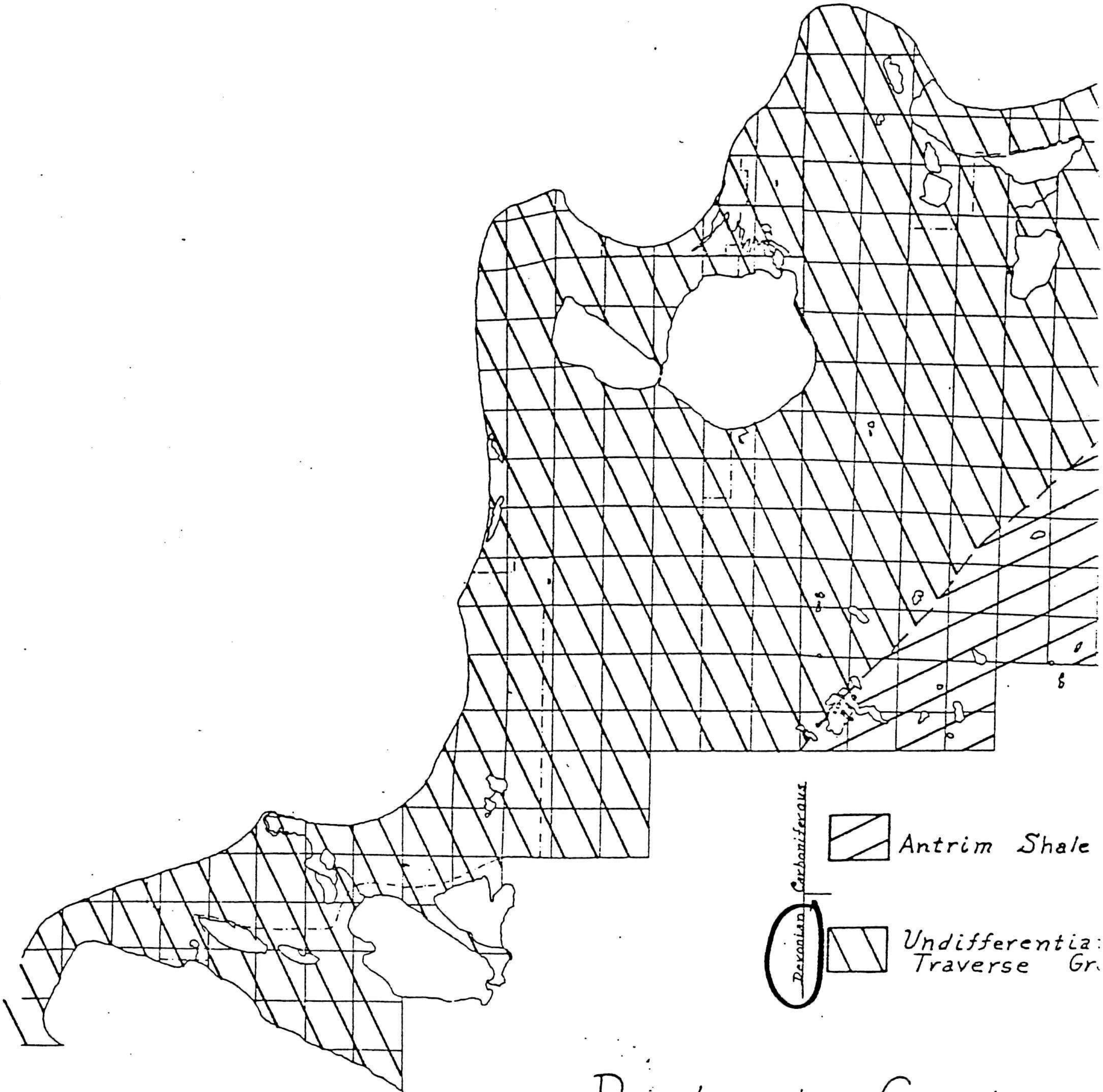
Figure 1 shows the bedrock geology of the park. Undifferentiated Traverse Group underlies all the park land including North and South Manitou Islands. Bedrock does not outcrop anywhere in the park because of a thick cover of glacial and lacustrine sediments.

Economic Importance

Recent drilling for natural gas near Williamsburg, east of the park, has encountered problems with gas escaping into a porous dolomite zone in the Traverse Group, followed by its uncontrolled escape to the surface. Safety precautions implemented after the Williamsburg accident have made it unlikely that a similar mistake could arise if drilling began near the park.

The wells drilled near Williamsburg penetrated gas-bearing pinnacle reefs in Silurian age rocks. These reefs grew along the rim of the Michigan basin at that time. Commonly, isolated pinnacle reefs occur on shallow shelf areas behind the main reef mass. In Silurian time such a shallow shelf environment existed where the park is today. Reef building happened again in this general area during Devonian time. It is not unlikely, then, that gas or oil may occur in economically important quantities beneath or adjacent to the park.

Besides vast quantities of sand, gravel, and poor quality clay, natural gas and oil are the only resources that could occur in economically important amounts within the park.



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Bedrock Geology

Figure 1

GLACIAL GEOLOGY

Introduction

The surficial deposits within the park boundaries were all formed during and after the last major ice advance in Michigan. This advance, assumed to be the Valders, pushed to its southern limit in the Lake Michigan basin about 11,800 years ago. The southernmost moraine built by this ice extends across the floor of Lake Michigan from Manistee on the Michigan side of the lake to Two Rivers on the Wisconsin side. During most of the advance and subsequent retreat of the Valders ice a large glacial lake (Lake Algonquin) filled the Lake Michigan basin south of the ice front. Water from this lake drained southward through the Chicago outlet. Bedrock on the outlet's floor maintained the elevation of Lake Algonquin's surface at a nearly constant 605 feet Thus as the Valders ice retreated northward up the Lake Michigan basin, low-lying land adjacent to the basin was drowned by the waters of Lake Algonquin. In the park, shore features of this lake occur at about 620 feet, or 15 feet above their elevation at Chicago. This increase in elevation results from crustal rebound following removal of the thick ice load.

Lake Algonquin was succeeded by several, shallower lakes in the Lake Michigan basin as the retreating ice uncovered new, lower outlets to the north that drained eastward across southern Canada to the Saint Lawrence valley. The period of low water in the upper Great Lakes ended when crustal rebound had elevated the northern outlets sufficiently that the old southern outlets began functioning again. A new, deep lake formed with its shoreline at 605 feet. The lake, Lake Nipissing, included the Huron, Michigan, and Superior lake basins within its boundaries. Erosion of the outlet, passing what is now Detroit, eventually lowered the water surface in the upper great lakes causin detachment of Lake Superior from Lakes Michigan and Huron and thus to the Gre Lakes as they are today.

Deglacial History

Figures 2 through 13 show successive stages in deglaciation of the park following the Valders advance. This series of figures was constructed from field notes and the study of soils maps, and various topographic features including outwash fans, arcuate arrangements of kettle depressions, ancient dra age channels, and wave planed surfaces and notched shorelines of former lakes

In general the figures show Valders ice retreating northwestward into th Lake Michigan basin. During this retreat Glacial Lake Algonquin was ponded south of the ice in the Lake Michigan basin. Its waters inundated low lying areas adjacent to the basin. Thus as the ice retreated the embayment containing the Platte lakes, then the one at Empire and finally the Glen Lake basin were flooded to a depth of about 620 feet to become bays of Lake Algonquin. Lake Leelanau also became a bay of this lake. Its waters extended south to th site now occupied by the town of Solon and about a mile and a half west of the town of Cedar.

Before the Platte lakes embayment was deglaciated, however, a second, rather large, lake began forming east of the Glen Lake depression (Figures 2-7 Eventually this lake extended from an ice dam in the Glen Lake basin eastward past the southern portion of Grand Traverse Bay and into the lowlands lying north and east of what is now Traverse City. The lake was dammed on the south

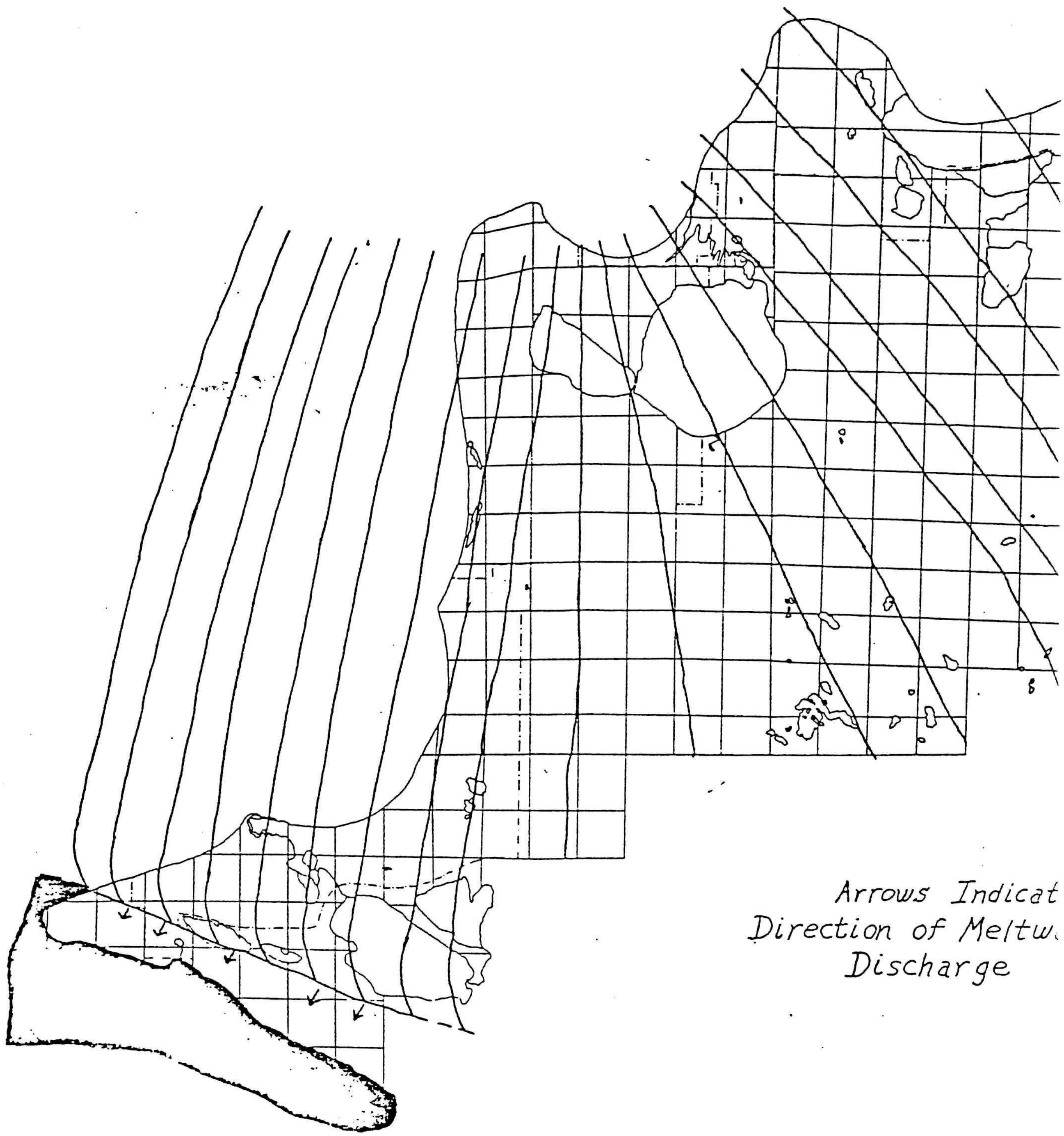

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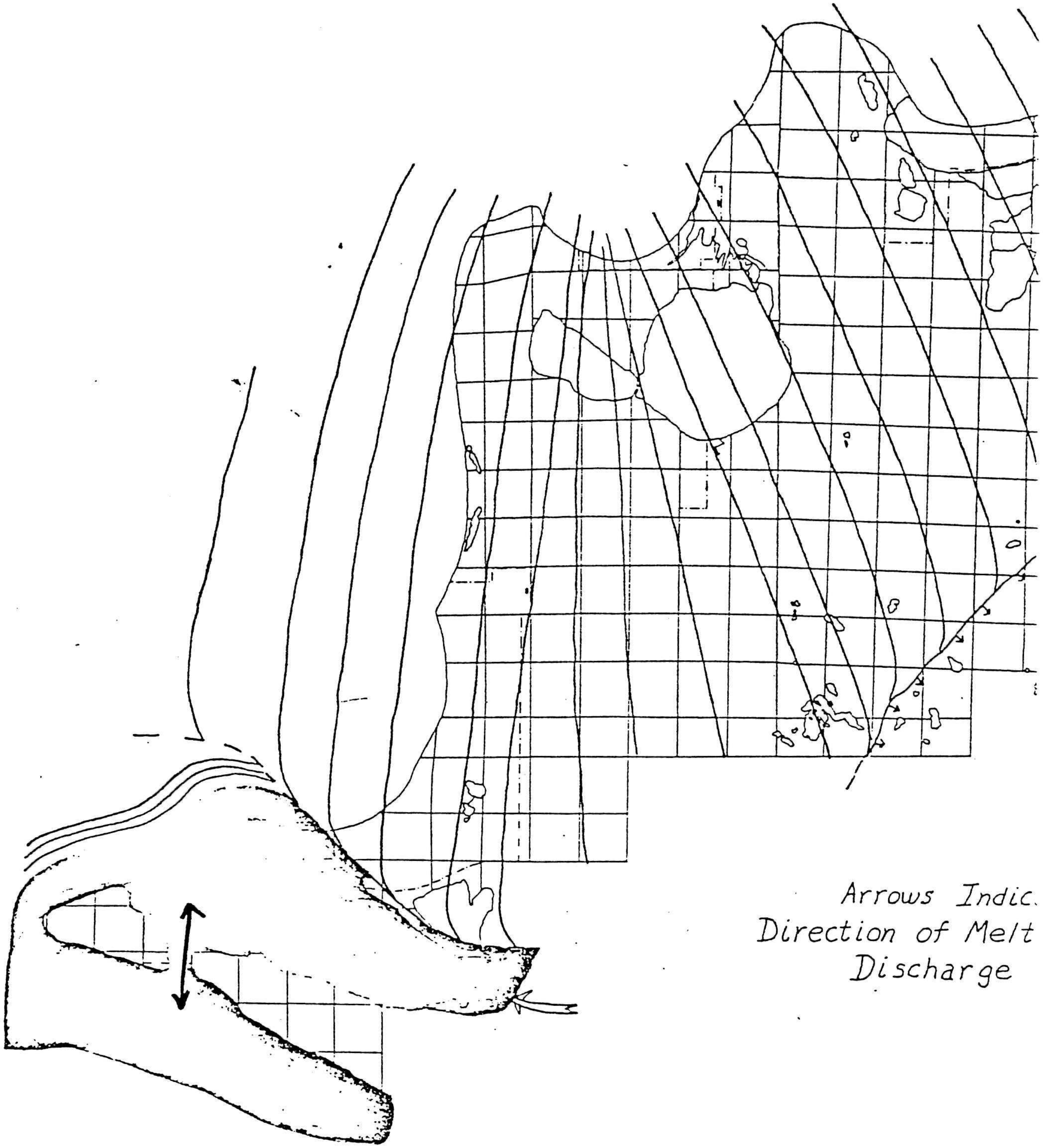
Figure 2



