A Proposed

SLEEPING BEAR
National Seashore

NATURAL HISTORY REPORT
1961

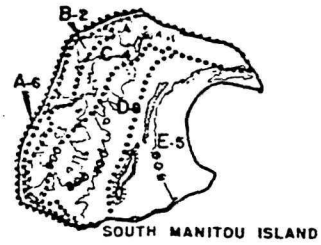
UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE 1961

Gifts of private funds have made possible the publication of this report as a public service.

Table of Contents

GEOLOGY SECTION

BIOLOGY SECTION



MAJOR PHYSICAL FEATURES
OF THE
SLEEPING BEAR REGION

A...SHORE BLUFFS
- A-1.Point Betsie Bluffs
- A-2.Empire Bluffs
- A-3.Sleeping Bear Bluffs
- A-4.Prospect Hill-Port Oneida Bluffs
- A-5.Pyramid Point Bluffs
- A-6.South Manitou Bluffs

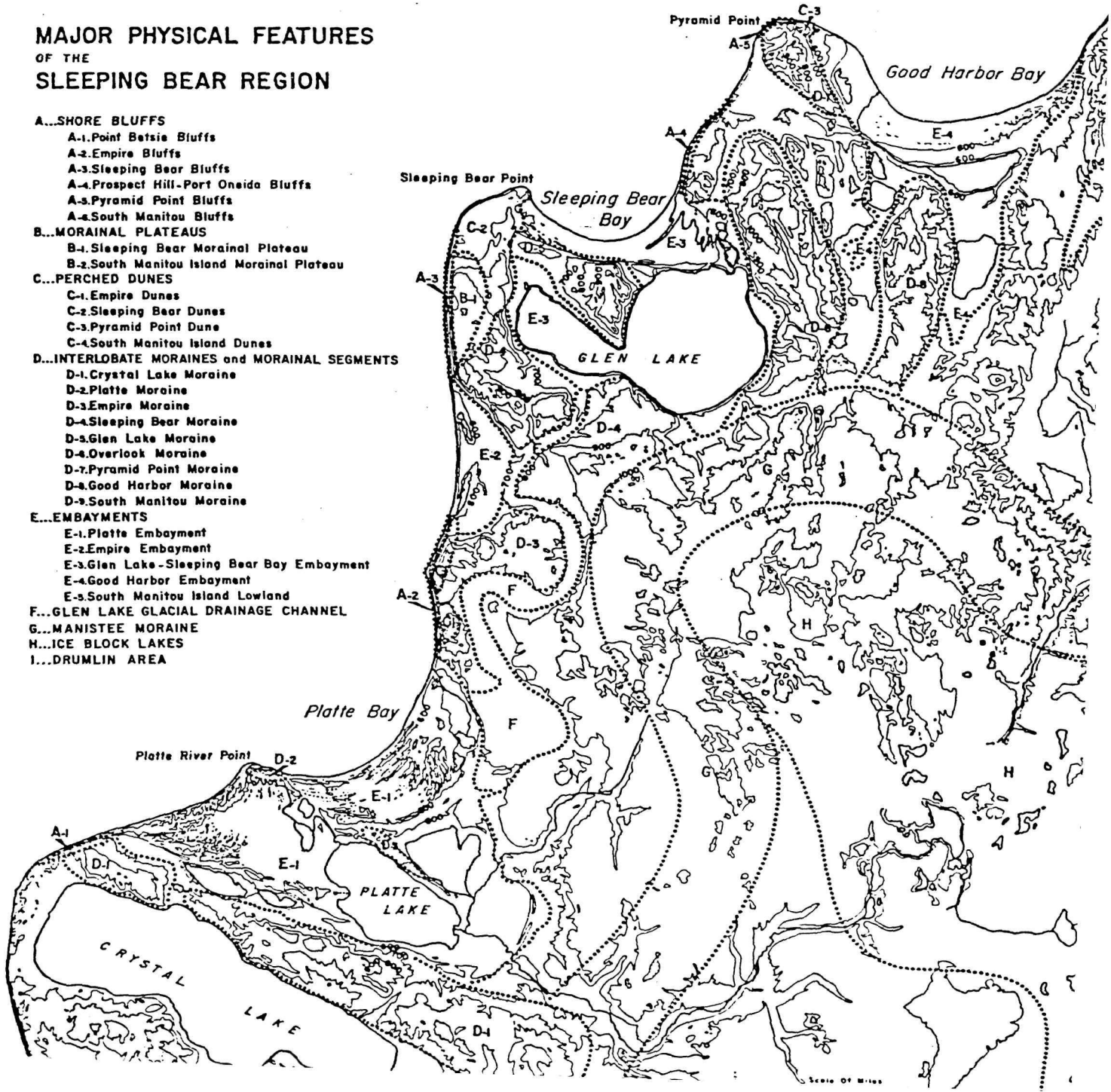
B...MORAINAL PLATEAUS
- B-1.Sleeping Bear Morainal Plateau
- B-2.South Manitou Island Morainal Plateau

C...PERCHED DUNES
- C-1.Empire Dunes
- C-2.Sleeping Bear Dunes
- C-3.Pyramid Point Dune
- C-4.South Manitou Island Dunes

D...INTERLOBATE MORAINES and MORAINAL SEGMENTS
- D-1.Crystal Lake Moraine
- D-2.Platte Moraine
- D-3.Empire Moraine
- D-4.Sleeping Bear Moraine
- D-5.Glen Lake Moraine
- D-6.Overlook Moraine
- D-7.Pyramid Point Moraine
- D-8.Good Harbor Moraine
- D-9.South Manitou Moraine

E...EMBAYMENTS
- E-1.Platte Embayment
- E-2.Empire Embayment
- E-3.Glen Lake-Sleeping Bear Bay Embayment
- E-4.Good Harbor Embayment
- E-5.South Manitou Island Lowland

F...GLEN LAKE GLACIAL DRAINAGE CHANNEL
G...MANISTEE MORAINE
H...ICE BLOCK LAKES
I...DRUMLIN AREA



GEOLOGY SECTION

The Ice Age . . . An Introduction

The well-established concept of an "Ice Age" or period of widespread glaciation, as accepted today, is less than 150 years old, and many important facts of its existence have only recently been comprehended. With the gathering of additional data the mists of doubt which surrounded man's first probing of this clearly documented and most recent of geologic epochs have been swept away, and the jumbled topography of the area of continental glaciation has taken on a new and absorbing significance.

> *"A rich store of information has been accumulated, most of it within little more than a century, on this latest of geologic epochs, and a far richer store awaits the scientist. All this knowledge, actual and potential is made possible by the comparative recency of the sedimentary deposits, fossil animals and plants, multitudinous land forms, and geologic structures that constitute the record. These are so young that the slow geologic processes—erosion, burial, submergence, distortion, metamorphism—that in the course of time hide such things from view, have destroyed them only in part or not at all." (Flint, 1957)*

This period of glaciation known as the Pleistocene, meaning "most recent", is, compared to the three to four billion-year age of the earth, as recent as yesterday. Determined variously as beginning around 1,000,000 years ago, the Pleistocene epoch was not a single continuous period of glaciation but a series of stages and substages, interspersed with cycles of warmth during which time the ice margin melted back completely or to some undetermined point.

Four glacial stages are recognized in the Great Lakes region for the Pleistocene. They are, from oldest to youngest, the Nebraskan, the Kansan, the Illinoian and the Wisconsin respectively. We need only be concerned with the most recent, for, in the State of Michigan, ice of the Wisconsin stage obliterated or altered the visible evidence of previous glaciations.

Wisconsin Glaciation

The evidence indicates that ice of the Wisconsin stage lasted approximately 50,000 to 10,000 years, with the ice having disappeared from the Sleeping Bear region about 11,000 years ago. During and following the recession of the ice, the waters of the Great Lakes fluctuated as they sought the lowest outlets, with the final adjustment as we know them today taking place about 2,000 years ago.

It is with these recent geologic happenings that this paper deals: late glacial and postglacial events down to the present that have shaped and are shaping the landscape of the Sleeping Bear region.

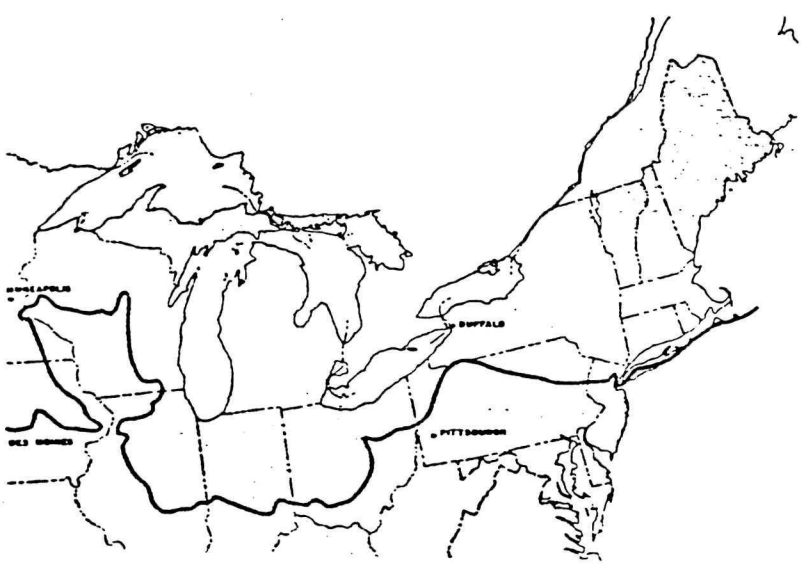
During its maximum extent, Wisconsin ice completely blanketed the State of Michigan, extending far south into Illinois, Indiana and Ohio (Fig. 1). Though all stages of glaciation wrought changes in the landscape of any given point affected by them, it is with the later substages of Wisconsin glaciation that we are concerned, for these are the ones which have left their indelible marks on the landscape of the study area.

Hough (1958) lists seven substages of the Wisconsin stage, each characterized by the occurrence of some distinctive evidence. These substages occurred generally successively further north, the last being north of the Great Lakes. The fifth, the Port Huron or Mankato substage, is the most important in the study area though the sixth or Valders phase touched upon it.

Port Huron Substage

The Port Huron substage is marked by a highly developed morainic system from south of Manistee on Lake Michigan northward around the tip of the lower peninsula and then southerly around the Saginaw Bay lobe to the vicinity of Port Huron (Fig. 2). Within this system is a well-defined series of end moraines, ground moraines, outwash areas, glacial channels, deltas and glacial lake beds. During the early part of the Port Huron substage much of the lower peninsula was free of ice and by the close of the substage the ice had melted back from the lower peninsula completely. Thus it was during this time that the characteristic topography of the study area was fashioned.

Fig. 1. As shown by the line, Wisconsin ice at its maximum extended far south of the Sleeping Bear region.



From Portage Lake in Manistee County to Little Traverse Bay in Emmet County, the northwestern corner of the lower peninsula is indented by a series of lakes, lowlands and bays. So prominent are these features that they immediately set this region apart from the area to the south. The reasons for the prominence of this "interlobate" area, as it is called, stems most probably from two causes: pre-glacial topography and the lobate nature of the ice of the Port Huron substage.

During successive advances of glacial ice a tremendous amount of inorganic rubble known as till was transported by ice movements from within the zone of glaciation to the periphery of the glaciated region. As the ice melted back,

the till was deposited in a variety of ways. If the rate of wasting of the margin of glacial ice approximately equalled the cumulative advance of the glacier, till deposited along its margin would form a high ridge known as an end moraine. If wasting away of the ice exceeded its advance and a general continuous retreat of ice ensued, till would be deposited unevenly over the resurrected landscape as a ground moraine. Between two adjacent lobes of a glacier, an interlobate moraine would be created. Other glacial features such as kettle holes, ice block lakes, outwash plains, glacial drainage channels, eskers, kames, kame terraces and drumlines are part of the landscape of the area of continental glaciation. Through glacial transport a tremendous amount of glacial debris covered the bedrock of the study area to depths exceeding 500 feet, while the amount of drift that covers the Great Lakes region as a whole has been estimated to average forty feet in depth (Flint, 1957).