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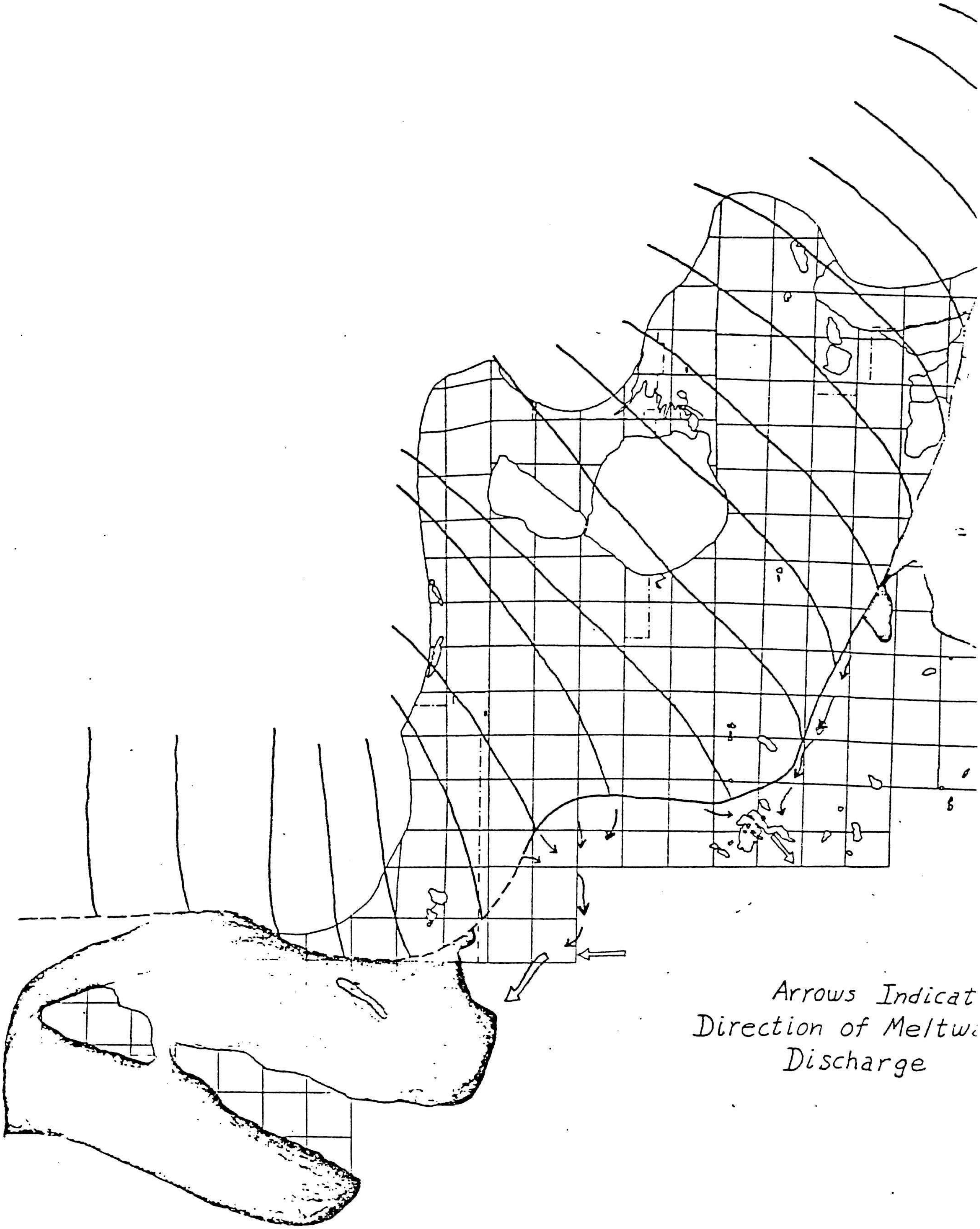

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Figure 4

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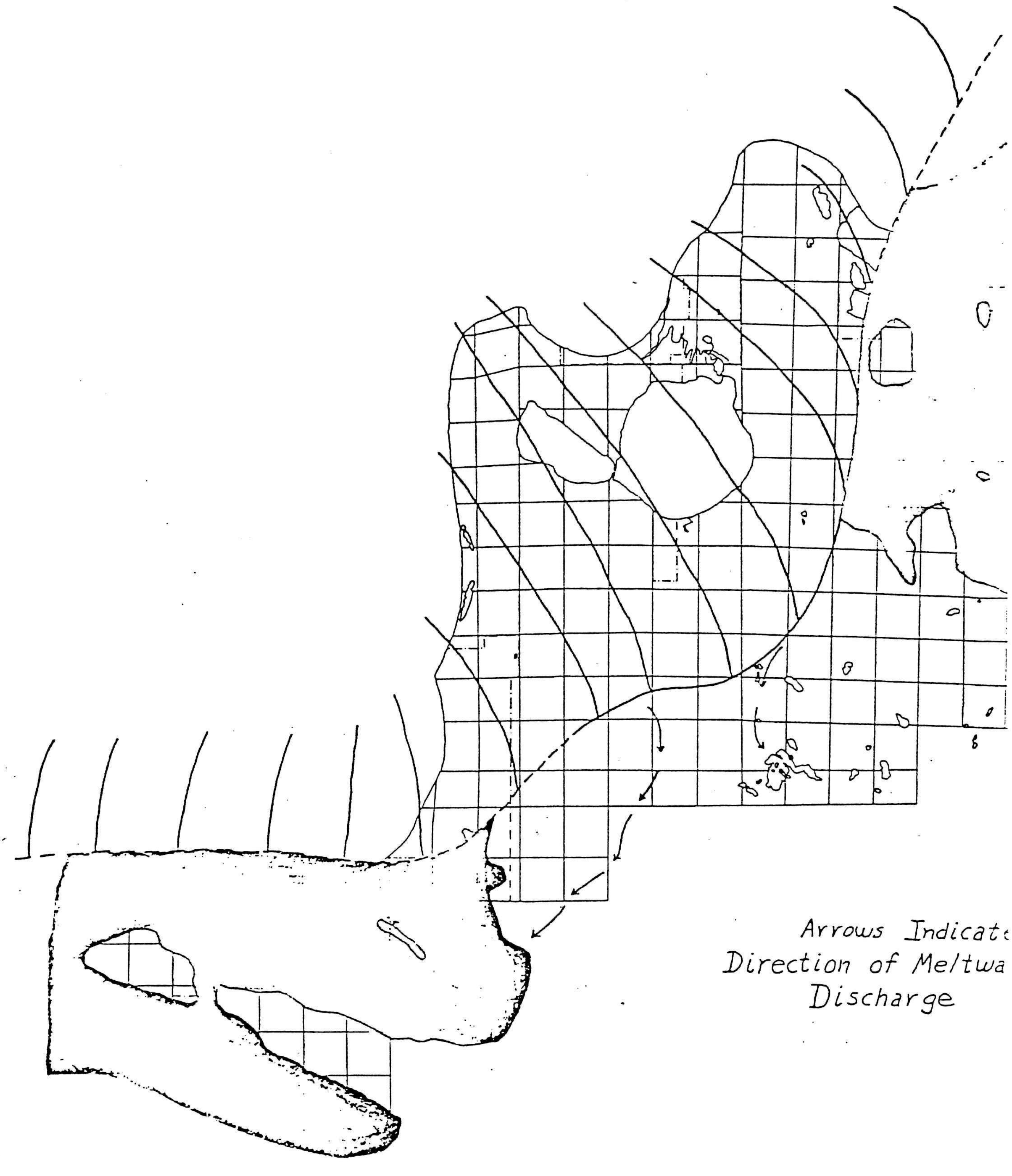

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Figure 5

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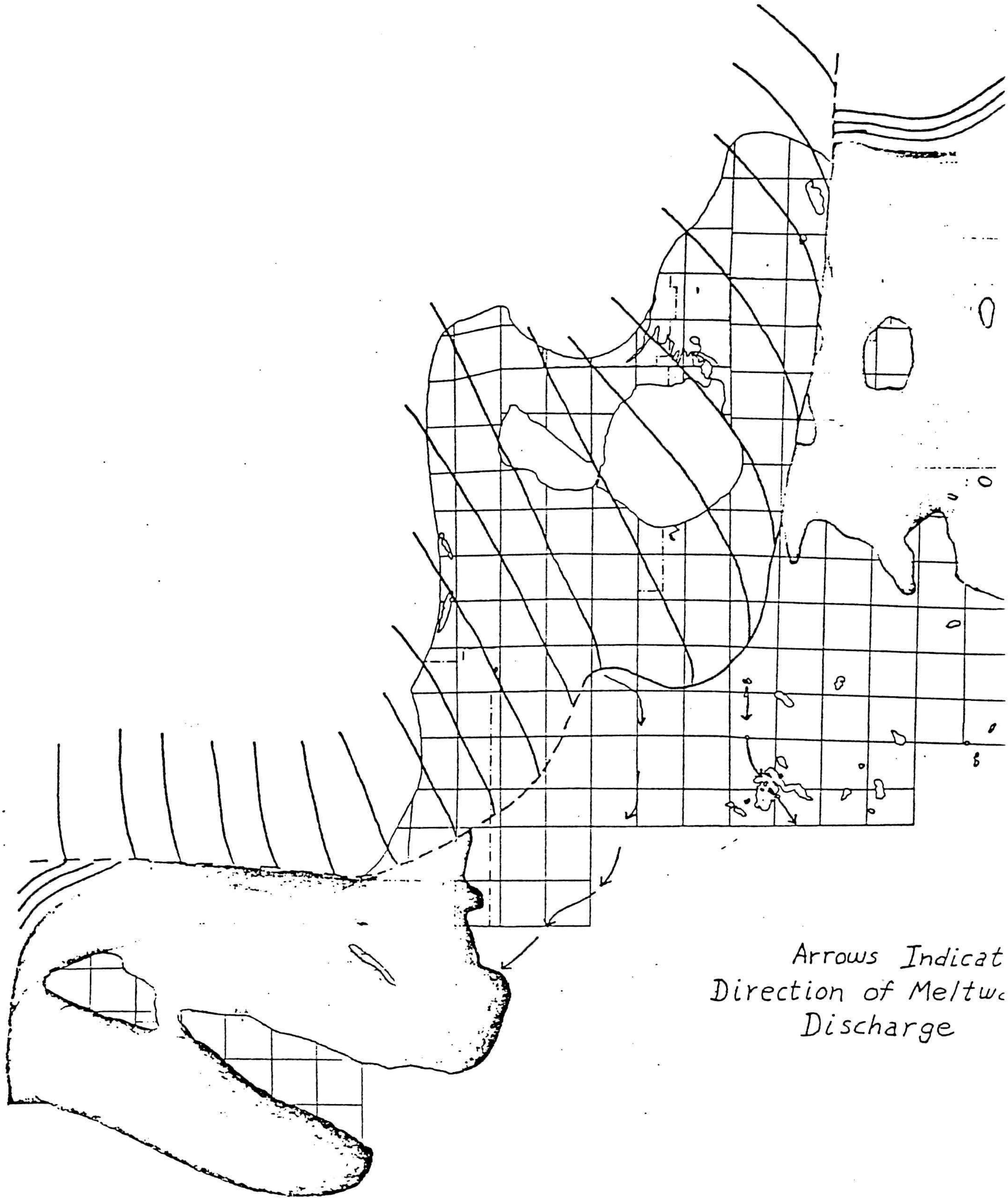

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Figure 6

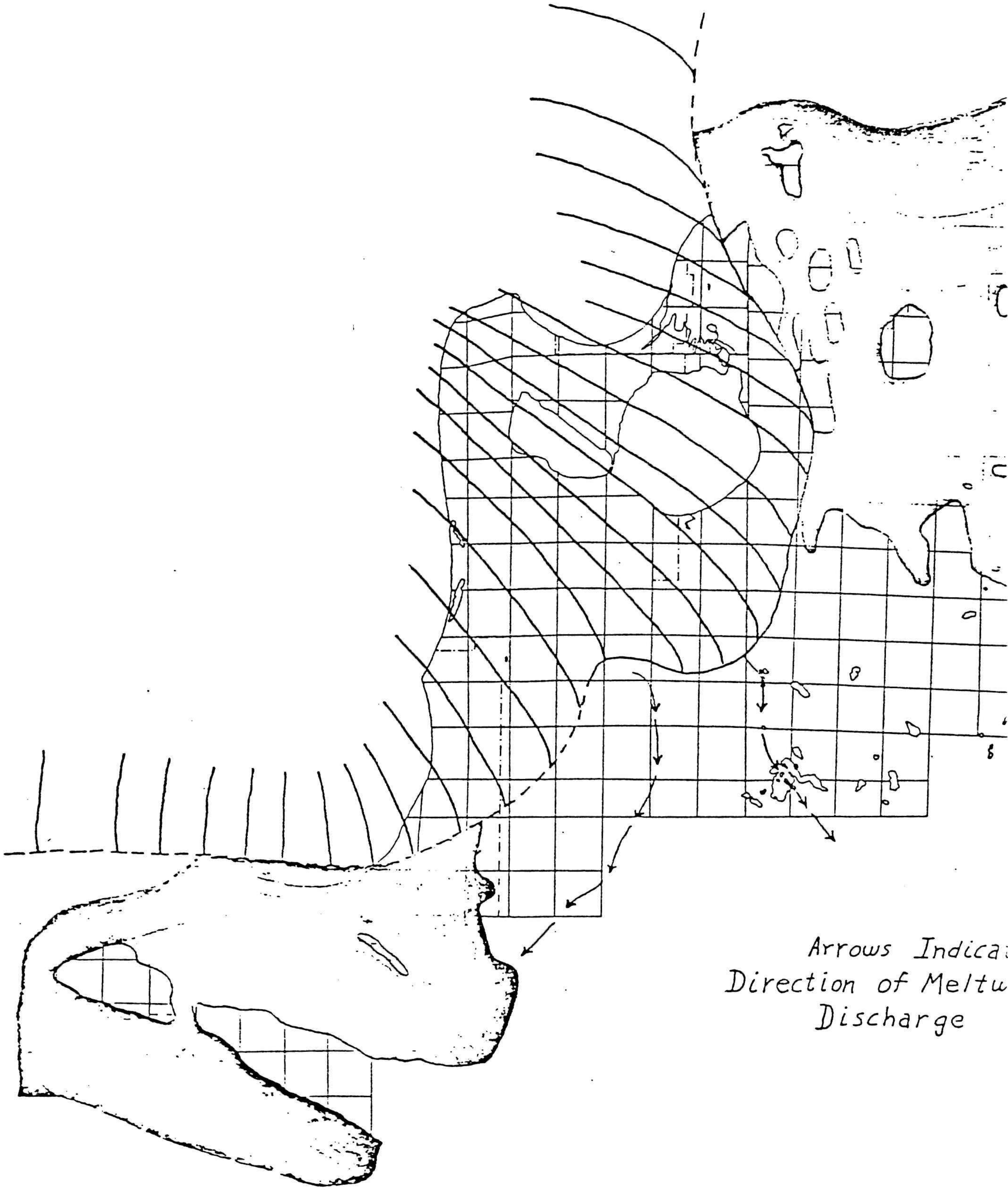

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Figure 7

and east by high ridges of glacial drift. Ice formed the northern and weste: sides. The lake's outlet apparently consisted of multiple channels that led southwest from the lake, mostly confined to the flat area between the towns c Lake Ann and Interlochen. The divide in these channels is between 860 and 8: feet.

This lake continued expanding as the Valders ice retreated northwestwarc into the Lake Michigan basin. Many of the high hills that were islands in th lake have well developed notches in their flanks cut at about 860 to 880 feet Below the notches there is widespread evidence of topographic smoothing by wave planation. Close agreement between the elevation of the wave-cut notche and that of the outlet divide demonstrates both the position of the lake's outlet and the extent of the lake.

The lake continued to expand until the Valders ice had retreated into th Glen Lake basin (Figure 8). Further retreat of the ice exposed two low sags on the basin's east rim to the ponded waters of the lake. Today the southern most sag can be seen extending due east from Burdickville. It contains a pav road on its floor. The northern sag runs west-northwest across the basin rim to interest Brooks Lake. These two sags passed a flood of water from the lar eastern lake westward around the southern tip of the ice lobe in the Glen Lak basin. Then the torrent turned south and flowed along the front of the Valde ice still lying in the Lake Michigan basin. It scoured a channel along this front for about eight miles before entering Lake Algonquin (Figure 9).

Rapid erosion of the southern channel quickly lowered the water level in the eastern lake. This, in turn, led to abandoning of the northern channel.

When th ..thern channel's floor stood at about 820 feet, the ice freed

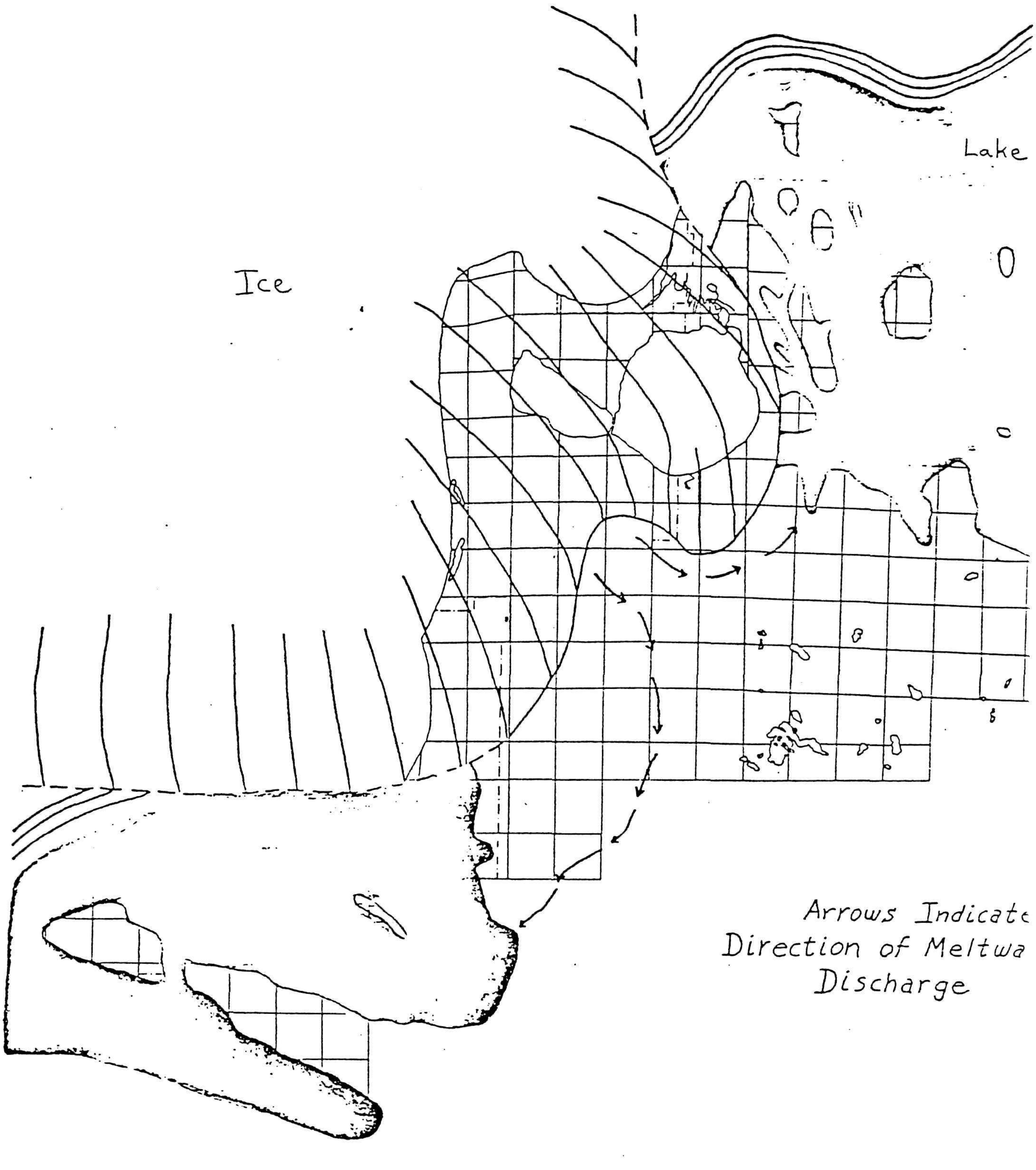

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Figure 8

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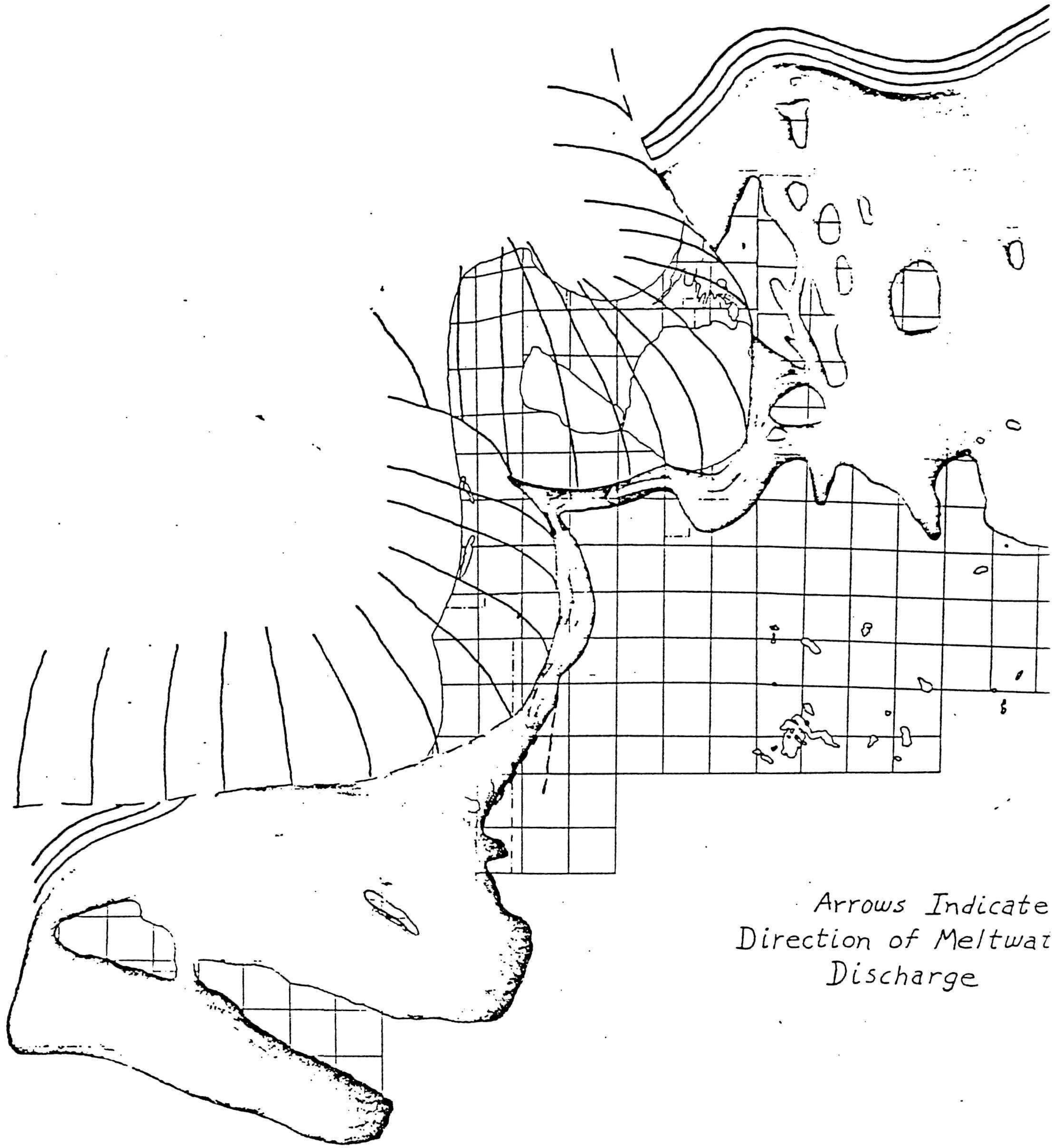

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Figure 9

the southern end of Glen Lake. From what is now the southern end of the causeway across Glen Lake, the lake water flowed southwest nearly to the present site of Empire. But an ice tongue still protruded into the embayment there so that the drainage was again forced eastward where it cut a large semicircular channel as it flowed south from Empire to the present day Leelanau-Benzie county line. At the county line the water turned sharply south-southeast and flowed past the present site of the Lighthouse Tabernacle before entering Lake Algonquin in the vicinity of Otter Lake (Figure 10).

The next significant change to the outlet channel occurred when the Lake Michigan ice lobe that had been plugging the Empire embayment retreated enough that drainage flowing southwest from the Glen Lake basin could enter Lake Algonquin at the present site of Empire. Thus the portion of the channel south of Empire was abandoned (Figure 11). This event occurred when the southern channel on the east rim of the Glen Lake basin had been lowered to about 780 feet.

Downcutting in the southern channel essentially stopped at 725 feet. For a short time, then, a lake developed in the Glen Lake basin whose surface stood at this elevation. The lake lasted as long as there was an ice dam along the north edge of the basin.

Figure 13 shows the 725-foot lake being drained after the Two Rivers ice retreated far enough to open a low outlet at the northwest end of the basin.