THE EFFECT OF PRE-GLACIAL TOPOGRAPHY

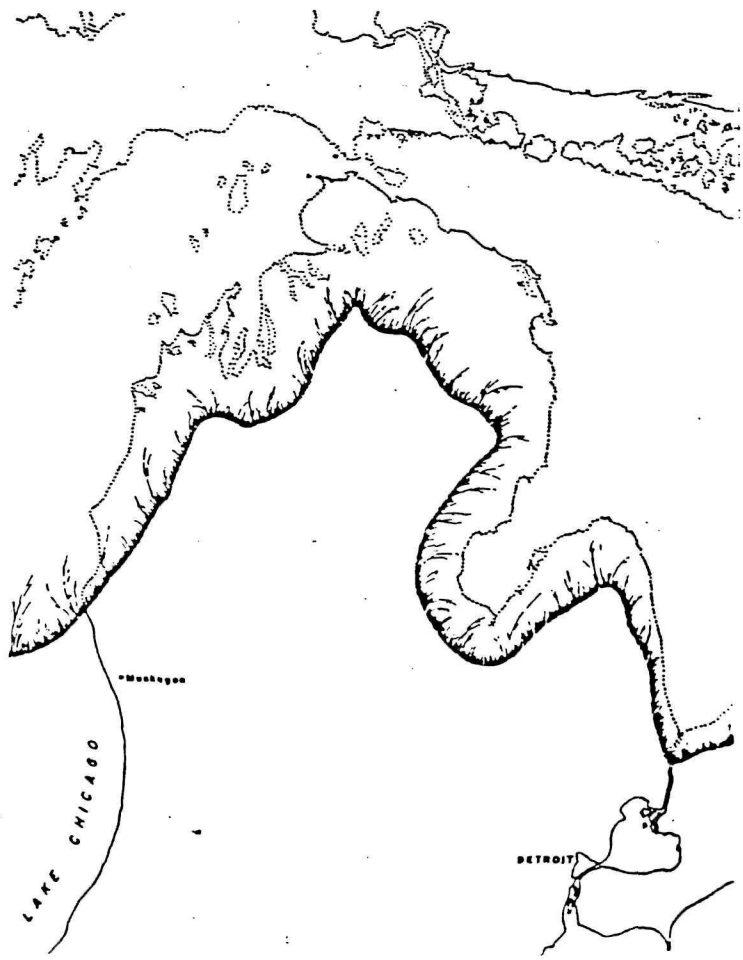
Though our knowledge of the pre-glacial landscape is obscure, it is generally accepted that the direction of ice movement was largely predicated by existing topography (Flint, 1957). Whatever the exact nature of the pre-glacial Great Lakes basins, it is almost certain that erosional processes and not diastrophic action or crustal warping were primarily responsible for their being (Hough, 1958). It is, of course, obvious that structure affects erosional processes.

The immediate region of the study area and northern Lake Michigan in general ". . . may appropriately be called a ridge and valley province."

> *"This area contains a number of islands and its bottom topography is characterized by a number of deep troughs, 250 to 500 feet deep, separated by ridges with 25 to 50 feet of water over them. The valleys are connected in what appears to be a drowned drainage system: the master valley, or deepest trough, extends along the south shore from a point west of the Petosky, Michigan, west-southwestward along the northern face of Traverse cuesta, across the mouth of Grand Traverse Bay, and thence westward to the deep northern basin." (Hough, 1958)*
>
> *"So we believe a number of streams in the area in what are now Little Traverse Bay and the deep gorges now filled with Walloon, Charlevoix, Torch, Elk, and Intermediate lakes were tributary to the main river in the Lake Michigan Valley. The little evidence we have from drilling through the drift shows their gorges extend for several miles southeastward." (Martin, 1957)*

In view of the foregoing, the deeply indented shoreline takes on new significance (Fig. 3). Glacial ice advancing south along these pre-glacial channels and along the larger topographic features of the Great Lakes, by

Fig. 2. During the Port Huron substage of the Wisconsin glaciation, most of the lower Peninsula of Michigan was free of ice. In the study area, however, the ice was still actively shaping the landscape.



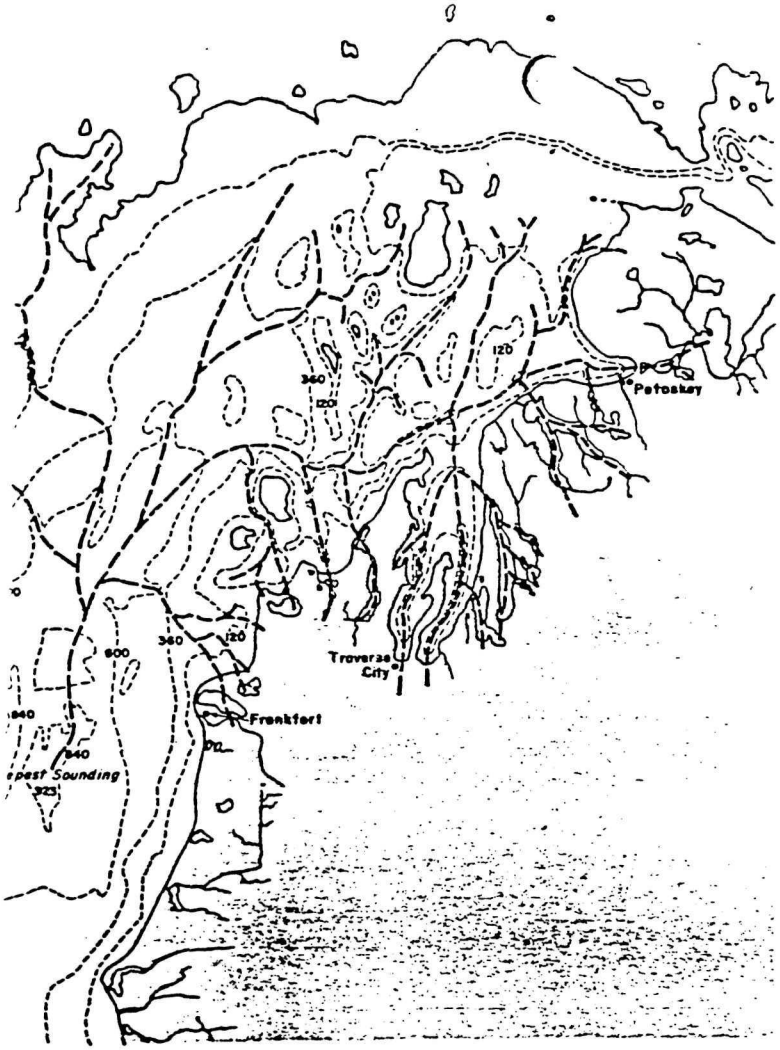


Fig. 3. A hypothetical reconstruction of a pre-glacial drainage system in the Lake Michigan basin based on present day topographic evidence. Lake contours are in feet.

following lines of least resistance, should be expected to show a highly lobate nature. And, indeed, lobation is a well marked characteristic of Wisconsin ice.

As the main lobe of the Port Huron substage pressed southward in the Lake Michigan basin, lateral lobes entered these tributary lowland valleys, pushing their accumulated load of glacial debris upstream (Fig. 4). Between the lobes a well-defined series of interlobate moraines was formed. Eventually the ice lobes merged and pushed south along a united, if still lobate, front to the Port Huron maximum. In these valleys the ice was thicker and consequently had more power to shape the landscape. After the thinner upland ice melted, the valley lobes remained and this had an important bearing on the glacial topography of the study area.

ICE BORDER LAKES AND GLACIAL DRAINAGE

At the Port Huron maximum the ice had advanced far to the south in the Lake Michigan basin, but only lapped upon the margin of the northern highlands of the Lower Peninsula, leaving this formerly glaciated region free of ice. Melting of the retreating ice formed lakes between the ice margin and the end moraines. Waters of these lakes, in turn, rose until they cut outlets through the moraines, forming outwash plains and glacial channels along the morainal front. Thus new drainage systems, independent of the pre-glacial system, came into being. The duration of active flow in these channels was controlled by the volume, the continued supply, and the extent of melting of the glacier. The direction of flow was controlled largely by glacial topography, moraines being cut through when water dammed sufficiently deep behind them. Channels flowed between moraines formed by the immediate stage or substage and those of previous substages. That many of these channels were excavated so deeply that they still carry important rivers is dramatic proof of the tremendous volume of water held

Fig. 4. The general direction of ice flow to the Manistee Moraine is suggested by the arrows and the orientation of the lines terminating in the various lobes. See Fig. 6 for position of Manistee Moraine.

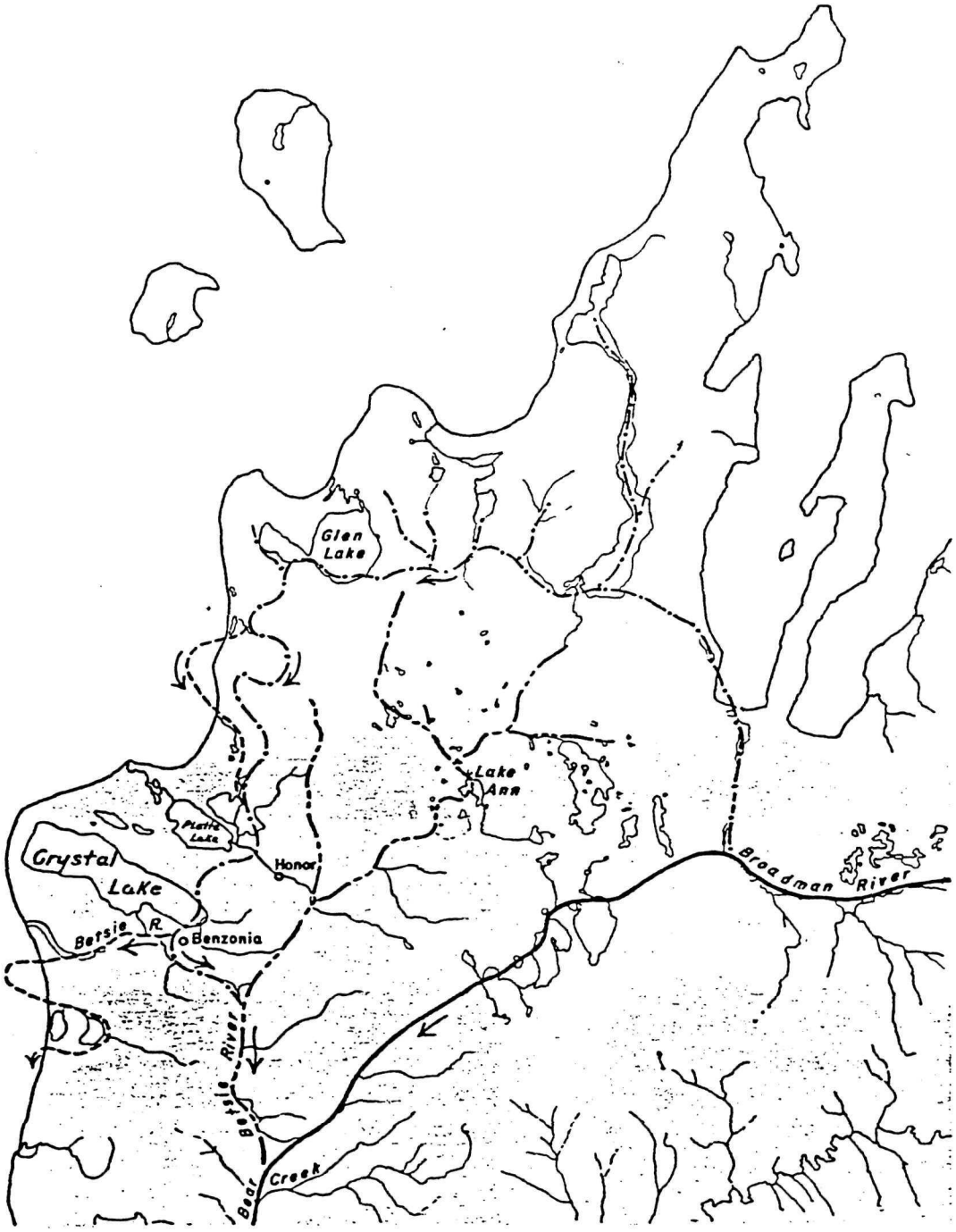


Fig. 5. Various glacial drainages of the Manistee ice are shown here superimposed on present day drainages. A gradual transition from the higher drainages on the right (solid line) to the lower levels on the left occurred as lower elevations became ice free. Following deglaciation some streams completely abandoned parts of their glacial channels.

captive in the glacial ice. As the ice melted back, however, lower elevations were exposed and many streams abandoned the old glacial channels for lower levels, leaving them high and dry (Fig. 5). Others ceased to flow actively once their source of supply, namely the glacial ice, disappeared.

The Port Huron ice did not retreat evenly and continuously. There were retreats, halts, and advances all along the line; however, three principal halts are recognized in the general region (Martin, 1957). The first two were south of the study area. The third and its consequent retreat occurred on, and was tremendously important in shaping, the landscape of the Sleeping Bear region.

The Manistee Moraine

The final halt of the Port Huron substage formed the Manistee Moraine (Fig. 6) and must be considered the climactic event of the glacial history of the Sleeping Bear region. At that time the southern end of the Lake Michigan basin was free of ice and was occupied by Lake Chicago at an elevation of about 640 feet (Fig. 2). The glacial ice entered the Lake Michigan basin somewhere in the vicinity of Manistee.

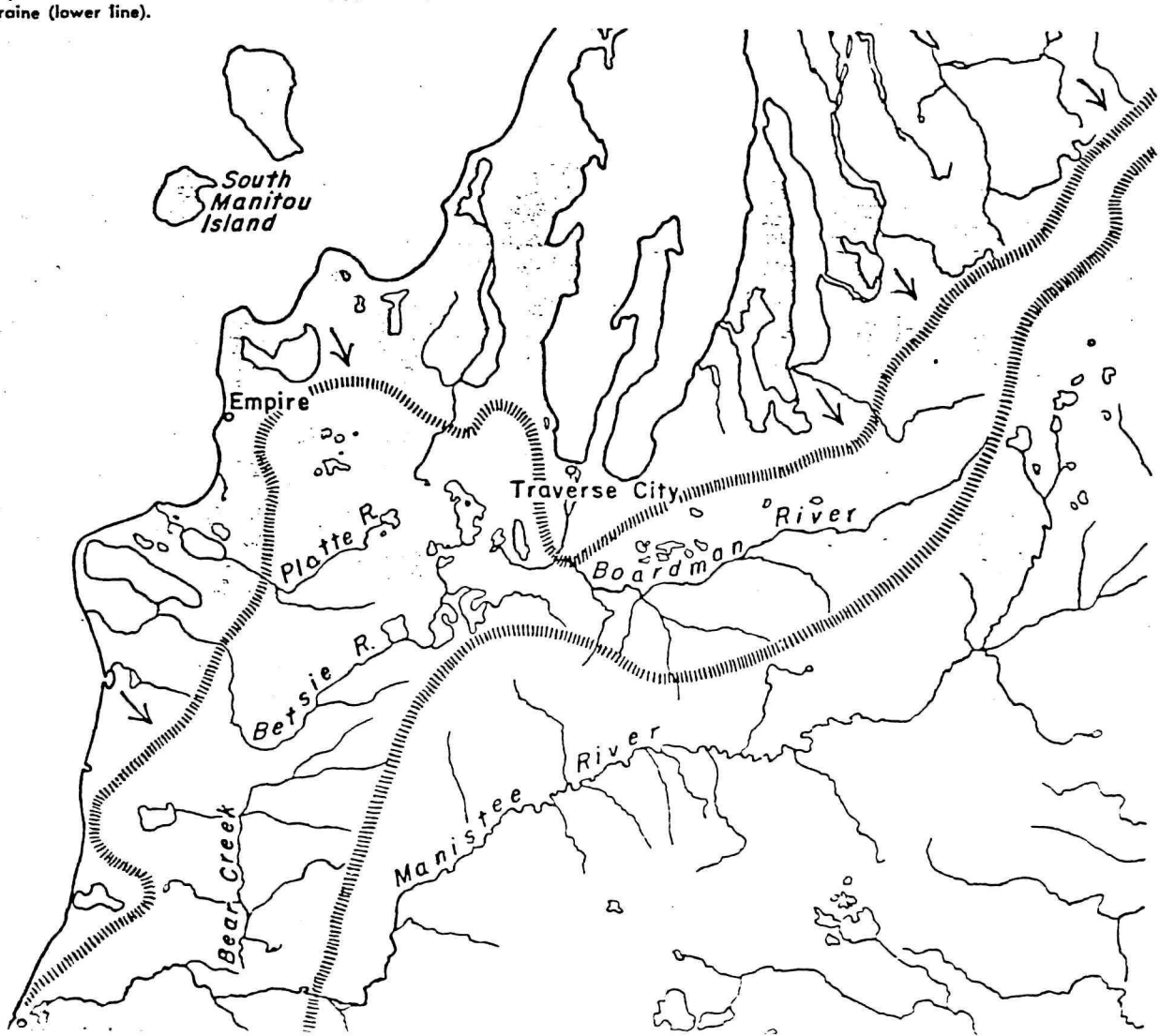
In the formation of the well-defined Manistee Moraine, the edge of the ice had attained a nearly static position where melting equalled advance. This implies a tremendous amount of run-off which through seeking the lowest possible outlets would finally find its way southwesterly to glacial Lake Chicago.

MELTWATER DRAINAGE

The original drainage pattern had been obliterated by previous glaciation, though outwash channels were beginning to form a new drainage system, much of which is still active today. Along the ice margin a vast river of meltwater was flowing south between the Port Huron and Manistee moraines.

As this water reached the south end of Grand Traverse Bay it became constricted between the Port Huron Moraine at 1,100 feet elevation and the massive lobe of ice at the south end of the East and West arms of Grand Traverse Bay. To the west of this point lay a plateau-like area between 900 and 1,200 feet in elevation along the northern morainal border

Fig. 6. Relative positions of the Manistee Moraine (upper line) and Port Huron Moraine (lower line).



and dropping in elevation southerly to about 750 feet above sea level in northern Manistee County. As the ice retreated from the area south of the moraine, large blocks of stagnant ice were left behind. These were buried, or partially buried, in the outwash plain and upon their eventual melting formed the series of lakes now found in western Grand Traverse, northeastern Benzie and southern Leelanau counties (Frontis Map).

During the formation of the Manistee Moraine and the early stages of retreat of Manistee ice, drainage was southwesterly down the ancestral channel of the Broadman River, thence westerly along the front of the Port Huron Moraine at an elevation of about 870 feet to the vicinity of Duck and Green lakes where it probably entered a large ice border lake at an elevation of about 840 feet above sea level.

It is helpful how to take stock of the general situation. In the Lake Michigan basin there was a tremendous mass of ice with a total depth at its deepest point of well over 900 feet (the deepest point in the lake) and more probably well over 1,200 feet. Lobes of this vast reservoir of ice fingered into Grand Traverse Bay, covered the Leelanau Peninsula, and filled Glen Lake, Platte Lake, Crystal Lake and the other shoreline depressions (Fig. 4).

The deeper the ice the more resistant it was to melting, and the greater was its ability to alter the landscape. It must be remembered that even as vast volumes of ice melted along the morainal margin, the main mass of ice was still advancing sufficiently to maintain the glacier's position along the morainal border.

DRUMLIN FIELDS

From Petosky southwesterly to Good Harbor Bay on the Leelanau Peninsula, the base of the glacial ice had ridden out of the depths of Lake Michigan to an elevation of from 600 to 900 feet above sea level. The ice in this area was thus the thinnest of any in the area behind the Manistee Moraine other than the interlobate moraines, being perhaps less than 100 feet deep in places. It was beneath this near stagnant ice preceding the final retreat of the glacier into Lake Michigan that the curious drumlin fields, the largest in the lower peninsula of Michigan, were formed. These drumlins were built atop ground moraine, indicative of a rather rapid advance of the ice. The forward movement of the original covering of shallow ice, of insufficient mass to continuously grade the surface of the glacial till, may have met locally with minor barriers in the form of accumulated drift, or may have scooped up sufficient till in minor depressions to form barriers to the flow of the ice. By flowing faster around the margins of the barriers than over them, it created alternating streamlined hills aligned with the direction of ice flow (Frontis Map). These drumlins were highly compacted by the ice and thus are extremely durable, perhaps to the extent that ice might advance over them more than once, giving them a stratified or laminated appearance in cross section.

ICE BORDER LAKES

At a given time in the process of retreat of the Manistee ice, its level fell below that of the terminal Manistee Moraine. At that stage, about 900 feet above sea level in the study area, the high ridge of the moraine would form an effective dam, and meltwater from the glacier would be trapped between the moraine and the glacier forming ice border lakes. The meltwater would consequently rise higher until it found the lowest possible outlet to the outwash plains. Originally this was probably at the southern tip of the Grand Traverse lobe where the meltwater cut through the moraine and flowed southwesterly at about 870 feet above sea level in the old intermorainal drainage. Eventually the ice melted back sufficiently far to connect the dammed-up meltwater of the Leelanau and Grand Traverse lobes, and a drainage was established from the end of the Leelanau lobe at 840

feet southwesterly to Lake Ann, thence down the Platte River to a point about 2½ miles southeast of Honor beyond which it entered the Manistee ice border lake which may have been somewhat lowered from its previous level.

As the Manistee ice dropped below the level of its moraine, the era of the constantly fluctuating ice border lakes came into being. These lakes must be considered as varying in level, of fusing when two or more adjacent bodies of water rose high enough to top an ice lobe or interlobate moraine, or for a single body of water to be fragmented by lowering of the water level. Originally most of the meltwater would have derived from the edge of the ice and from its surface. However, as melting continued, the tops of the interlobate moraines south of Pyramid Point and the low spine of the Leelanau Peninsula must certainly have been exposed. This undoubtedly hastened melting by providing additional surfaces for the warming air to attack. As this ice melted, it would have been blocked both east and west by the deep ice lobes in Grand Traverse Bay and Lake Michigan.

GLEN LAKE CHANNEL

Originally the top of the Manistee Moraine was probably everywhere at about a 900 feet minimum elevation above sea level, but meltwater eventually cut through the morainal dam via the two channels already mentioned, and, most importantly, through the Glen Lake Channel south of Glen Lake (Frontis Map). This channel undoubtedly maintained a level of about 860 feet during the early stages of its existence; but for some reason, probably through receiving the greatest proportion of the Leelanau Peninsula meltwater, it undercut the other ice border drainages and became the outlet for the area west of Grand Traverse Bay for a long while. While the Glen Lake Channel was cutting down to its base elevation of 770 feet (70 feet below any other outlet at that time), the Manistee ice border lake was also dropping to an elevation of somewhere around 760 feet above sea level. Thus a slow river of meltwater —if the hypothetical reconstruction is accurate —meandered southward from Glen Lake, through the Sleeping Bear Moraine, skirted the ice filled Empire Embayment, cut behind the Empire Moraine, flowed over the outwash plain east of Otter Lake and around the inner margin of the ice of the Platte lobe, found its way into the ice filled Crystal Lake depression, flowed west of Benzonia and south along what is now the northward flowing Betsie River and joined the shallow upper end of the Manistee ice border lake.

From how large an area the Glen Lake channel gathered its water is debatable. Certainly most of the Leelanau Peninsula meltwater flowed through this channel. The Grand Traverse Bay ice lobes may have proved sufficient to have kept waters from the northward as far as Charlevoix from flowing in this direction or more probably kept the Leelanau Peninsula waters from flowing northeasterly via Burt and Mullet Lakes into Lake Huron or into a Lake Huron ice border lake. How long the Glen Lake Channel was operative is not known. The outside edge of the large meander at Empire is bordered by a sheer cut back, 100 feet high. It seems possible that eventually the ice in the Bar Lake Embayment might have receded far enough lakeward to permit the waters to flow around the lakeward side of the Empire Moraine and thence into the Platte Embayment bypassing the Empire meander and that portion of the channel south to the Platte depression. This would ultimately bring the channel bottom down to the 720 feet level through the Sleeping Bear Moraine and to 700 plus feet through the Crystal Lake Moraine. It would then be impossible for the water to flow over the 770 foot divide between the Betsie River and Bear Creek, indicating drainage to the mouth of the Betsie River and thence south along the ice in the Lake Michigan basin to the 640 foot level of Lake Chicago. There seems to be some evidence of this at the east end of Crystal Lake, the circular basin along the Betsie River south of Benzonia and remnants of a lake plain along the Manistee River at 680 feet above sea level. All of the foregoing is extremely logical but needs substantiation by further study.

The Valders Substage

Eventually the ice in Lake Michigan melted back sufficiently to vacate even these ice border channels and the Port Huron substage came to an end. Later, Valders ice flowed far to the south in the Michigan basin but neither built conspicuous moraines nor altered the landscape of the study area in any important fashion. It did, however, leave evidence of its passing in the form of red, slightly pebbly clay deposits in ice margin lakes of the area. Such evidence may be found at Betsie Point, the Empire Bluffs and between Glen Arbor and Port Oneida (Melhorn, 1960).

It is thought that during the retreat of Valders ice, Lake Huron may have drained into Lake Michigan through Mullet and Burt Lakes and the northern interlobate lakes by a system of connecting channels to Grand Traverse Bay, thence from south to north through Lake Leelanau and along the front of the ice at an elevation of about 620 feet (Hough, 1955). This interesting possibility would have the combined waters of lakes Erie and Huron (Lake Lundy) passing into the Calumet stage of Lake Chicago along the lakeward margins of the study area (Fig. 7).