At about the time that this channel opened up the ponded water east of Glen Lake began draining westward through a new channel just east of Prospect Hill. Drainage of the ponded water was apparently shared by the new channel and the older, southern channel. Continued glacial retreat soon exposed the

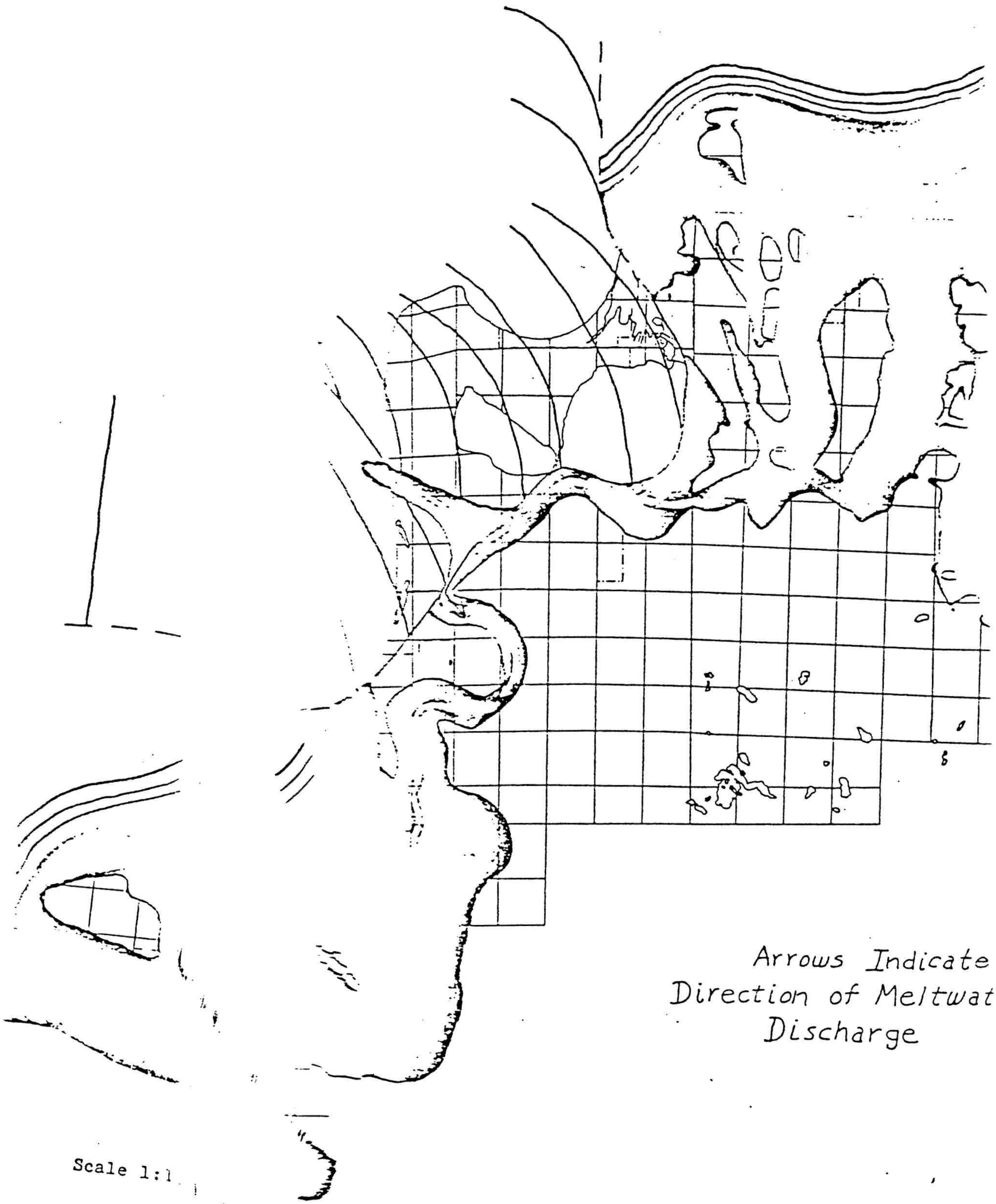

Figure 10
820 ft'

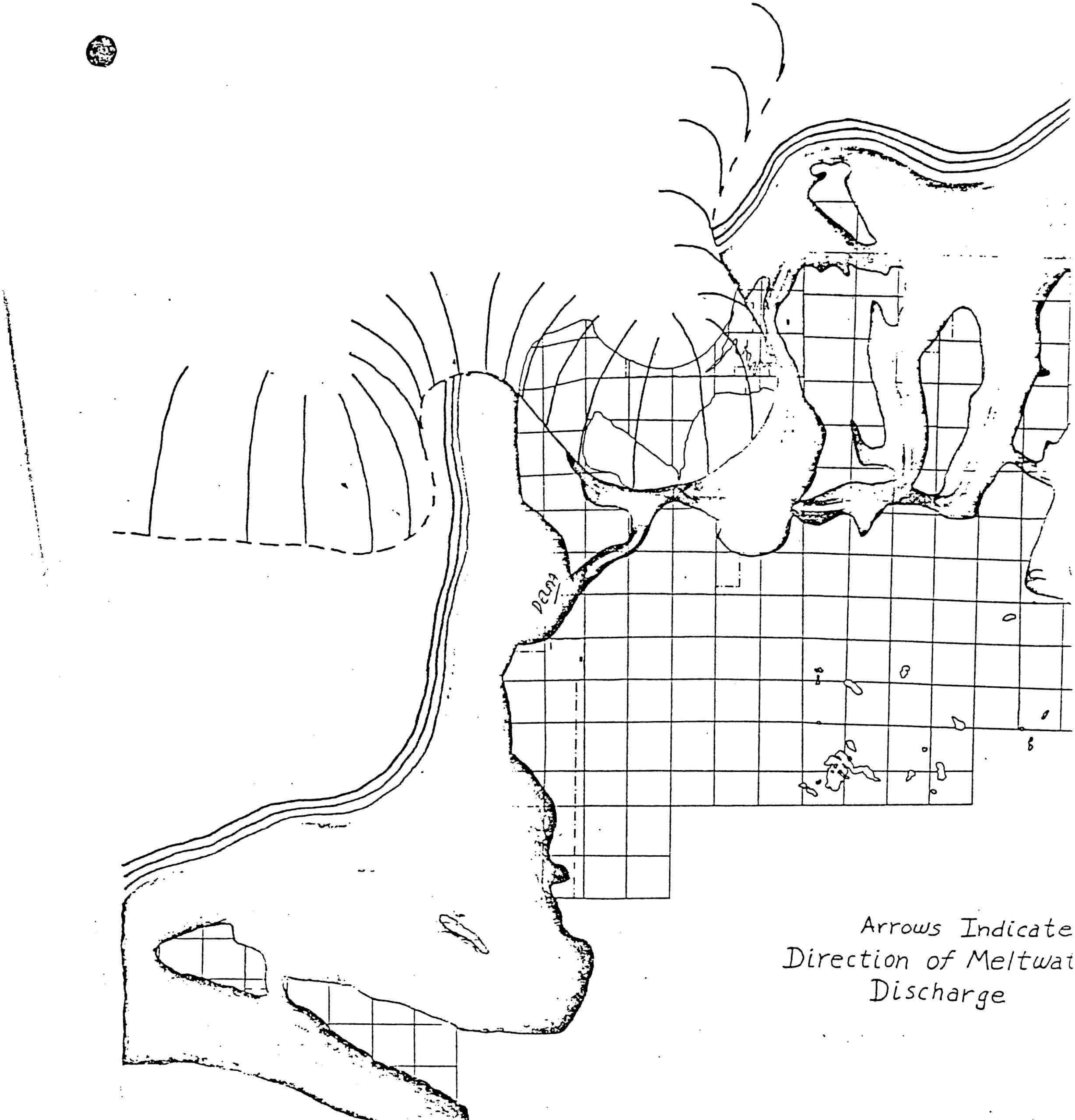

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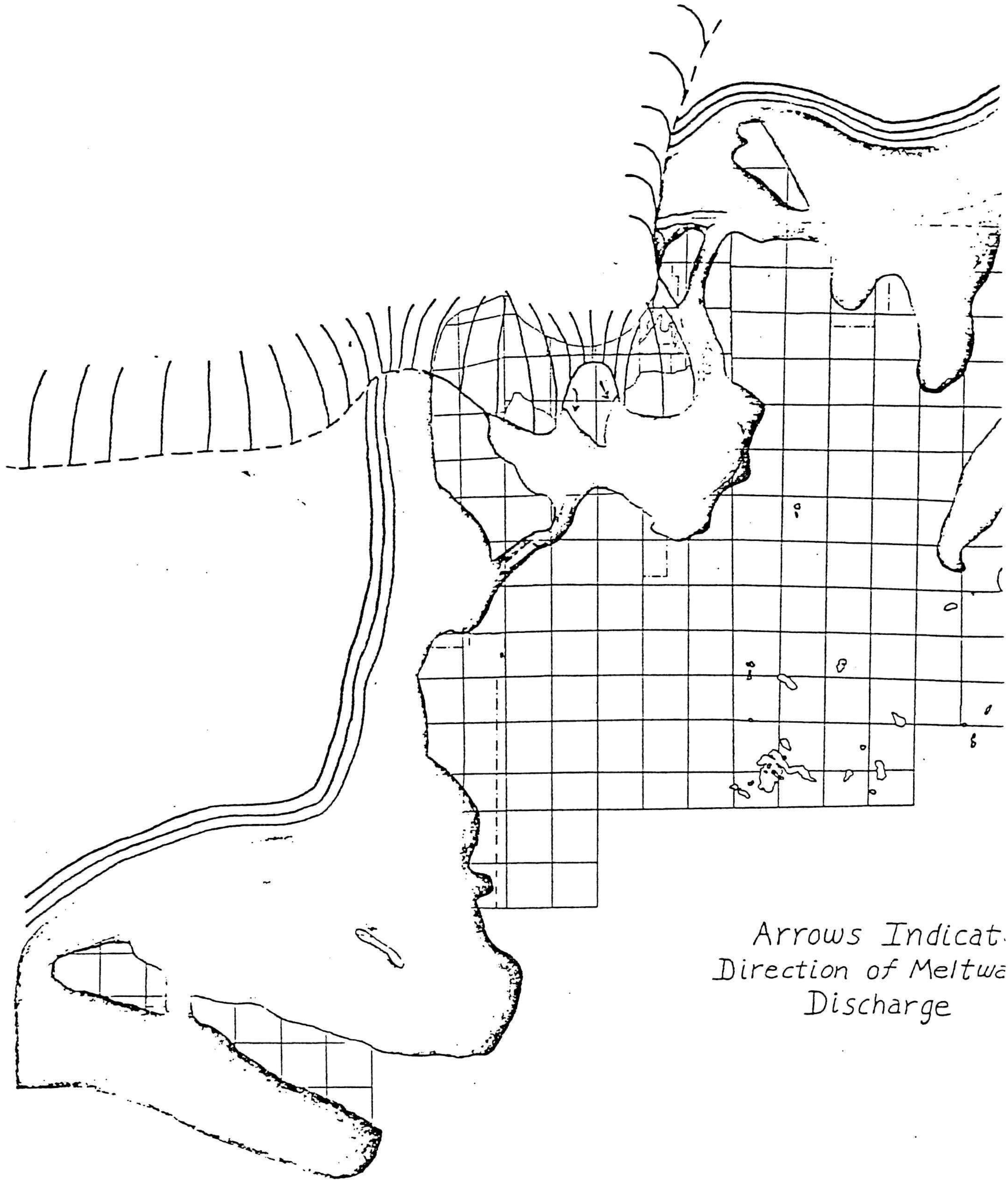
Figure 11
760 ft



Arrows Indicat
Direction of Meltwa
Discharge

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Figure 12

6 5 %

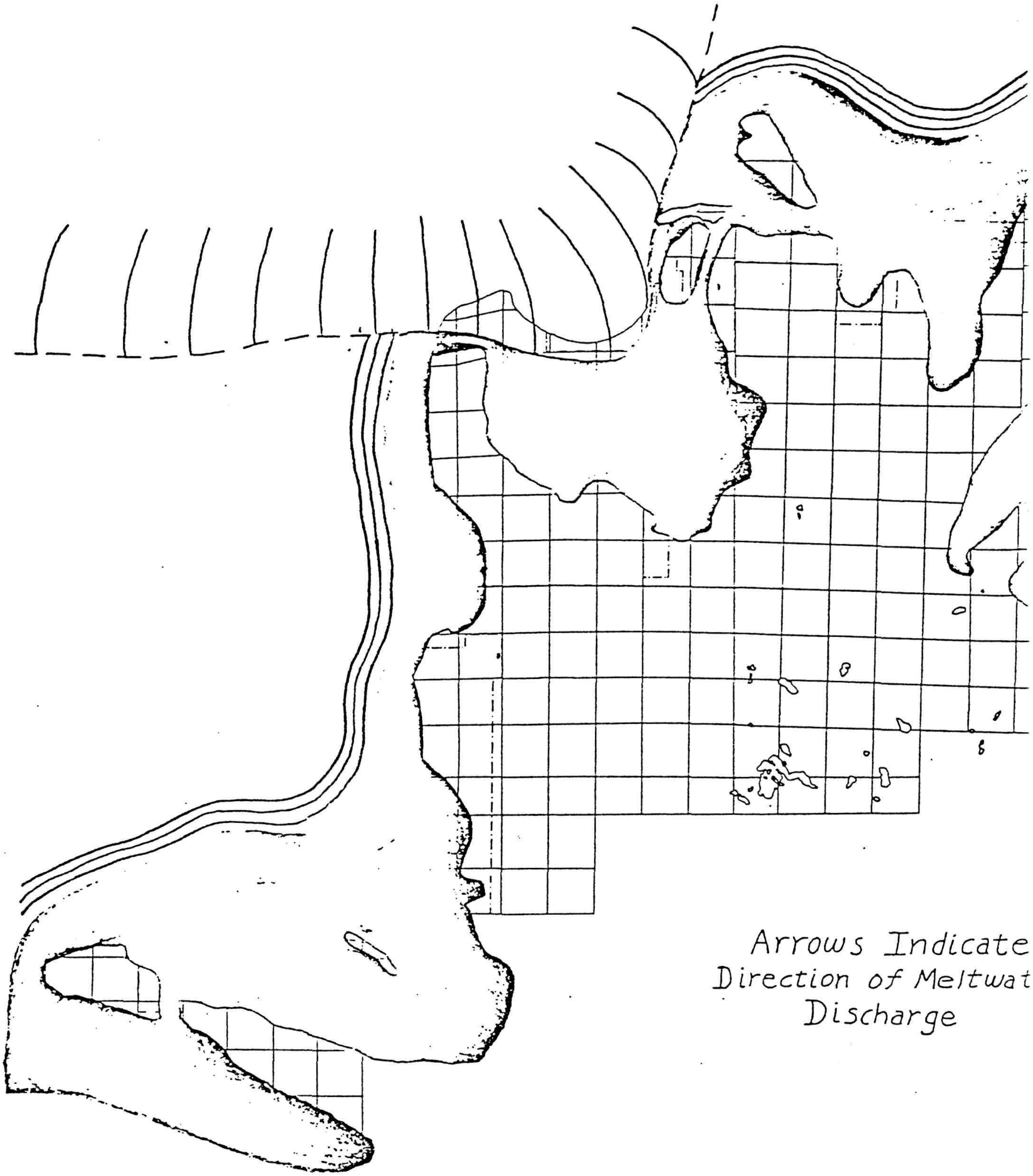

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Figure 13
725 ft

lowland of the present basin of Lake Michigan causing the ponded water east of Glen Lake to abandon the two channels through the outwash fan and instead flow directly along the ice front.