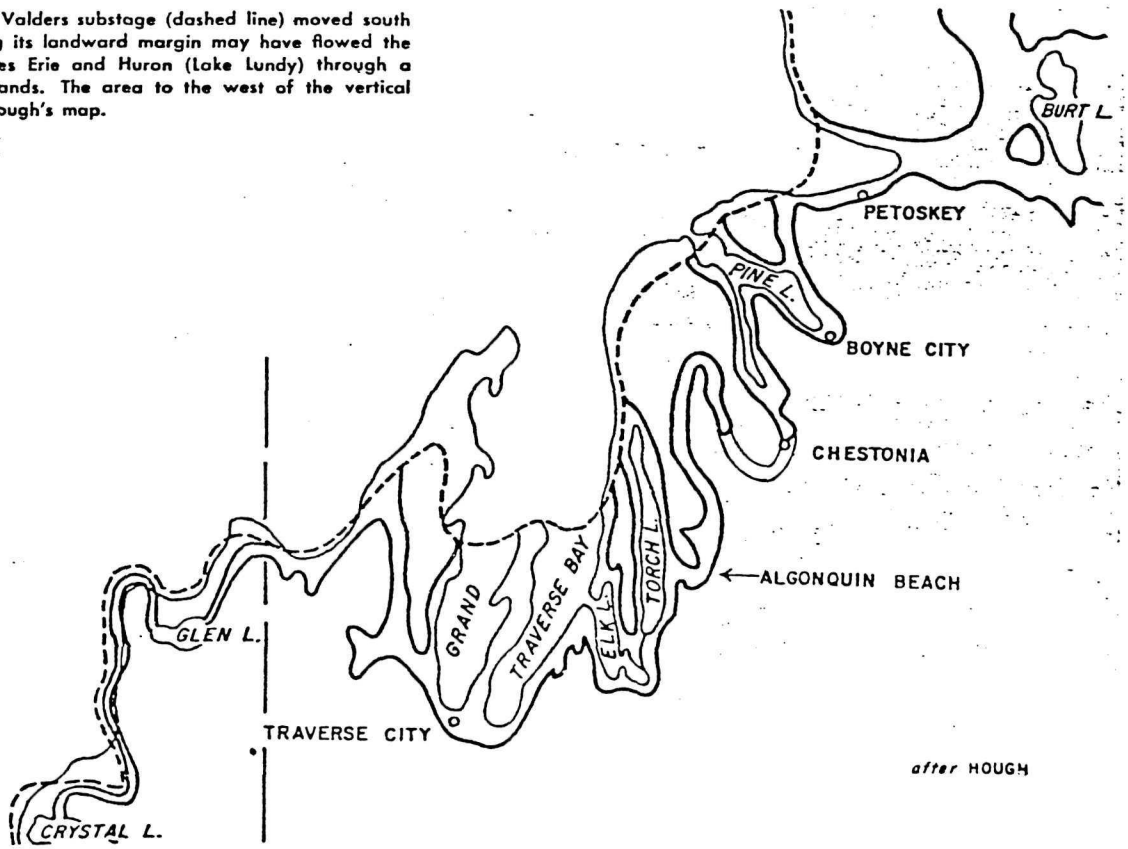


Fig. 7. Glacial ice of the Valders substage (dashed line) moved south to the study area. Along its landward margin may have flowed the combined waters of Lakes Erie and Huron (Lake Lundy) through a series of lakes and lowlands. The area to the west of the vertical line is an extension of Hough's map.

Post-Glacial Lake Stages

Following the retreat of Valders ice, the Grand Traverse region was never again to be glaciated. Though the continental glacier continued to diminish to the northward, its net effect on the study area was not entirely lost, for, though the inland topography had been ordained by Port Huron ice, the shoreline was to undergo tremendous changes in the maturation of the glacial and post-glacial Great Lakes.

FOUR IMPORTANT LAKE STAGES

Lake Chicago existed south of the study area during the Port Huron and Valders substage but had no effect on it other than that the drainage from the study area flowed southwesterly toward it. It is with the beginning of early Lake Algonquin that the post-glacial shore features began to be developed. Those changes were continuous but are left in visible evidence by four lake stages: the Algonquin, the Nipissing, the Algoma and the present Lake Michigan. The changes are connected with static levels of the lake of sufficient duration to create prominent shore features in the form of wave-cut terraces and beaches. Such evidence is found everywhere on the Great Lakes in one form or another, but is probably nowhere any better developed than in the Platte Embayment, Glen Lake, Good Harbor Bay and the bordering moraines of the Sleeping Bear, the Empire Bluffs, Pyramid Point and on South Manitou Island. The maturation of the shoreline is still continuing and its influences have had a marked effect on the botanical history of the area, as will be seen in a later section of this report.

THE HINGE LINE

When the Algonquin stage came into being at an elevation of 605 feet, the ice in the Lake Michigan basin had nearly or completely disappeared, though eastern Lake Superior still lay beneath the glacier (Hough, 1958). The Algonquin stage was not continuous, but was marked by low water stages, changes of outlets and other features of great interest generally but not unusually pertinent to the study area. This information has been ably summarized by Hough (1958), and those seeking further information are recommended to his work.

In the main, it is important that Lake Algonquin existed at an elevation of 605 feet above sea level (25 feet above present Lake Michigan) and that it occupied this elevation long enough to strongly influence its shoreline. It was terminated by a constantly lowering succession of Lake levels ending with the Chippewa low water stage at an elevation of 230 feet above sea level.

At the beginning of the Lake Algonquin stage, the study area would have consisted of long peninsulas (the interlobate moraines) and islands interspersed with deep, narrow bays (Fig. 8). By the end of Algonquin time, shore maturation would have succeeded to the point of truncating the moraines and sealing off at least part of the bays with bars and beaches.

During the glacial epoch the tremendous weight of the accumulated ice had caused a depression of the great land mass below it. The depression was greatest near the centers of glaciation, least at its outer margins. With the complete wasting away of the ice a gradual upwarping of the depressed area began. The extent of this upwarping can be measured by the Lake Algonquin beaches which in the southern ends of Lake Michigan and Huron still stand at 605 feet above sea level, but which have been found at a level of 1,015 feet in northern Lake Huron indicating a rise of 410 feet. The point at which uplift ceases is known as the hinge line and lies just south of the study area (Fig. 9). Consequently, uplift was not great in the study area, but was significant enough to separate the shore

Fig. 8. During early Algonquin times the shoreline of the Sleeping Bear region was very irregular and much longer than at present.

features of Lake Algonquin from those of Lake Nipissing which also occurred at an elevation of about 605 feet. However, since uplift had occurred between the two stages, Nipissing shore features lie lower than those of the Algonquin stage and, therefore, have not obliterated them except locally along shores where erosion has been pronounced.

A rather protracted interval of time separates the Algonquin and Nipissing stages, during which much of the upwarping took place. Thus in the study area, Nipissing beaches are only mildly or not at all inclined above the horizontal (Fig. 9). The lake basin was, during this interval, occupied by several low water stages whose shores lay below the present level of Lake Michigan. In this interval, normal erosive forces were dissecting the landscape. Thus as the Nipissing waters rose, their destructional power filled-in valley mouths and truncated intervening ridges.

With the termination of the Nipissing stage, the waters of the Lake Michigan basin never again, until the present, reached a stable level for a sufficiently long period of time to form any features as strongly marked and well developed as the Nipissing shoreline. The closest approach was the Algoma stage at an elevation of about 595 feet. Evidence of the Algoma stage is found as a fossil beach on the Platte Plains, but Algoma features generally lack the dynamic clarity of the Algonquin and Nipissing stages.

SHORELINE MATURATION

During early Algonquin time, the waters of the lake were circulating along a veritable maze of shore features in the northern end of the basin. Headlands, islands, long narrow bays were soon under the attack by the lake waters. The erosional power of the waves ate away the

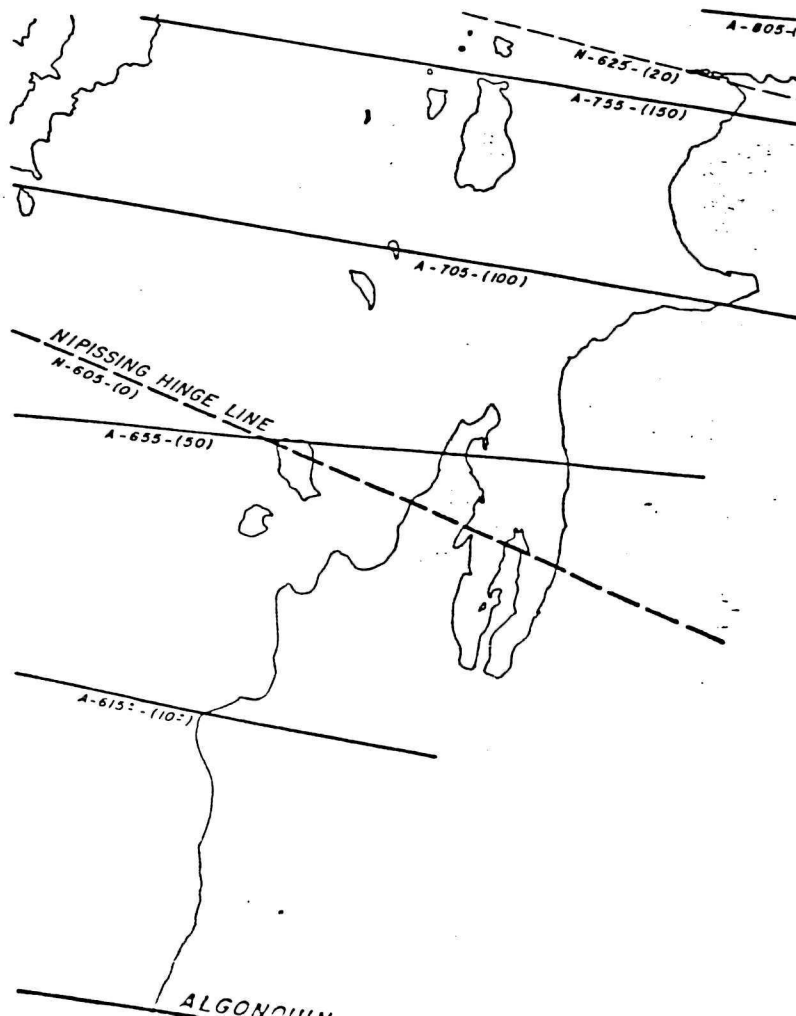


Fig. 9. Algonquin and Nipissing hinge lines with elevations in feet above sea level and the number of feet of uplift to the north of the lines shown in parentheses.

headlands and islands and the depositional forces built bars across the mouths of the bays thus separating them from the main lake. Likewise, during Nipissing times, this process was furthered as it was again somewhat during the less well defined Algoma stage. The present lake level continues this work with the net result being a filling of embayments and a cutting away of moraines (Frontis Map). The shoreline consequently has become more regular and will continue to do so in the future as the processes continue.

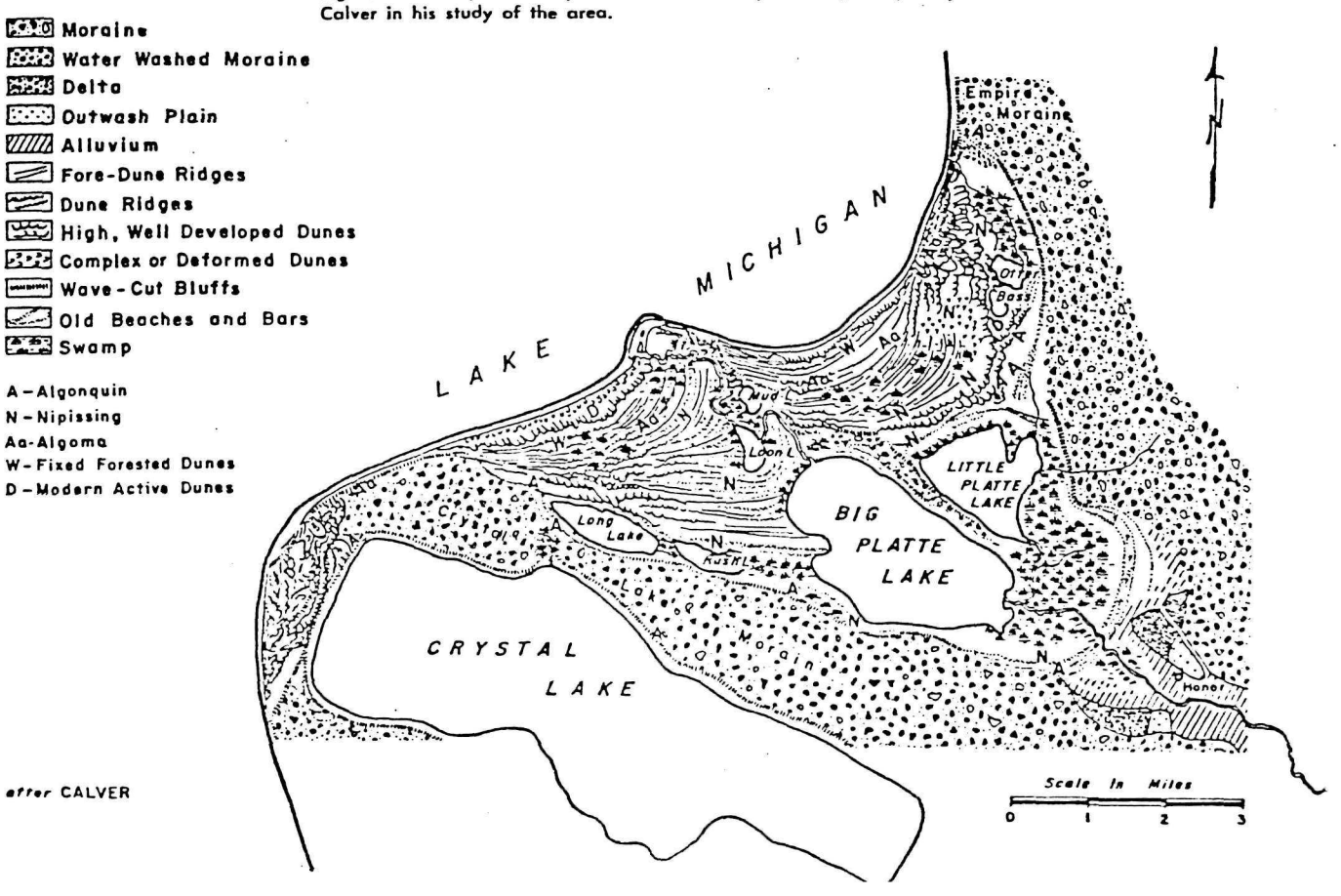
The only detailed work on the shorelines of the study area was done by (Calver, 1946) in the Platte and Crystal Lake depressions. Detailed work on the Bar Lake Embayment, Glen Lake, Good Harbor Bay and South Manitou Island needs to be undertaken, but based on a cursory examination, on evidence brought to light by Calver and others, on the general rule of shore maturation and on evidence obtained from topographic maps, a set of general conclusions can be set forth.

Originally, the waters of Lake Algonquin covered all the land in the study area to approximate elevations that, following upwarping, lie at about 615 to 620 feet, varying, of course, on the distance north of the hinge line. As shown in Fig. 8 this would have produced a most ragged shoreline—one which could not long remain unchanged.

THE PLATTE PLAINS

Along the headlands, evidence of previous lake stages has been destroyed by continuing erosive action of Lake Michigan waters. It is in the four mainland embayments with their surrounding moraines that the graphic details of shore maturation and previous lake stages is best preserved. Of these the Platte Lake Embayment or depression is by far the most complex and interesting. It is the largest of the four embayments. It lies in the form of a triangle roughly 8 x 8 x 6 miles along its sides. It is nearly equally divided by the small Platte interlobate moraine. It contains nine lakes with two separate drain-

Fig. 10. The complex history of the Platte Embayment is portrayed by Calver in his study of the area.



ages. It contains the greatest complex of beach ridges, swales and dunes in the study area.

Originally the Platte Embayment was a bay in Lake Algonquin with the interrupted Platte Moraine appearing as islands. A well defined wave-cut terrace is incised in the Crystal Lake Moraine along the south side of the embayment. West of Honor the shoreline leaves the moraine as a bayhead bar to cross to the west morainal boundary where it continues with two interruptions to the Empire Bluffs. Similarly, well defined terraces are found in the section of the interlobate moraine between Platte Lake and Little Platte Lake. Details of Algonquin, Nipissing and Algoma features for the Platte Plains are shown in Fig. 10.

The Platte Moraine, though partially washed over in Algonquin time, was, following uplift, eventually capable of asserting enough influence on currents, by acting as a barrier to water transported sediments, to form two bays during the Nipissing stage. The Nipissing shoreline impounded a large lake including Long, Rush, Big Platte and Little Platte Lakes and possibly the Otter Creek Lakes. The Algoma stage is less clearly marked and more closely related to the present shoreline than the two previous lake stages.

NIPISSING DUNES

The larger dunes of all the embayments are thought to be associated with the Nipissing stage; generally this is the story along the entire eastern shore of Lake Michigan. It should however, be pointed out that dune formation continues along the present shoreline and that many of the larger active dunes are associated with these continuing processes; namely, the Aral Dunes, Sleeping Bear Dunes, Pyramid Point Dunes and various dunes on South Manitou Island. Alignment of dune ridges indicates that some variation of westerly winds and of lake currents flowing along the shore counter-clockwise was effective in filling the embayments (Frontis Map).

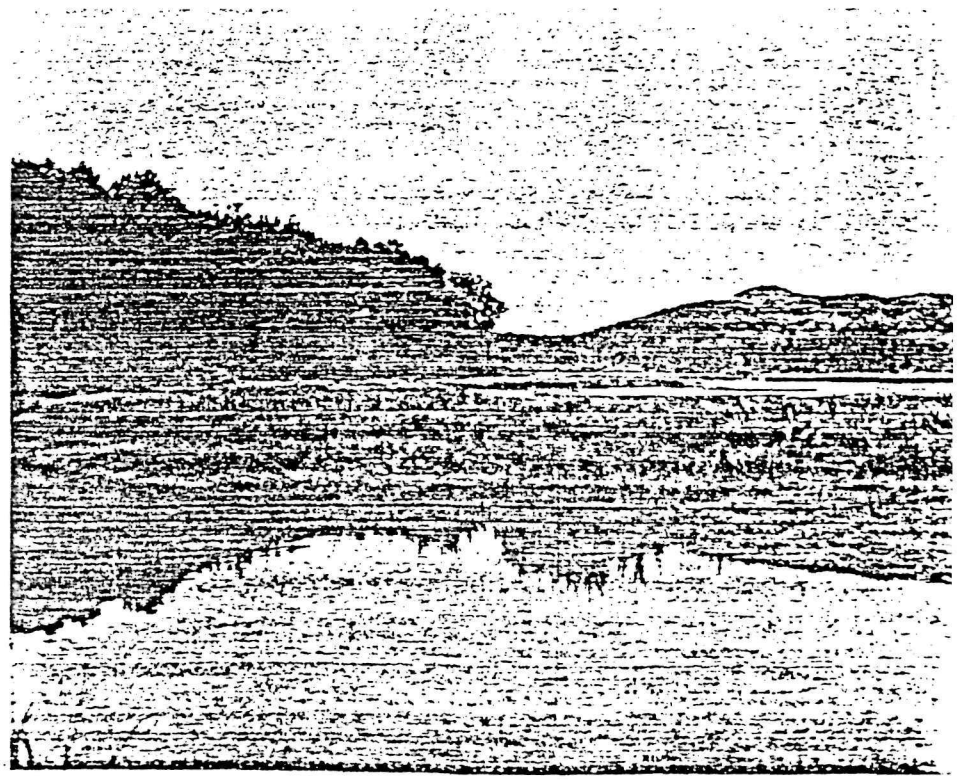


Fig. 11. A now extinct lake, its bed heavily underlain with marl, occupied the flat marshy area through which Otter Creek flows today. Dunes of the Aral complex, now stabilized with trees (left), were encroaching upon this lagoon.

THE OTTER CREEK AREA

Under the wave-cut bluffs east and north of the Otter Creek lakes are a series of cold flowing springs. Drainage from these springs is generally southwesterly towards Otter Creek which flows contrarily towards the north-northwest. It is in this area that a now extinct lake once existed (Fig. 11), the bed of which is heavily underlain with marl deposits. In one place where marl had been dug out of a pit to a depth of several feet, large numbers of springs bubble up through the marl creating a most unusual pattern. The pool is literally filled with algae of various species. Interspersed with this green backdrop are large patches of grey, patches from 3 inches to 1½ feet in diameter, all bubbling like cauldrons in various stages of agitation. The pool has dimensions of about 60 to 110 feet.

Otter Creek, itself, is short, hardly over two miles long counting the connections between its three lakes, and has practically no watershed in the Platte Plains. Yet even during periods of protracted drought it carries a remarkable volume of water. It seems apparent that it is almost entirely spring fed from the springs aforementioned, and that these derive their waters, in part, from subterranean flow in the old Glen Lake glacial drainage from about midpoint in the large Empire meander southward. It seems fairly possible that Otter Creek once drained into the Platte Embayment to the south but that filling of the embayment by the Nipissing beach lines and dunes cut off this flow. Later drainage to the north may have been responsible for the extinction of the former Otter Creek Lake.

BAR LAKE EMBAYMENT

The Bar Lake Embayment is slightly over three miles long and less than one and one-half miles wide. Along its northeast boundary it is bordered by the steep, wave-cut slope of the Sleeping Bear Moraine. At Schauger Hill and along the north part of this slope, Lake Algonquin was undoubtedly the eroding agent. Beyond the point, the Algonquin shoreline continues as a series of prominent beach ridges about two-thirds of the way between Lake Michigan and the inner edge of the embayment. They pass directly through the town of Empire to their connection with the Empire Bluffs. Behind the shoreline lay a concentric lagoon, still discernable as a low depression. The remainder of the wave-cut slope, whose base elevation (640-700 feet above sea level) is too high to be influenced by Algonquin waters, must be related to earlier ice border lakes or drainages.

During Nipissing times both the Empire and Sleeping Bear Moraines projected further lakeward than at present. Within this more deeply indented shoreline, copiously suppled with sands from the Empire bluffs, and perhaps the Sleeping Bear bluffs, a shoreline was built spanning the embayment and creating a crescentic lagoon in its lee. A series of large dunes developed along the barrier beach and in time dissected the lagoon creating North and South Bar lakes. Continued erosion of the two flanking moraines has since straightened the shoreline, and erosion is cutting away the Bar Lake Dunes.

GLEN LAKE

At Glen Lake, the most prominent shoreline feature is the steeply wave-cut north face of the Glen Lake Moraine which continues easterly as a well developed beach ridge along the north side of Glen Lake. At its eastern end this ridge curves northward as a less pronounced series of beach lines to adjoin the wave-cut terrace at Prospect Hill. It is not known to the writer whether this represents the Algonquin or Nipissing stage, but the latter is suspected.

The west arm of Glen Lake once opened northwesterly to Lake Michigan between the Sleeping Bear and Glen Lake moraines. Such a channel has longe been filled by the sands of the Sleeping Bear Dunes. The steep, wave-cut morainal slopes west and northeast of Burdickville

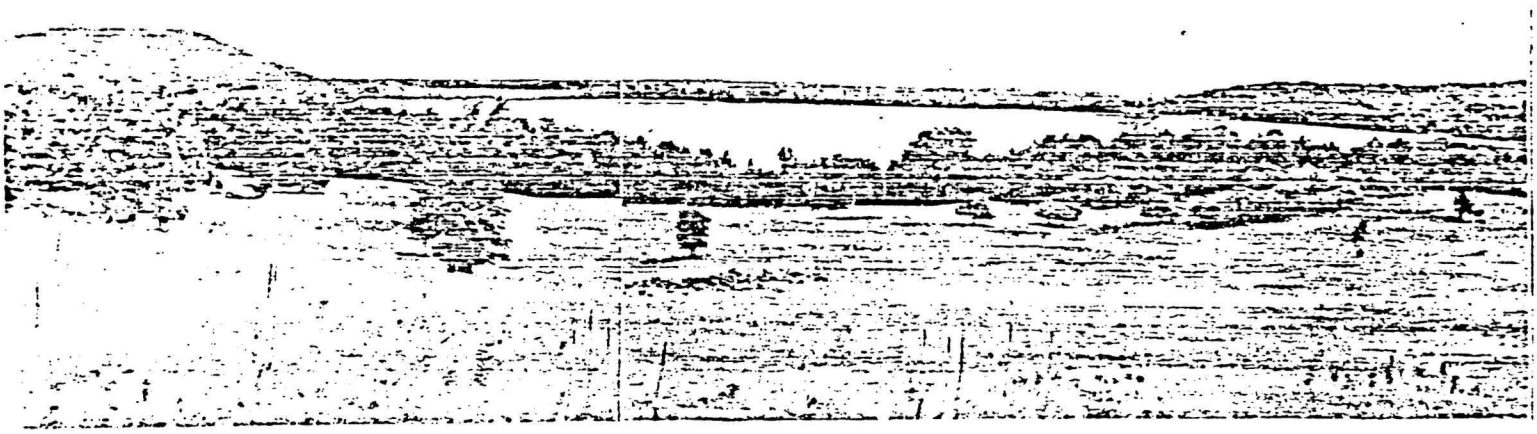


Fig. 12. View of School and Bass Lakes in low area between two morainal segments. These lakes were sealed off during Algonquin times. An Algonquin wave-cut bluff is apparent on the lakeward side of the highland at the right of the picture.

were cut during the Algonquin time and it is probable that Glen Lake was open to Lake Michigan during that time.