A minor readvance apparently occurred soon after the complete deglaciation of the Glen Lake area. The ice during this advance apparently overrode very little of the mainland, at least in the Glen Lake area. A small outwash fan was built by this ice south of Glen Haven (Sec. 19, 20, and 29 of T29N, R14W and Sec. 24 of T29N, R15W). Also at this time ice apparently rode up against the northwestern side of Pyramid Point. As the ice rode south, meltwater which had originally flowed west passed what is now Point Oneida became blocked and diverted southward. Initially the water spilled through the old southern channel and the newer one near Prospect Hill. The newer channel at first contained a bifurcation (visible in the center of Sec. 12 of T29N, R14W) with part of the water flowing south-southwest through what is now the dry channel carrying highway 22 northeast from Prospect Hill and the remainder flowing northwest from Section 12 into Section 11 where the flow turned more than 90 degrees and passed south-southwest back toward Glen Lake. Downcutting in the east branch of this channel (perhaps accompanied by glacial damming of the west branch) led to the old southern channel and the western arm of the northern channel being abandoned.

At the maximum extent of this ice readvance the northern rim of the Glen Lake basin was again ice dammed. The water level in the basin again rose to 725 feet, with overflow passing southwestward to the Empire Embayment.

Glacial retreat began soon after the readvance reached its terminal position. The [illegible] level in the Glen Lake basin again dropped to that of Lake

Algonquin and the northern drainage channel was abandoned for the last time.

Not long after the mainland portion of the park was completely deglaciated the retreating Two Rivers ice paused long enough to deposit the high outwash fans that presently form the west sides of North and South Manitou Islands. After this episode of deposition glacial ice did not again advance over any portion of what is now the park.

RECOMMENDATIONS IN RELATION TO GLACIAL FEATURES

Because the geologic processes that formed the land surface of the park are both huge and compound there are very few areas where one can stand and observe more than a small, disjoint segment of the geologic history. One exception is the high, sandy bluff between the dune sliding portion of D. H. State Park and the privately owned Sleeping Bear Dune Park. From this bluff top one can view both the inlet to and outlet of the 725-foot lake that once existed in the Glen Lake basin. Also just north of the causeway across Glen Lake a very deep notch was cut into the high outwash fan by the waves of this lake. The notch, too, is visible from the vantage point of the high bluff. Looking north-northeast from this point to where highway 109 cuts through the low outwash fan just south of Glen Haven, more (although somewhat subtler) evidence for the existence of the 725-foot lake is visible. Along the south face of this fan the topography changes abruptly at about the 725-foot level. Below that elevation hill slopes are gentle and very few valleys can be seen. Above that elevation hill slopes are steeper and well developed valleys appear. This area displays particularly well the pronounced smoothing effect that waves in the lake had upon the topography.

Several other interesting but more disjoint portions of the park's geologic history can also be viewed from this high bluff. (1) To the southeast of the causeway across the lake a wide, flat platform having an elevation of about 860 feet and bordered on the south by higher, irregular ground preserves rather impressive evidence for the erosive energy of flowing water. This platform was scoured during the initial outpouring of lake water from the high, eastern [illegible] [illegible] platform however is not as clearly seen as the shoreline notch [illegible] youngest outwash fan [illegible]sed above. This is primarily so because [illegible] former is somewhat obscured by its forest cover while the latter is [illegible] mainly by grasses making [illegible] but the finest detail visible. (2) A por[illegible] [illegible] the channel joining the [illegible]est arm of Glen Lake and Lake Algonquin is [illegible]le from the bluff. An [illegible]ndoned, narrow gauge railroad grade betw[illegible] [illegible] Lake and Sleeping Bear [illegible] follows the channel floor for part of its [illegible] past the youngest outwash fan. Now much of the western end of this cha[illegible] [illegible] buried beneath dunes. [illegible] For persons unfamiliar with the thickness [illegible] [illegible] glacial ice can accumulate the vista from the high bluff affords a [illegible] contrast in elevations between the high outwash fans rimming the Glen [illegible] [illegible] and the lake surface itself. With this relief for a scale it becomes [illegible] easy to visualize the [illegible] Lake basin filled with an ice tongue that [illegible] [illegible] one time over twice as high as the highest hills bordering the [illegible]

A second [illegible] [illegible] geologic importance is th[illegible] sinuous drainage channel that extends south-[illegible] from the Glen Lake cau[illegible]ay, past Empire, Old Baldy Dune and the L[illegible]e Tabernacle and eventua[illegible] ends in the Platte lakes embayment. Th[illegible] [illegible]el is best seen from the [illegible]ved road that connects Empire and the Glen L[illegible] [illegible]eway and from the portio[illegible] [illegible] highway 72 east of Empire that utilizes [illegible] [illegible]nel floor as a roadbed. [illegible]hway 22 south of the Empire Air Force Stat[illegible] [illegible] runs along the channel [illegible] but here the low surrounding hills [illegible] [illegible] channel's considerable [illegible] do not combine favorably to create a str[illegible] [illegible] convincing visual impre[illegible].

Third[illegible] [illegible] [illegible] an important, late gla[illegible] meltwater channel preserved in the northeast quarter, Section 29, T29N, R14W on farmland owned by Pierce Stocking. The channel lies adjacent to and parallels, approximately, the eastern edge of the farm. It begins at the crest of the outwash fan (at 670 feet elevation) and slopes south-southwest into the meadow east of the farm buildings. There are two terrace levels at the channel's mouth, the lower one graded to the 620-foot Lake Algonquin level in the Glen Lake basin while the upper one is graded to a level 20 feet higher. The channel thus demonstrates that glacial ice still rested against the latest formed outwash fan after the water level in the Glen Lake basin had fallen to that of Lake Algonquin. This also must mean that the connection between the Lake Michigan and Glen Lake basins had to have been across Sleeping Bear Point. The park would lose an important asset if future development disturbed the excellent state of preservation characteristic of much of the length of this channel.

Finally, there are a few rather impressive kettle holes within the park boundaries. The best of these is actually a double kettle hole found in the northeast quarter, northwest quarter, Section 15, T28N, R14W. The steep walls in the larger of the two holes are well preserved except where an abandoned road has cut across a portion of the southeastern wall. Two other interesting kettle holes are found in the northwest quarter, Section 14, T28N, R14W.

The most spectacular kettle in the area lies outside the park proper, although it is included within the land proposed to be used for the parkway and park buildings. This depression occurs in the center of Section 23, T28N, R14W. It is over 100 feet deep and its floor and sides are almost perfectly preserved. Here, as with most of the steep sided kettle depressions, some boulders and trash have been rolled in.

If the public should acquire ready access to these kettle holes, steps will have to be taken to prevent their otherwise rapid destruction. All the kettles are developed in loose sand and, accordingly, even minor amounts of climbing on their walls will quickly alter their well preserved shapes.

West Lake Leelanau Drumlin Field

A large area in northeast Leelanau County is covered with drumlins. The park's eastern boundary, however, stops about a third of a mile west of the westernmost drumlin. Also those drumlins nearest the eastern park boundary have for the most part been extensively altered by waves of the deep lake that covered most of that area. Brief examination of topographic maps of the drumlin field seem to show that the drumlins were formed by a brief readvance of the ice which overrode and partially destroyed earlier, glacial features. What appear to be overridden outwash fans and adjacent drainage channels may be seen in the area of Schomberg, two and a half miles east of Little Traver Lake. If this is so then the readvance that molded the drumlins occurred after the Valders maximum.

LACUSTRINE GEOLOGY

Introduction

The earliest evidence in the park for the existence of a large lake in the Lake Michigan basin is found in the thick deposits of laminated, red silts and clays that compose the cores of several hills. Good exposures of these laminated lake deposits occur in the wave-cut cliffs on Pyramid Point and South Manitou Island. Poor exposures are also found on Sleeping Bear Point. Other occurrences in the region were noted by Leverett (1915, p. 314) from Frankfort nearly to the straits of Mackinac.

The deposits probably formed in a late Wisconsinan lake that existed in the basin prior, at least, to the Valders advance. At that time incomplete crustal rebound in the Sleeping Bear area would have assured partial to total submergence of the present day park land beneath the waters of a glacially dammed lake.

The next lake in the Lake Michigan basin for which there is geologic evidence was Lake Algonquin. Figure 14 shows the extent to which Lake Algonquin inundated the present park land. Because this lake only lasted for about 700 years after the Valders ice retreated from Sleeping Bear Point, and because erosion and slope wash have had about 10,000 years to alter the topography since the lake disappeared, its geologic record is not as complete as that of the next deep lake to fill the basin.

Even so a rather detailed record of the lake's presence still remains. Around the entire periphery of Glen Lake can be traced the 620- to 630-foot upper shoreline of Lake Algonquin. Where the shoreline is represented by an

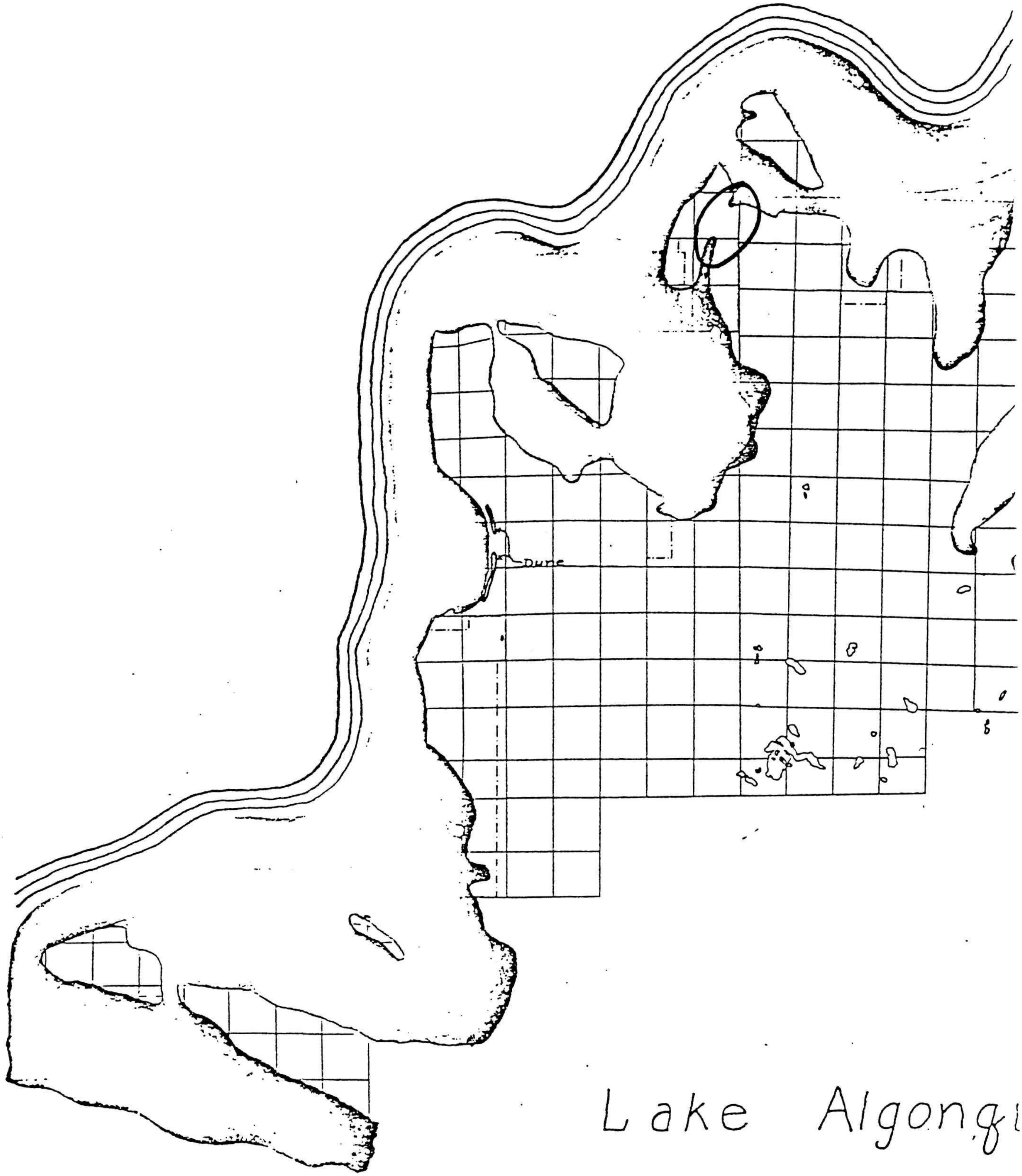

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Figure 14

P.27

offshore bar it is commonly developed to a height of 3 to 4 feet and usually displays quite well its asymmetric cross section (with the steeper side facin offshore). Three to four lesser Algonquin beach ridges normally occur below the highest one. They are seldom well developed, however.