In Good Harbor Bay, Bass, School and Lime Lakes were closed off early in Algonquin times. All three of these lakes lie at an elevation of 620 feet (Fig. 12). Later, during Nipissing time, Little Traverse Lake was sealed off by a wide crescentic belt of dunes similar to those along Michigan Highway 22 in the Platte Embayment. Shell Lake, however, has probably been closed off by the Algoma or the present shoreline.

SLEEPING BEAR MORAINE AND DUNES

The work of shoreline modification goes on today and its most dramatic work is seen in the Sleeping Bear Moraine. Storm waves continue to eat into the loosely aggregated till of the Sleeping Bear Moraine along a three mile front. The clay is carried away in suspension, the sand and finer gravel are removed by longshore currents and the larger materials are washed over by the sand laden waves and partially eroded in place. Some of the sand is transported south but most of it moves north and east. Thus a general molding of headlands to the north and northeast is apparent. The large, solitary dune at Pyramid Point lies on the lee or east slope of the morainal headland from which it derives its materials. Exposed only to northwesterly wind, the dune is consequently moving to the southeast.

The dunes of Sleeping Bear are moving predominantly to the northeast. However, they are also affected to some extent by northwesterly winds. Thus, while their general line of advance is apparent, it is locally and periodically frustrated by the northwesterlies. This gives the dunes their soft flowing contours described by Cowles (1889) as a "restless maze".

The dunes are being derived from the constantly deflating morainal plateau and part of the sand is actually obtained from the barren face of the bluff. The numerous ventifacts (wind sculptured rocks) clearly show the abrasive influence of sand transported atop the morainal plateau by westerly winds (Fig. 13).

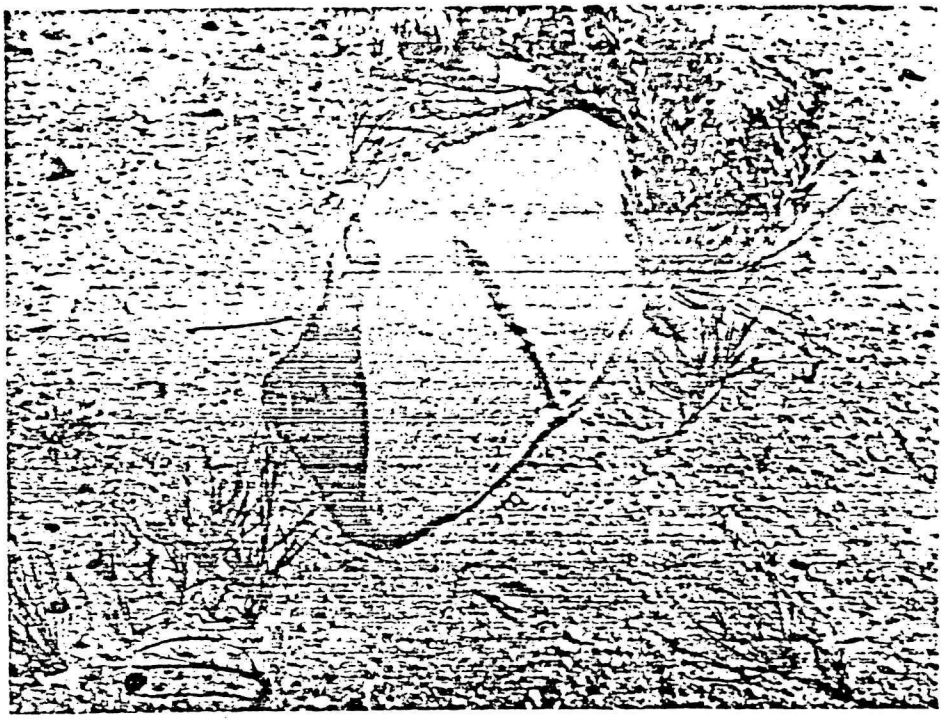


Fig. 13. Atop the morainal plateau of the Sleeping Bear are a number of glacial erratics carved by wind-transported sand. In the boulder shown, the veins of quartz are more resistant than the granitic matrix and thus stand out in relief.

Dune Development

TWO TYPES OF DUNE FORMATION

One of the most impressive features of the post-glacial period has been the construction of several dune complexes in the study area. Their development is continuing to the present and is best observed in the Aral Dunes, the Sleeping Bear Dunes and on South Manitou Island. It becomes immediately apparent to the observer that the dunes are of two sorts: those built at or near lake level as concentric or arcing lines showing some relation or alignment with the present shoreline, and those perched dunes showing a direct relationship to eroding headlands. Acknowledging this to be the case, it then becomes evident that of the two natural lake forces or processes, deposition and erosion, each is indirectly responsible for a type of dune complex, though the wind is the effective agent in the actual dune construction. This concept is important in explaining the present perched dunes and their varying stages of development.

THE EMPIRE DUNES

The Empire Dunes comprise a southern and northern section. They are not at present united. They are, in fact, separated by an interval of nearly a fourth of a mile and are not even aligned in the same direction (Fig. 15). Those of the south section are oriented from southwest-northeast. Those of the north section are generally aligned from northwest to southeast; however, Old Baldy Dune, an active blowout of the extreme south end, is aligned with the south section.

Calver (1946) contends ". . . that the effective wind direction for any one period may be diametrically opposed in adjacent localities" and ". . . that the effective wind direction in any one locality may shift as much as 90 degrees over a period of time". In large part this is borne out by the Empire Dunes.

Reconstructing the Empire morainal headland as it must have once looked, it will be seen

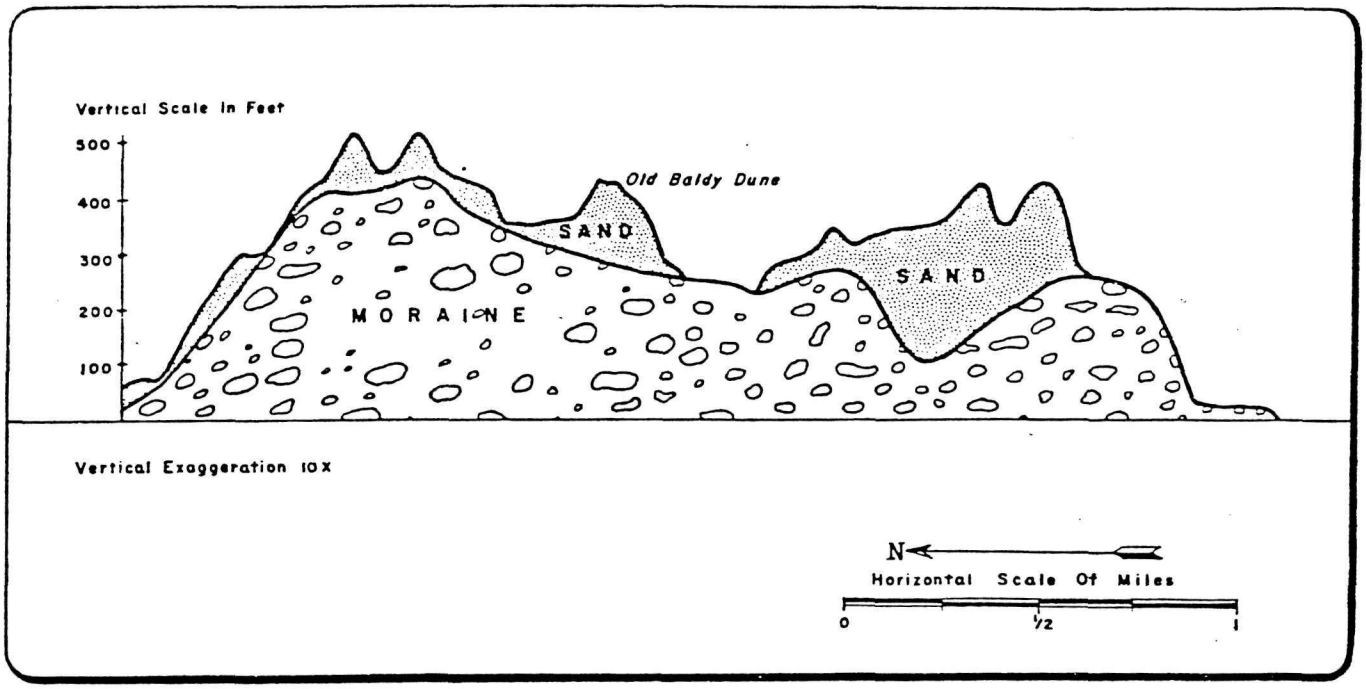
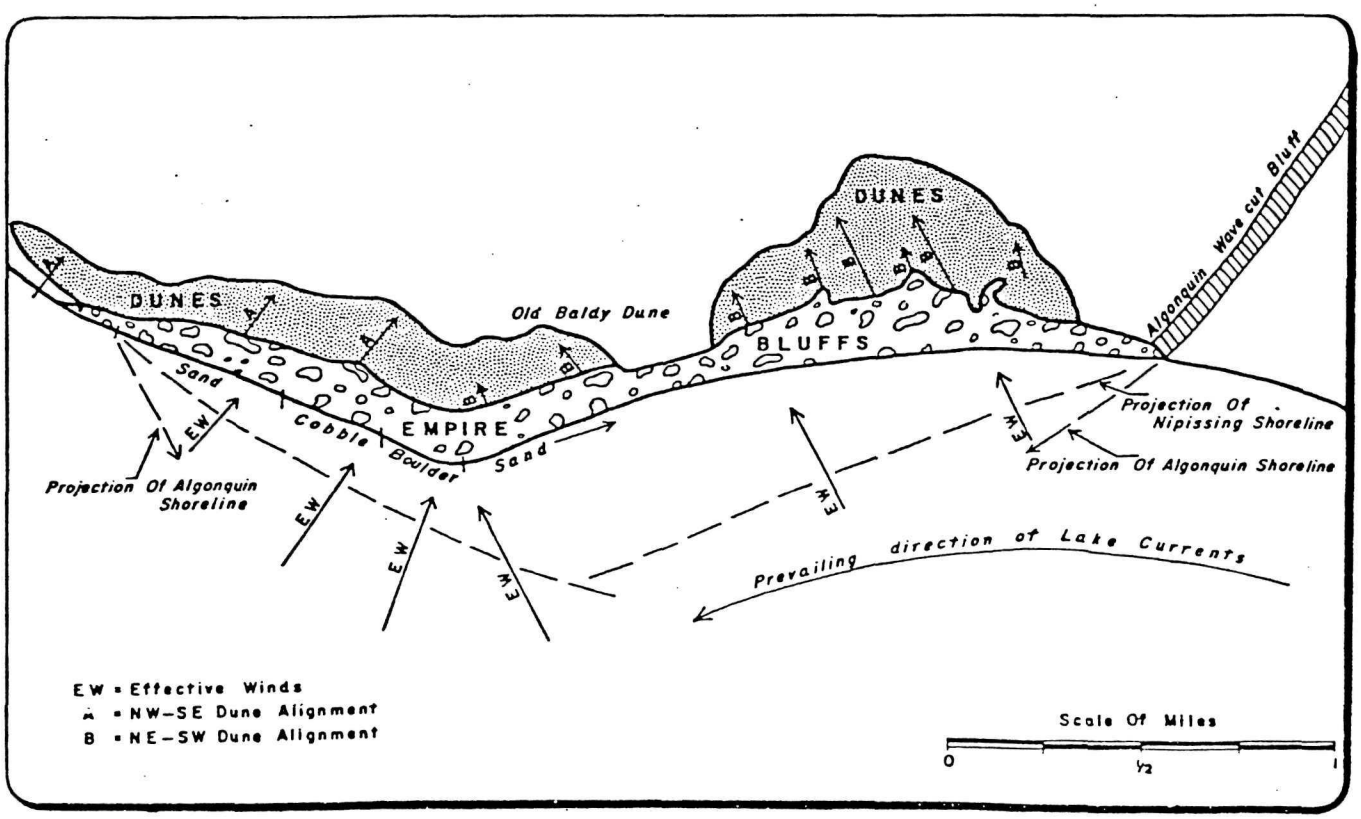


Fig. 14. In this schematic drawing of the Empire Bluffs as they would appear from a point offshore on Lake Michigan, the dunes are seen to be in two sections. Old Baldy dune is shown to be in the northern section of dunes. Seen below, however, it is seen that it is south of the point of the bluffs and consequently most affected by southwesterly winds.

Fig. 15. Alignment of dunes, shape of bluffs and nature of beach material are indicators of prevailing lake currents and effective winds. Part of the area shown as bluffs below the dunes is in reality the eroded face of the dunes.



that the lake erosion would be most effective from the southwest in the south portion and from the northwest along the north side. Further, based on known facts of lake currents and prevailing winds, it is probable that erosion was more rapid along the south side of the moraine than at the north. Thus a larger series of dunes accumulated.) However, since erosion has been greater from the southwest, the point of the headland has been shifted progressively north and east until effective winds at Old Baldy Dune are no longer from the northwest but from the southwest. That is to say that Old Bady now lies in the lee of the headland as far as northerly winds are concerned, and is thus affected mainly by those winds from the southwest. (Figs. 14 & 15).

Erosion along the south section of the Empire Bluffs has terminated as indicated by the foredune ridge between bluff and beach, and by the covering of trees on the bluff. The perched dunes are completely stabilized with deciduous forest. On the north section, erosion continues both north and south of the point. Consequently, several active blowouts occur.

SLEEPING BEAR DUNES

On the Sleeping Bear Dunes erosion continues actively. Here the processes of headland dune formation can be studied firsthand. As the moraine wasted away under the impact of storm waves, a tremendous amount of gravel, sand, and cobble was deposited to the northeast of the moraine. As erosion continues, the headland is being cut back to the point where some of these earlier depositional features are being reworked. These fossil beaches are plainly evident at, and southwest of, Sleeping Bear Point.

It seems probable that at some stage a system of high, perched dunes developed along the western face of the Sleeping Bear Moraine, of which the Sleeping Bear Dune is a solitary survivor. As the moraine diminished to the landward these dunes were rejuvenated and blown over the lee or northeast slope of the moraine where they lie today. Additionally, they probably lie atop a series of dunes built in the lee of the moraine by northwesterly winds, however, no direct evidence of this was discerned.

On the Sleeping Bear Moraine, as the northern end of the moraine is eaten away, erosion becomes more effective to the south. There, at Schauger Hill, several long linear blowouts are rejuvenating formerly stabilized sand. A short way to the north all evidence of former dunes has been removed, the moraine being graded to a nearly level plateau. Along the face of this bluff, former ravines running lakeward now act as wind funnels for the movement of sand up the bluff and inland.

At Pyramid Point only northwesterly winds are effective in dune formation, and the single large dune lies partly on the moraine and partly on the adjacent lowland, straddling the wave-cut bluff. (Fig. 16).

On South Manitou Island effective winds blow from nearly every quarter as would be suspected from its insular position. Neverthless, the largest and most active dunes are associated with southwesterly winds and the receding headland at the southwest corner of the island. A technique for dating the older perched dunes throughout the study area would shed valuable light on their time of origin, which in any case was not pre-Algonquin.

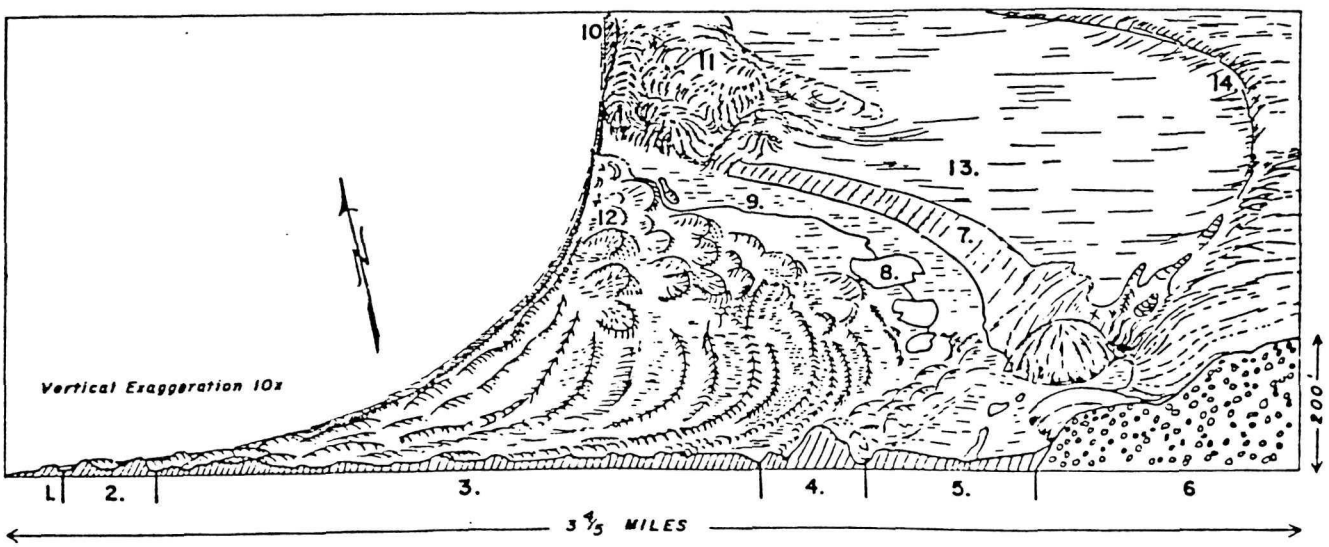
DUNES OF THE EMBAYMENTS

The dunes of the embayments are associated with lake levels from Algonquin times to the present. Principally, however, they are related to the Lake Nipissing and present shorelines. Lake Nipissing was a rising water stage following the extreme low level of Lake Chippewa. Possessing great destructional power, it sharply truncated the several headlands of the area, liberating a tremendous amount of sand and other sediments for the filling of embayments. The stage was of sufficient duration to build high storm beaches on which the wind could act in the formation of dunes.

Fig. 16. The massive dune at Pyramid Point is derived from the sands of the eroding headland and is fashioned by northwesterly winds.

Features of the Otter Creek Area

1. Beach and foredune
2. Deflated zone
3. Ridge and swale area
4. High dune ridges
5. Platte Lakes lowland
6. Moraine
7. Otter Creek Bluffs
8. Otter Lake
9. Otter Creek
10. Empire Bluffs
11. Empire moraine
12. Aral dunes
13. Glen Lake channel
14. Meander slope



BIOLOGY SECTION

Introduction

During the glacial epoch, arctic vegetation undoubtedly occurred everywhere near the margins of glacial ice, just as it does today in glaciated regions throughout the world. As the ice advanced, the marginal zone of arctic vegetation maintained a position ahead of the glacier; and as the ice wasted away, the vegetation reclaimed the land formerly lost to it. This was a relatively slow process so it is not entirely correct to think of a vast deglaciated region as being utterly devoid of plant life, though such a zone, usually quite narrow in width, undoubtedly existed along the glacial border.

The sequence of vegetative succession on the postglacial topography is still being worked out in detail by such techniques as the study of pollen grains in successive peat layers of bogs. Generally it is safe to say, however, that the movement of plant species from south to north was, and is, an orderly process, progressing from those arctic types capable of withstanding a severe climate through various stages of conifer forest (spruce-fir, spruce-tamarack, pine, etc.) and the still advancing deciduous forests of today. Though several thousand years have elapsed since the retreat of the ice, and though in a general way the principal plant associations are well established, it will be the purpose of this treatise to show the continuing progression of plant succession based on the glacial and post glacial phenomena, lake stages, soil, climate, moisture, exposure and other factors operating within the study area.

Plant Succession and Floral Diversity

THE RANGE OF SUCCESSION

In any land area bordering on a large and active body of water there is likely to be a beach zone essentially devoid of plant life. This is particularly true if the beaches are sandy, if offshore water is deep, and if prevailing winds move landward across the water. Such is the case on the eastern shoreline of Lake Michigan. In the study area, beach sands represent the most resistant residue of gravel, rocks, and boulders of the heterogenous glacial till, rounded and made nearly indestructible by the wave-induced abrasive grinding of each grain to near spherical proportions against its fellow grains. On the wet beach, that area subject to highest summer wave action, the sand is constantly washed and shifted by the water and is the most severe environment in the area, no plants at all being able to survive upon it. At the other extreme lies the climax deciduous forest of the moraines, the ultimate to which all other types are verging. Between these two extremes, and between the extremes of quiet inland lakes and climax forests, are a host of well defined intermediate plant communities which are displayed in the Sleeping Bear region in remarkable clarity and detail.

THE TIME AND PLACE OF EARLY ECOLOGICAL STUDIES

Before the turn of the present century, Dr. H. C. Cowles began studying the ecological intricacies of one side of the story: that of succession from sand beach to climax forest. Working in the sand dune region that borders the eastern and southern shores of Lake Michigan, he drew his inferences, facts, and conclusions in large part from two areas which best represent the dune complex on the Great Lakes: the Indiana Dunes of Indiana and the dunes and adjacent area of the Sleeping Bear region.

Speaking of the later he says:

> *"This advancing dune is far and away the grandest along Lake Michigan, presenting an almost continuous front, measuring four kilometers from north to south, all in active progression. The average height above the country on which it is encroaching is about 60 meters, so that it presents a most imposing sight when viewed from the fields in front of its line of advance. The dune complex at Glen Haven (Sleeping Bear Dunes) is like that at Dune Park (Indiana Dunes), but on a far grander scale; sometimes there are hollows within it more than 30 meters in depth scooped out by the wind, and reaching down to ancient beach." (Cowles, 1889)*

THE BEACH AS A PLANT ENVIRONMENT

All the beaches of the study area are of sand, gravel, cobble or boulders, with sand beach predominating and with sand occurring, of course, in all types of beach. Except for some possible algal growth on the boulders, the wet beach is truly devoid of plant life.

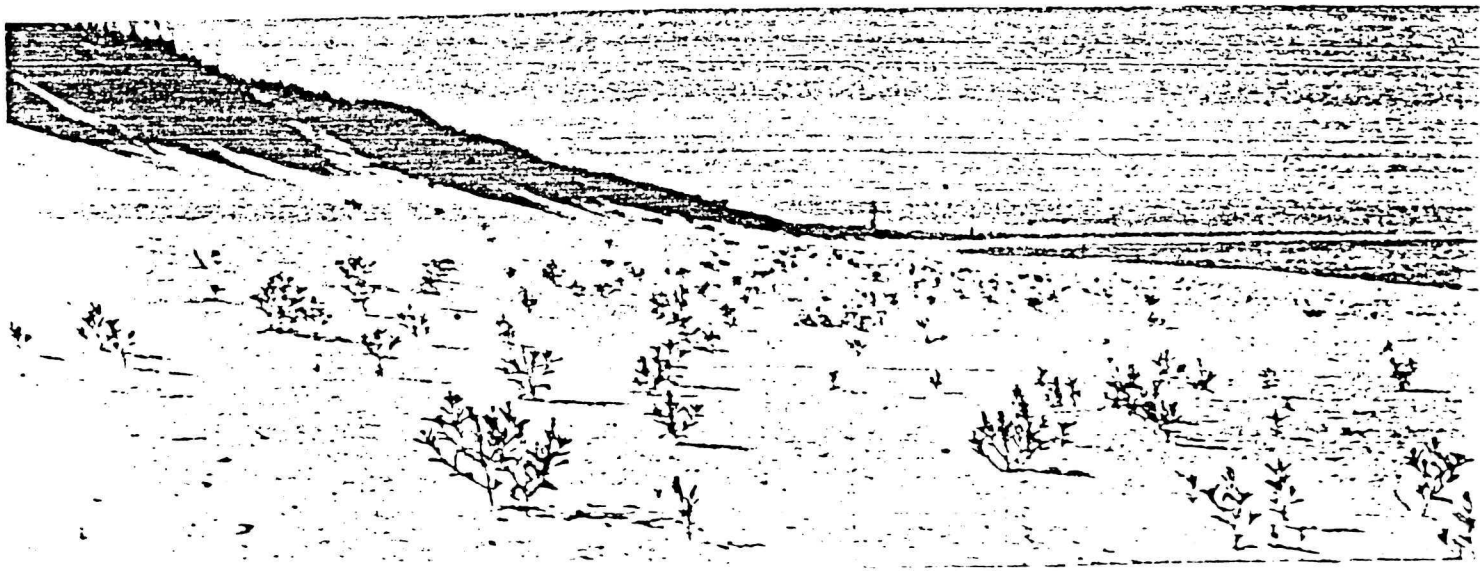
On the middle beach, that area which is washed by the high waves of winter storms, one plant occurs. This is the American searocket (*Cakile edentula*), a succulent annual with floating seed capsules. This member of the mustard family (Fig. 1) is common on both the shores of our Atlantic Coast and the Great Lakes.