Other geomorphic evidence for the existence of this lake can be seen in the longitudinal dune developed at the back of the Empire embayment (Figure 1 and in the numerous, small valleys graded to its shoreline.

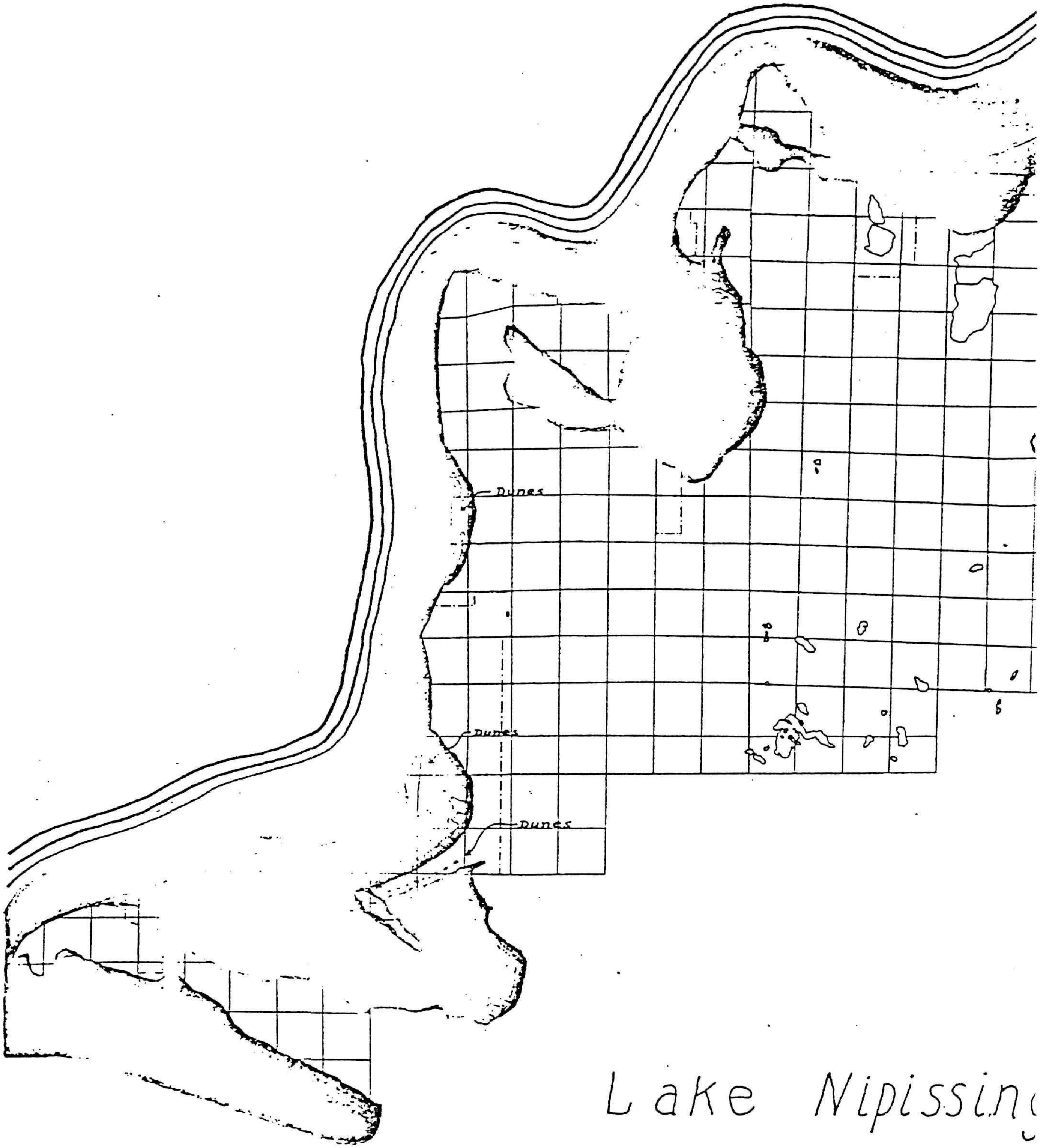
The longitudinal dune is the only one in the park certainly of Algonquin age. Its shape contrasts sharply with that of the later Nipissing dunes. They are only represented as parabola-shaped dunes, indicating that they have migrated leeward from their spot of origin. The Algonquin dune, however, sti preserves well the longitudinal shape it developed while accumulating sand to the lee of the beach. This dune experienced almost no migration until recent years.

Many of the hill slopes facing Glen Lake have numerous, small valleys on them which clearly are graded to the Lake Algonquin beaches. Very few of these are meltwater channels. All earlier lakes in the basin were so short lived that water channeling (other than by meltwater) did not have time to develop.

As the Wisconsinan ice finally retreated out of the Lake Michigan and Lake Huron basins, the earlier southern outlets of the glacial lakes in these basins, located at Chicago and Port Huron, were abandoned in favor of lower outlets to the north. The primary northern outlet was through an extinct bay in the Huron Basin, into the Ottawa river and finally into the salty St. Lawrence Sea. [illegible]s lower lake stages developed in both the basins. Ultimate the water level in the Lake Michigan basin dropped to about 350 feet below the present level of Lake Michigan (Hough, 1955) or to an elevation of about 230 feet. This low-level lake has been given the name Lake Chippewa. The low-water stage began about 10,000 B.P., and passed through its lowest level Lake Chippewa, at about 7,500 B.P. Due to the continual crustal rebound in the north, the southern outlets once again became functional and Lake Chippewa gave way to the rising water level of the Nipissing Lake stage about 5,000 B.P. (Hough, 1966). Only a very incomplete geologic record of the low-water interval can be found within the park. Some authorities believe one consequence of the low-water interval was the universal development of far traveled parabola-shaped dunes along the Nippissing shoreline. These dunes are thought to have migrated in front of the rising water, thus accumulating large amounts of sand and losing their initially longitudinal shape. A second effect of the low-water stage would have been to join North and South Manitou Islands with the mainland, thus destroying the previous barrier that had existed to the unrestricted exchange of plants and animals between the islands and the mainland.

Figure 15 shows the extent of the Nipissing inundation. Less area was flooded than during Algonquin time mainly because crustal rebound had elevated the area about 20 feet since deglaciation. Very little uplift has occurred in the area of the park since Nipissing time.

Several interesting geologic features originated during the Nipissing lake stage. (1) Glen Lake became isolated from the Lake Michigan basin by the formation of a bay mouth bar between Prospect Hill and the highland south west of Glen Arbo[illegible] he town of Glen Arbor is built on this bar. (2) High



Lake Nipissin

Scale 1:153,043

Figure 15

dunes were deposited at the mouth of the Empire embayment on top of what was probably an Algonquin bar. These dunes are now forested and form the hills between North Bar and South Bar Lakes. (3) High dunes migrated onto the surface of what probably is an Algonquin age bar just west of where Bass and Otter Lakes and Otter Creek are today. These dunes have, since then, been periodically remobilized so that they now appear as a disperse group of high, parabola-shaped hills spread across the bar's surface. Currently the western most of these dunes have lost their vegetation cover and are again migrating. (4) A bar developed from a headland between the present Platte and Little Platte Lakes to the Algonquin wave-cut cliff east of Bass Lake. Low dunes developed on the surface of this bar. Presently the bar forms the northwest side of Little Platte Lake. (5) A second bar developed from the headland west-northwest of the present day Long Lake. It grew east-southeast as far as the present day Birch Point in Platte Lake. The growth of this bar served to isolate a finger of deep water between the bar and the high hills north of Crystal Lake. The lowering water level in the Lake Michigan basin at the end of the Nipissing lake stage separated this finger of deep water from the main lake. Today Long Lake and Rush Lake lie along the axis of the former finger of water.

The Nipissing lake stage ended prior to 3,500 B.P. Its termination was caused by the abandonment of the North Bay outlet, due to further crustal rebound and to erosion at the Saint Clair River outlet making it lower than the Chicago outlet which also was abandoned (Hough, 1966). From this time until 3,000 B.P. the water level in the Lake Michigan basin lowered slowly in response to the continued downcutting at the outlet. A pause in the lowering occurred when the water level reached 595 feet. This pause has received the name Lake Algoma. Within the park there is little evidence for a distinct Algoma stage.

In the Platte lakes embayment there is a sequence of bars, beach ridges and longitudinal dunes between the 605-foot shoreline of Lake Nipissing and the present (580-foot) shoreline of Lake Michigan. This sequence of deposits developed partially because of the steady drop in lake level that has occurred since the Nipissing stage and partially because of lakeward building of the shoreline by the Platte River delta. Although a definitive study of the origin of the landforms in this area has not been made, probably most of the long, low, arcuate, sandy ridges in the embayment are longitudinal dunes formed just inland from the water's edge. Viewed stereoscopically on aerial photographs these dune ridges can be used to reconstruct not only the sequential position of the lake shore but also the lengthening of the Platte River as it built its delta outward on the shallow lake bottom.

From about 3,000 B.P. to the present the water level in the Lake Michigan basin has remained rather constant at about 580 feet. During this interval there has been continuous wave erosion along the bluff south of Sleeping Bear Point, along the Empire bluffs, and at Pyramid Point. Conversely slow formation of new land is proceeding at two points; (1) south of the Platte River's mouth and (2) at Sleeping Bear Point.

Little of significance occurred on either North or South Manitou Islands during their inundation by the higher water lake stages. The basin of Florence Lake, on South Manitou, was created as a back beach depression during Nipissing time.

RECOMMENDATIONS IN RELATION TO LACUSTRINE FEATURES

The high, Nipissing dunes in the Empire and Platte embayments are the only ones of their kind in the park. Those in the Empire embayment are stabilized at present while the ones in the Platte lakes embayment are partially remobilized.

The Nipissing dunes in the Empire embayment are especially interesting because of their juxtaposition with the low, Algonquin dune mentioned earlier. From east to west in the embayment a rather detailed record of the shorelines of lakes Algonquin and Nipissing can be seen in less than a mile's distance (Figure 17). Associated with the Lake Algonquin shoreline is a well developed offshore bar, a recurved spit, and the longitudinal dune. Further west is a well developed Nipissing beach and further west still the high, Nipissing dunes.

While the geologic history preserved in the embayment lacks the spectacular beauty and grandeur of other areas within the park, exploitation of the area in a manner which leads either to the remobilization of the dunes or destruction of the shoreline features would, geologically, lessen the park's value. Reforestation of the embayment also would not be advantageous to viewing and understanding the geology since the low, elongate shore features require unobstructed viewing over a large distance. The open, grass covered condition that much of the embayment is now in maximizes the ease and thoroughness with which one can comprehend the features before him or her.

The Nipissing dunes in the Platte lakes embayment, in contrast, are not part of a readily observed historical succession, and thus they lack the

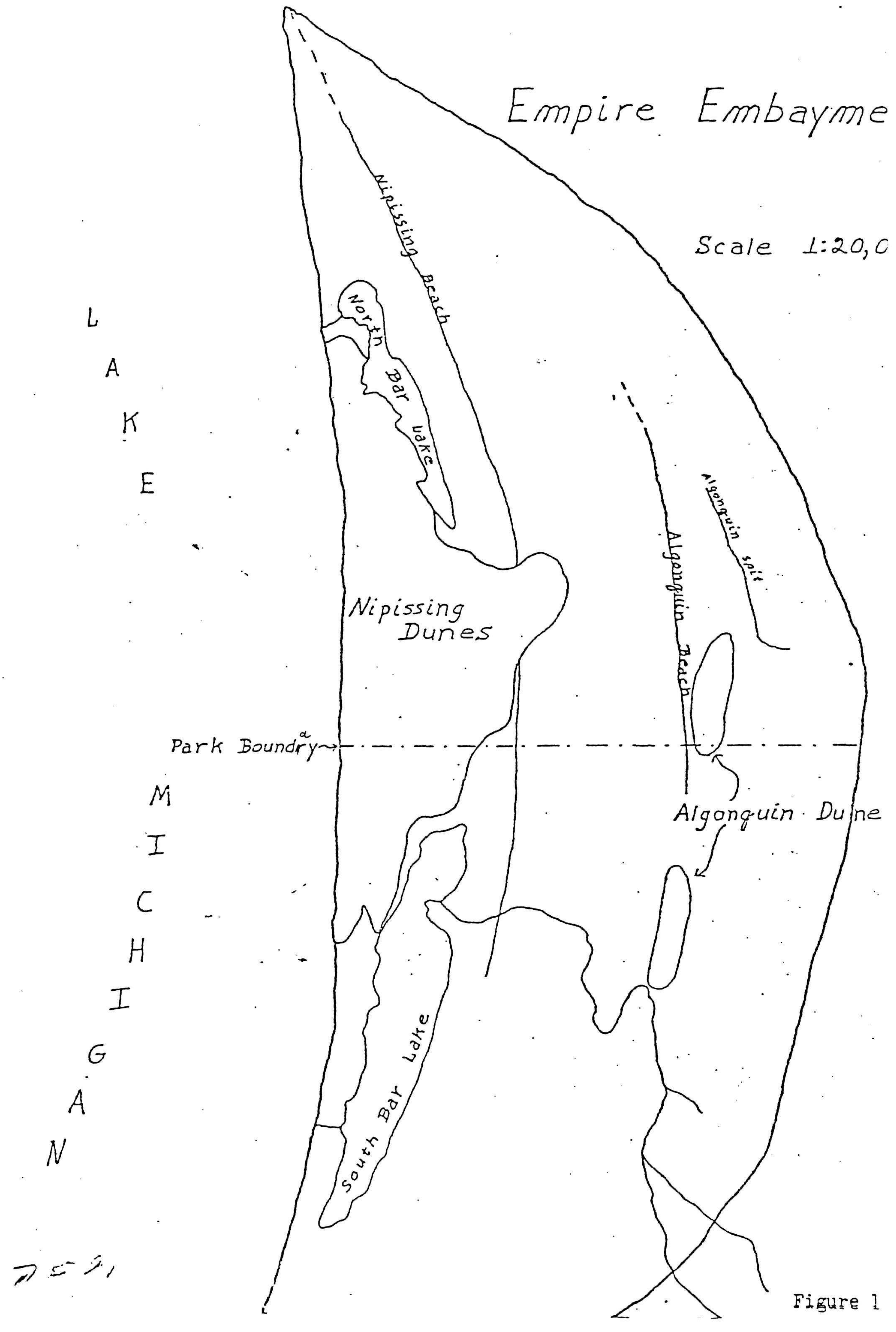

Empire Embayme
Scale 1:20,0
LAKE MICHIGAN
Nipissing Beach
North Bar Lake
Algonquin Beach
Algonquin spit
Nipissing Dunes
Park Boundry
Algonquin Dune
South Bar Lake

Figure 1

geologic importance of those near Empire. Denudation and remobilization of these dunes through heavy recreational usage, while not particularly detrimental to the geology, would not represent wise exploitation of the dunes. If remobilized these dunes would eventually migrate over Otter Lake, Otter Creek and perhaps over Bass and Deer Lakes as Well. Ultimately erosion and transport of the sand migrating into the creek would probably destroy a considerable portion of the dunes, although this destruction will have to proceed for hundreds of years before decimating the dunes. Since there is very little, if any, addition of sand to these dunes from the present shoreline, whatever migration they experience can not be compensated for by the growth of new dunes in the place from which they came. Preferably then, these dunes should not be used in a manner that will encourage instability and migration.

Sleeping Bear Point

In 1971 and prior to that in 1913 slumping of large volumes of sand into Lake Michigan occurred at Sleeping Bear Point (French, 1972). This slumping happened because several geologic processes are interacting at the point to cause the formation of new, unstable land.

Figure 18 shows a flat area of land whose surface elevation lies just above the mean water level of Lake Michigan but below the elevation to which storm driven waves climb. The surface of this flat is striped with low, parallel, gravel ridges built by successive storms. This implies that rather rapid deposition of sand from long shore currents is occurring at Sleeping Bear Point and the point is being extended northeastward into Lake Michigan. The lake's floor at the point descends steeply from the shoreline and accordingly offers a very unstable platform for the expanding point to build on. Also influencing the point's instability is the large mass of dune sand that is migrating toward its tip. The interaction of these three factors insures that continued, periodic slumping of the point will occur.

Unless the platform over which the point is building participates in the collapse, future slumping on the point should occur approximately within the limit of the 1971 slump. Since the Lake Michigan wave-cut cliff has not been involved in the slumping anywhere on the point and always is separated from Lake Michigan by a wide expanse of modern beach flat, the implication is that no appreciable retreat of the platform is occurring.

When the point has again extended onto the unstable edge of the platform, slumping should be most easily triggered when certain conditions prevail (French, 1972). (1) Saturation of the dune and lake deposits above lake level by heavy rains or melting snows increases the mass bearing on the unstable platform's edge. (2) Strong currents generated by high winds and waves may increase the instability by subaqueous erosion and perhaps by somewhat increasing water circulation through the unconsolidated lake deposits. This decreases the sediment packing and reduces its ability to support a load. Earth tremors may also trigger slumping.

The likelihood that periodic slumping on Sleeping Bear Point will continue seems excellent. Perhaps the interval between times of major slumping is typified by that between 1913 and 1971. Perhaps this interval is atypical. Further study would be required to answer this question.

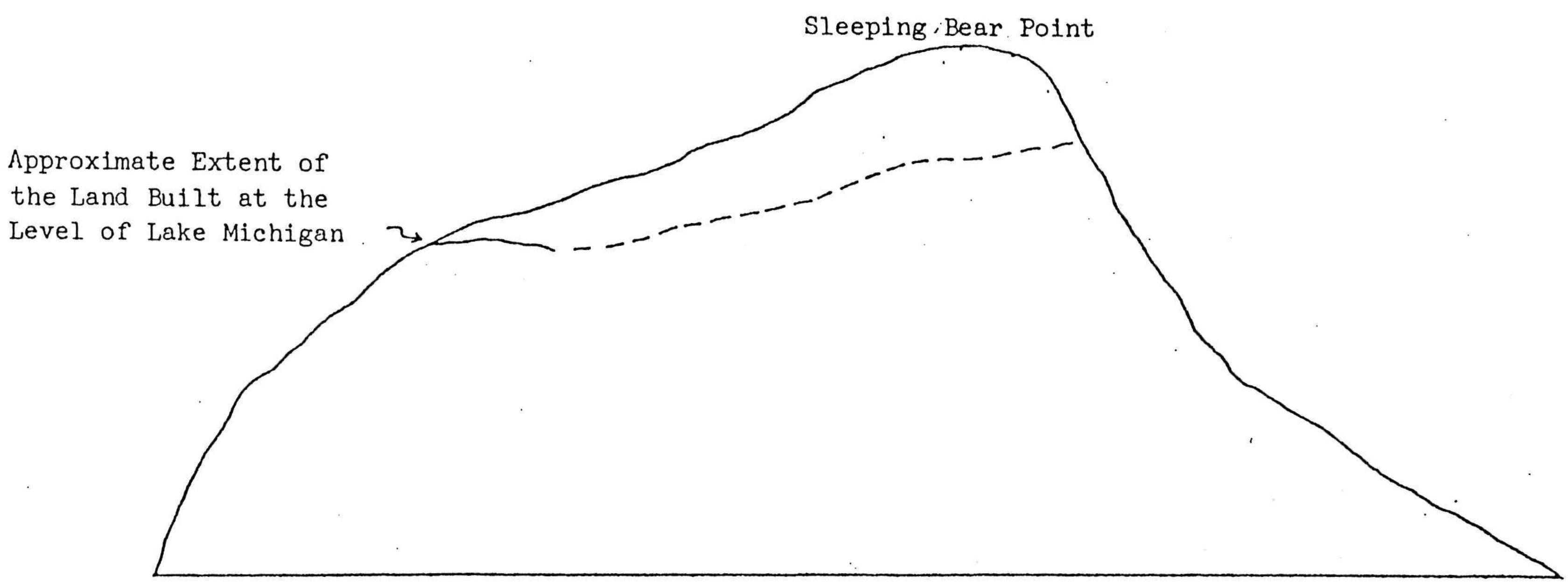
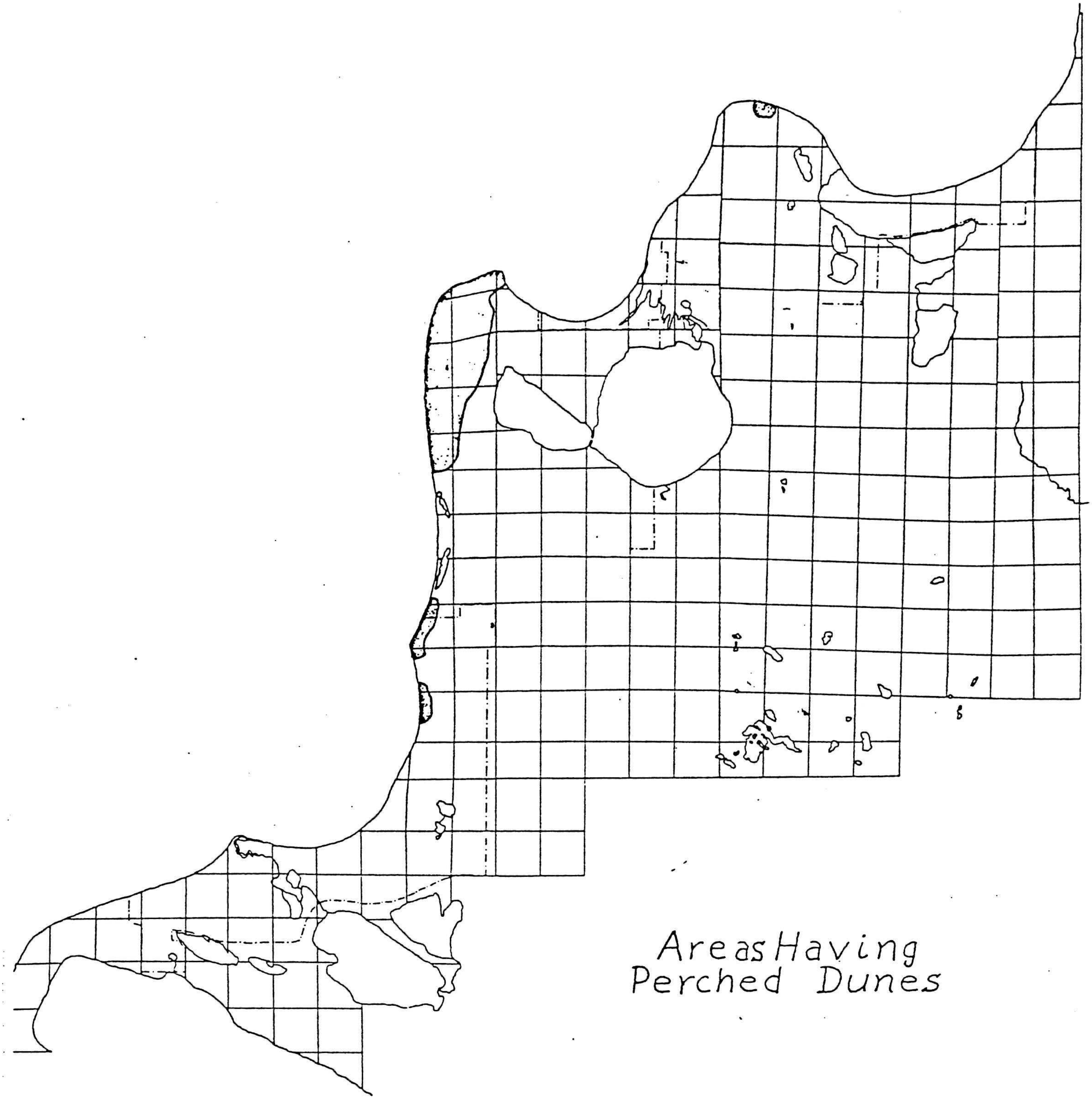

Sleeping Bear Point
Approximate Extent of
the Land Built at the
Level of Lake Michigan

Figure 18



Areas Having Perched Dunes

Scale 1:153,043

Figure 16

6 5 70 P.33

Erosion on South Manitou

Along portions of the wave-cut cliffs on South Manitou gullies have developed. Where this occurs the cliffs are observed to contain a large proportion of red, laminated silts and clays beneath a thick, sandy cap. Erosion apparently starts in the following manner. Groundwater filtering downward through the sandy cover eventually comes into contact with the impermeable clays beneath. When this happens the water will start flowing down the inclined, upper surface of the clay. If this surface is inclined toward the wave-cut cliff's face, the groundwater will eventually emerge as a spring at the top of the impermeable section. Since these springs are often fed by water that has flowed for a considerable distance underground, they often are semipermanent and create a water soaked, unstable patch on the hill slope beneath their point of emergence. The unstable mass normally is fixed by a vegetation mat that flourishes on the saturated ground. If such a slope were undercut by waves, however, the entire unstable mass can slump from the slope face leaving the exposed sediment suseptible to gullying. Undercutting proceeds most effectively when lake level is high. Although I found little evidence of restabilized gullies on South Manitou, I know this commonly happens in other areas when lake level begins to fall. Probably the small gullies on the island will behave in this fashion.

Several of the gullies near the wreck of the Fransisco Morazan seem so well developed that they will continue growing regardless of how lake level changes. Their proximity both to the wreck and to an access road at the top of the bluff suggests that the development of this severe gullying may be related directly to trails worn in the bluff's face by people visiting the wreck. Steps should be taken immediately to prevent people from continuing to use the gullies. Efforts should also be make to stabilized the larger gullies. They could develop quite rapidly if unchecked because of the stratigraphy in their lower, laminated unit. This unit consists of interlayers of fine sand and clayey silt or silty clay. Water channeled in the gullies quickly erodes the sandy units. This removes the support for the overlying, more clay-rich, units which then collapse. The larger a gully grows the more flowing water will be concentrated on its floor following a rain. Erosion is strongly dependent upon the amount of water carried by the channel. If the gullying is allowed to continue it could grow headward quite rapidly and endanger some of the virgin forest in this portion of the island.

The park contains two fundamentally different types of dunes, perched dunes and (what will here be called) beach dunes.

Beach dunes originate when the sand on beaches drys and is set in motion by shore winds. The sand will blow inland beyond the reach of storm waves. There the sand becomes fixed by vegetation. As more sand blows inland an elongated dune begins forming parallel to the shore. This dune will continue to grow until either its vegetative cover is destroyed or until the beach which feeds the growing dune is abandoned. In the latter case a low elongate dune ridge remains to preserve the shape of a portion of the lake's shore at a particular time. In the former case parabola-shaped blowouts develop destroying the initial, linear shape of the dune. Because these blowouts occur in a region having a temperate climate and abundant rainfall, they very seldom become truly migrating dunes before vegetation stabilizes them again. Thus almost always the arms of the paraboloid extend back to the area from which the blowout originated.

Perched dunes differ from beach dunes primarily in two ways. First their source of sand is only indirectly related to the lake's shoreline. And, secondly, most perched dunes have migrated considerable distances.

Perched dunes receive their name because they are found atop high lake bluffs often many hundreds of feet above the beach. The bluffs beneath perched dunes are always composed predominantly of sand (usually outwash sand) with lesser amounts of gravel. This restriction of perched dunes to sandy luffs demonstrates that the sand source for the dunes is not the beach as it is with beach dunes. Indeed the very high, steep, c[illegible]pes are never found to have sand migrating up their faces except near the very top of the cliff. Clearly then the sand source for the perched dunes is the sandy bluff itself.

Sand for the dunes is not continuously derived from the cliff face whenever strong winds are blowing. Instead a freshly exposed portion of the upper cliff face suffers rapid deflation until most of the wind transportable grains have been removed. A gravel lag remains. Thus the high bluffs near Sleeping Bear Dune appear to be composed largely of gravel when only the surface is examined. Beneath the gravel lag, however, the bluff usually consists of more than 90 percent sand.

Growth of the perched dunes could not progress once the gravel lag formed if there were not processes acting on the bluff face that could, periodically, strip away portions of the lag. In the park two important ways of removing the lag exist. The first is by rain water gullying the bluff's edge. This occurs only when the bluff's upper surface slopes westward toward the prevailing winds and toward the cliff face. After each rain, fresh sand is exposed in the sides and floor of the gully. Wind blows the sand eastward out of the gully's head. There it collects into small, rapidly migrating dunes. As these dunes migrate they coalesce with other small dunes to form larger, more slowly moving dunes or they may overtake and join a larger dune. Usually migration continues until the dunes have passed over the bluff's crest onto the sheltered lee slope. On bluffs whose upper surface slopes away from the cliff face and also slopes to the lee of the prevailing wind, removal of the pebble lag occurs only by sheetwash on the cliff during heavy rains or when the cliff's face collapses because of undercutting by lake waves. The amount of sand exposed annually to the wind by these processes is probably quite large.

Once the freshly derived sand migrates onto the lee slope of the bluff its velocity slows. Normally vegetation will cover and stabilize the dune soon afterwards. If, however, the vegetative cover cannot establish itself on the dune, migration will continue unhindered.

The park contains excellent examples of both stabilized and migrating, perched dunes. These two groups of dunes are, geologically, the most important assets of the park. The best, stabilized perched dunes occur along the west side of South Manitou Island while the best migrating dunes occur between Schauger Hill and Sleeping Bear Point on the mainland.

Perched Dunes on South Manitou

South Manitou possesses a truly unique belt of perched dunes along the upper surface of the high outwash fan that forms the island's west side. The dunes attain their uniqueness largely because they display so completely and with such great variety all the stages that perched dunes may pass through from their inception and growth to their eventual destruction. Typically within a half mile's distance of the cliff's face the complete process of dune formation can be seen. Miniature, rapidly moving dunes line the lee edge of the bluff's crest (which here coincides with the top of the wave-cut cliff). Low vines that rooted themselves initially in these small dunes are often seen now to have their roots well to the windward of where the dune sits presently. Some of these vines have grown rapidly enough that their tips still cover the dune (which apparently contains the moisture needed to sustain the plant's life). Others have not grown fast enough and lie dead pointing in the direction of the dune that passed by.

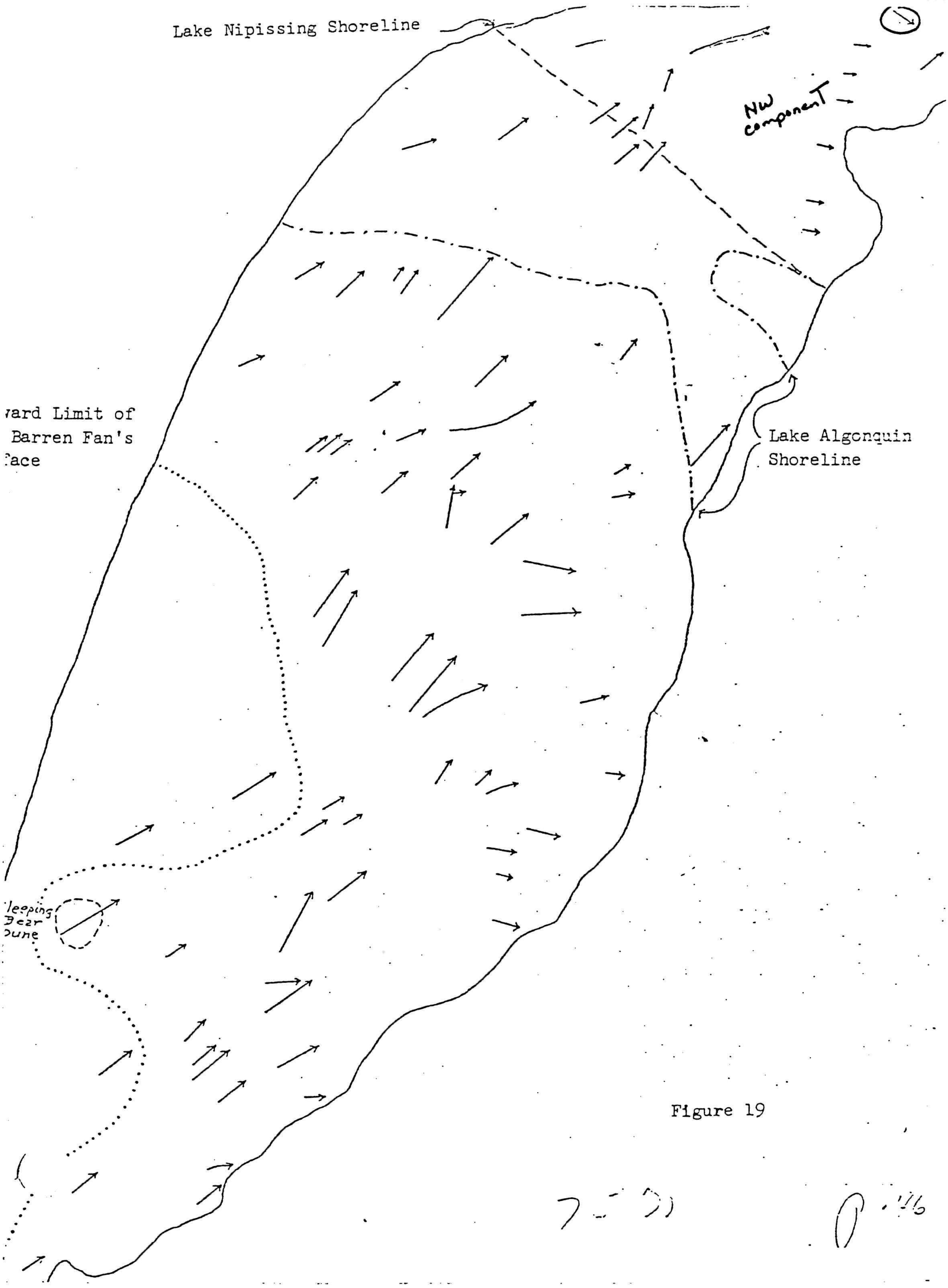
Migrating eastward the miniature dunes coalesce many times and grow into masses of moving sand 5 to 6 feet high. Their surfaces are often sparsely covered with beach grass. A few are nearly stabilized by dense growths of young cedars.

Further east still these dunes migrate against the flanks of huge, longitudinal dunes. Typical of the impressive detail found throughout this area, these longitudinal dunes display a gradation in their vegetation cover from west to east. Beach grass grows on the newly arrived sand on the west side of the dunes while a well developed cedar forest blankets the long stabilized eastern side. Other longitudinal dunes have had their vegetative cover destroyed, perhaps by fire or drought. The subsequent blowouts which developed have exhumed numerous, well preserved, cedar snags, exposed the cross bedded interior of the old dune, and resurrected the dune migration processes that had been arrested earlier.

Preservation of the complexity and beauty of these dunes depends to a very large extent upon preserving their vegetation cover. Destruction of this cover could, possibly, create a situation similar, but less severe, to that existing on the mainland near Sleeping Bear Dune. There the high outwash fan has been almost completely stripped of its original dune cover. Today sand derived at the cliff face is moved across the entire width of the high, fan's surface and into a depression on the lee side before it becomes a part of larger dunes. The high surface of the fan is mainly a pebble armored [illegible] ...ison of South Manitou ... the mainland is not [illegible] the climate and topography of the two areas may [illegible] ...less disruption and perhaps destruction of the [illegible] dunes is a real possibility if visitation to [illegible] ...er what it is at present. In my estimation the [illegible] asset if the area containing these perched dunes [illegible] ...ference. Even at the present level of usage [illegible] that visitors will not wear trails down the [illegible] longitudinal dunes. Such trails are the first [illegible] ...owcuts.

[illegible] Bear Dune Peninsula

[illegible] the peninsula originated as perched dunes. [illegible] of the peninsula derived much, if not all of [illegible] these dunes and what were originally perched "uperched" [illegible] the direction of Sleeping Bear Point. Migra- [illegible] at least intermittently, since deglaciation [illegible] ...ow dunes that originated in the vicinity of [illegible] far enough to the northeast to override the [illegible] and to traverse the width of the flat built [illegible] ...is much movement the peninsula has clearly [illegible] of dune instability. Accordingly, the present [illegible] dunes with a high, gravel-covered outwash fan [illegible] ...al condition for this area. It may even be [illegible] a state of approximate equilibrium between the



Lake Nipissing Shoreline
NW component
ward Limit of
Barren Fan's
Face
Lake Algonquin
Shoreline
leeping
Bear
Dune

Figure 19

rate the dunes migrate and the rate at which sand is added to them from the outwash fan.

Another characteristic of the peninsula manifested not only by Figure 19 but on the topographic map of the area is that the migrating dunes are moving essentially along a line that passes from a point one half mile south of Sleeping Bear Dune to Sleeping Bear Point*

These observations suggest that the Sleeping Bear peninsula is ideally suited for heavy recreational usage. Little damage would occur to the dunes if heavily used because they are mostly denuded and migrating already. Other than the exceptions cited later, apparently no geologic or economic harm will occur if the dunes continue to migrate freely, for they are primarily moving in a direction that is already dune covered. Thus a nearly ideal half cycle of dune development, migration, and destruction has and is operating on the peninsula. It can continue to operate with little harmful effect to the park and with very little maintenance by the Park Service.

Using the dune peninsula as recommended here could cause several problems, however. First there is the theoretical possibility that the amount of sand migrating into the lake at Sleeping Bear Point exceeds the amount being derived from the outwash fan and beach. If this were the case the

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*The arrows on Figure 19 indicating (blowout directions) show strong divergence from the trend of this line only near the lake shore and near the edge of the deep, Glen Lake basin. The lake shore divergence is caused by onshore winds. That near the edge of the Glen Lake basin apparently occurs because of the low air pressure in the basin relative to that of the wind sweeping across the high outwash fan's surface. Thus the peripheral portion of the relatively compressed air in the wind is bent eastward and flows down the pressure gradient. Very little sand is transported eastward by this phenomenon. The onshore winds, however, do exert somewhat of a change in the direction of sand transport near the tip of Sleeping Bear Point.

dune field might slowly be destroyed. Heavy usage of the dunes would increase somewhat any imbalance that did exist. But if this were the situation a very long time would be required before the effects of a net deficit in the sand balance would become obvious. Equal amounts of time would be available to correct the imbalance.

A second problem is how to protect Sleeping Bear Dune from further erosion. Although this may seem an admirable pursuit, it will be very difficult to realize. Even before the latest blowout on the dune began in the 1930's (Gates, 1950), Sleeping Bear Dune was no more than a small remnant of an initially much larger dune. It, like Schauger Hill to the south, formed on the outwash fan's surface well back from the edge of the wave-cut cliff. Subsequent undercutting by waves has caused the cliff to retreat until much of the original mass of the dune has either slumped into the lake or been remobilized and blown inland. Currently the dune remnant rests on the exposed cliff edge where either wind or the retreating cliff can finish destroying it. With considerable effort it should be possible to preserve the dune. This would involve not only revegetation but also stopping waves from cutting at the cliff's base.

Other Perched Dunes

Other perched dunes within the park are found on the Empire bluffs, at the intersection of the Leelanau-Benzie county line with Lake Michigan and on Pyramid Point. All except the latter ones are stabilized. These dunes generally are partially eroded and do not display the wonderful detail and complexity of those on South Manitou. Neither can they be allowed to migrate freely without either passing into depressions where the wind cannot reach them and where they will also lose their distinctive shape or passing into Lake Michigan. Accordingly these dunes are best left stabilized.

CONCLUSIONS

An attempt has been made above to set forth the park history in as much detail as was possible considering the scope of the study. Mention has also been made, where necessary, of some geologic processes whose effect upon the park land has resulted in the creation of either unique or important features.

This study concludes that the perched dunes on South Manitou Island are the park's greatest geologic resource, and that they possess a complexity and beauty probably equalled by few other temperate climate dunes in the Great Lakes area. The other area having considerable geologic importance is that of the Sleeping Bear Dune Peninsula. Although the diversity there does not compare well to that on South Manitou, the area offers excellent examples of all aspects of dune migration.

In addition to these two major areas there are several of lesser significance which, nonetheless, deserve protection because of their importance in elucidating various stages of the park's geologic history. Areas seemed worth preserving have been compiled below beneath headings which explain to what aspect of the park's geologic history the area primarily pertains.

Glacial History

(1) The late glacial channel on the Pierce Stocking farm.

(2) The youngest outwash fan (in the northwest corner of the Glen Lake basin).

(3) The high bluff between Sleeping Bear Dune Park and the sand climb in D. H. Day State Park.

(4) The glacial drainage channel extending south from the causeway across Glen Lake.

(5) The 725-foot notch cut by waves into an outwash fan just north of the same causeway.

Lake History

(1) The Empire embayment

(2) Nipissing dunes in the Platte lakes embayment

Dune History

(1) The dunes on the Empire bluffs, at Pyramid Point and those on the Leelanau-Benzie county line and especially those on South Manitou Island.

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