On the upper beach, beyond the reach of the highest winter storm waves, is an austere environments of shifting wind blown sand weak in nutrients and unprotected from the icy winter winds that blow in off Lake Michigan. Unlike the middle beach, however, it is free from winter storm waves and thus is capable of supporting biennial and perennial plants in some number.

CONSTRUCTION OF THE FOREDUNE

One of the most striking geological and botanical features of the area is the strongly pronounced foredune of the Platte Plains from the Empire Moraine southwest to near the mouth of the Platte River. The beaches of the Platte Plains are receiving a continual increment of

Fig. 1. American searocket is the only plant commonly found on the middle beach.



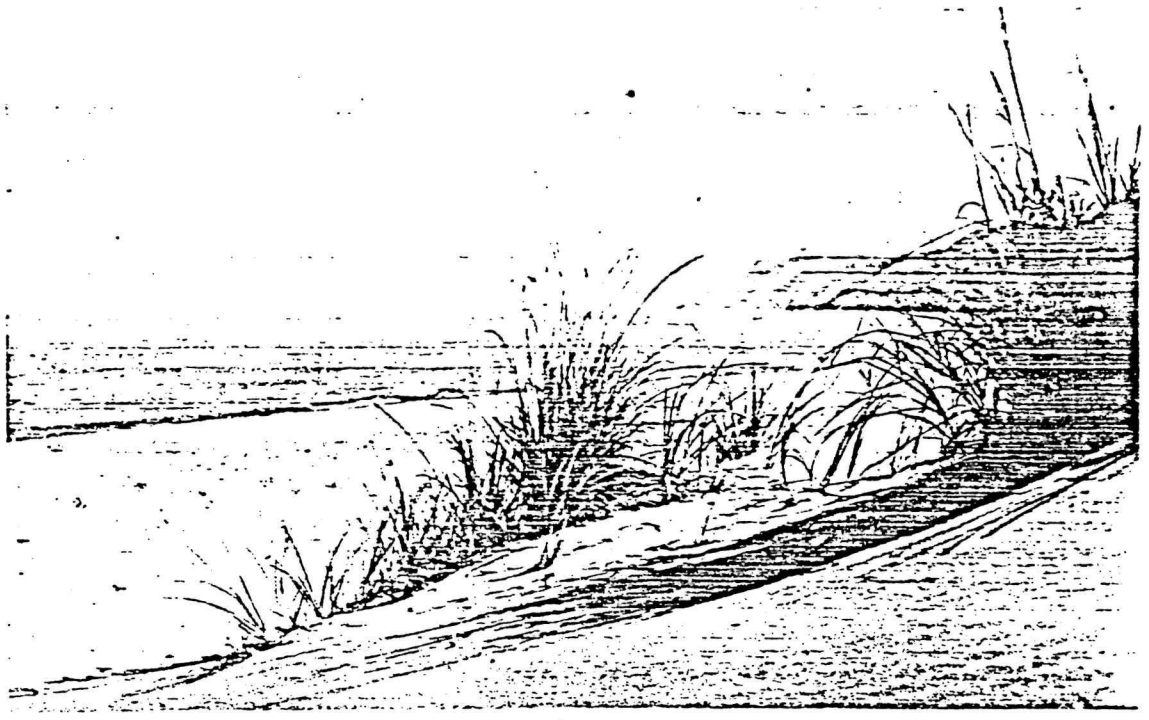


Fig. 2. American beachgrass, a pioneer sand binder.

sand by subaqueous transport via longshore currents from the vicinity of Betsie Point and elsewhere. Once the sand is moved upon the beach beyond the influence of the waves, it is at the mercy of the wind until it reaches some obstruction where the velocity of the wind is checked. In this manner are dunes constructed.

With the formation of even a small dune, a suitable habitat for American beachgrass (*Ammophila breviligulata*) is created. This coarse, attractive grass is the pioneer sand binder in the study area, spreading rapidly by rhizomes and capable of existing on the rawest of sands (Fig. 2). Indeed, it has been stated that beachgrass flourishes only when annually covered by a new layer of sand (Waterman, 1922a). Since the grass acts as a barrier to wind transported sand, fresh layers are assured and a dune ridge behind the beach is soon created. Over the years as more sand is added, a foredune is constructed by the combined influence of wind and plant.

Since in the Platte Plains the beaches are continually filling and extending lakeward, the foredune grows too, becoming continuous throughout its length and generally very broad and flat-topped though inclining lakeward. Beachgrass is very nearly the only plant on the windward edge of the dune, but once atop it, it shares its dominance with another tall grass, the prairie sandreed, a similar coarse grass with a feathery panicle of seeds, quite different from the whitish, spike-like heads of the beachgrass. It, too, spreads by rhizomes. In addition to these two grasses, a number of other plants are characteristic of the foredune.

The foredune is a marvelous example of the effect of plant life on geology. It is built through the interaction of wind, sand and plant. The wind transports the sand inland from the beach. The beachgrass binds the previously accumulated sand, and plant and dune act as a barrier to further free movement of wind and sand. Where the supply of fresh sand is abundant, the growth of beachgrass is luxuriant (Fig. 3); where the supply dwindles, the beachgrass thins and is replaced by other, less efficient sand binding plants. Thus the lakeward edge of the dune builds outward under the binding power of beachgrass. The inland margin, robbed of fresh sand and, consequently, of its most

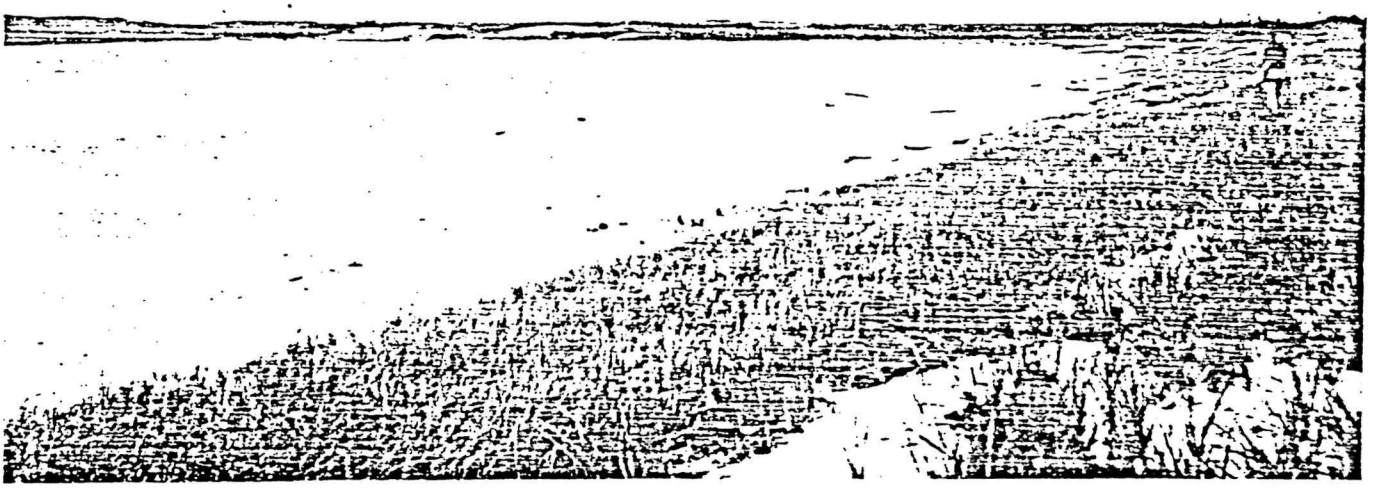


Fig. 3. Along the wide beaches of the Platte Plains, beachgrass grows luxuriantly on the gently sloping face of the foredune.

efficient sand binder, is gradually cut away by the winds. This process in part creates the customary trough or deflated zone behind the foredune.

The western half of the Platte Plains is remarkable for possessing a double foredune; a younger dune imposed upon an older, higher dune which is in the first stage of deflation.

THE DEFLATED ZONE

Inland from the foredune is a characteristic area of low jumbled dunes possessing a peculiar vegetation that has been referred to as heath (Cowles, 1889). As here described it represents a transition from the foredune to the tree-clad dunes and older beach ridges of the sand plains. It is a harsh environment, subject to drying by the wind in the full sweep of which it lies. The wind has lost its load of sand to the beachgrass of the foredunes, but is able to remove the scantily vegetated sand of the inland edge of the foredune and the deflated zone, though the area is better protected than the beach.

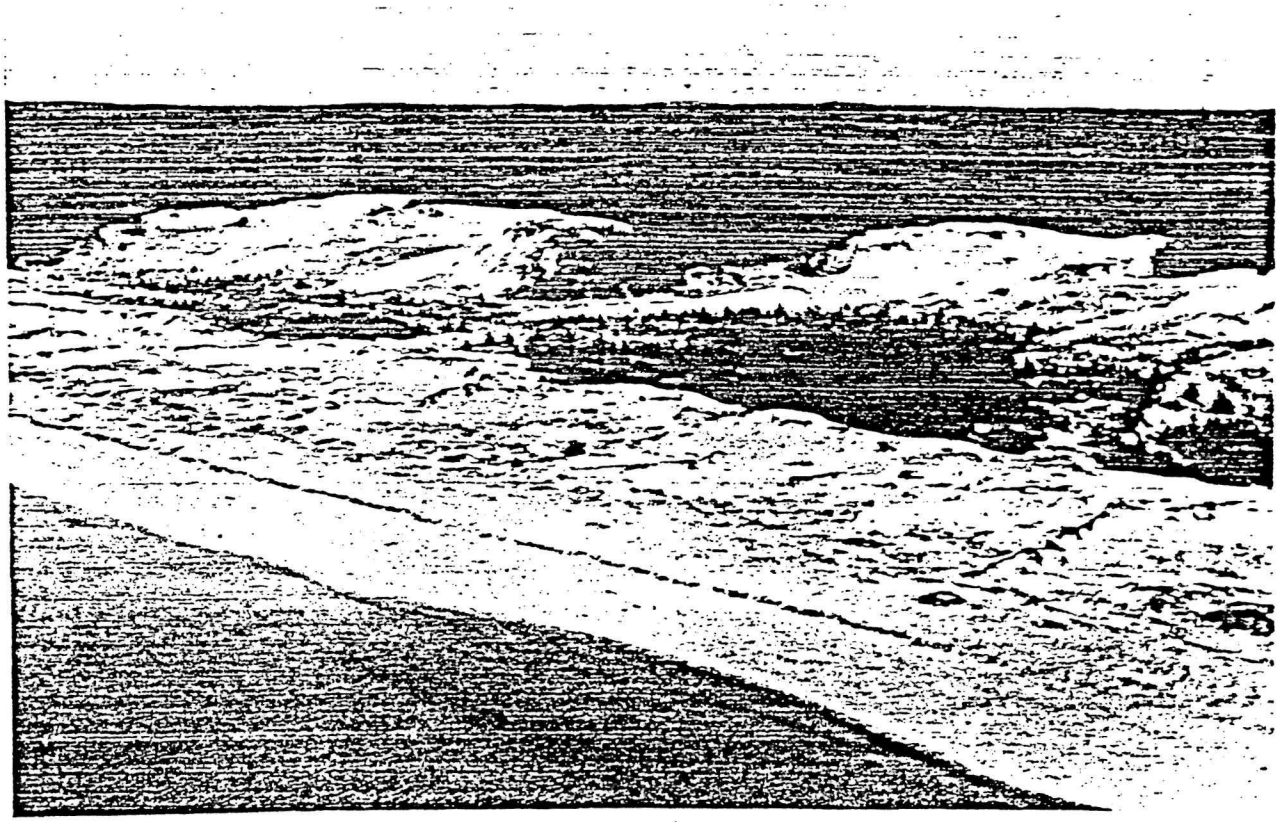
Despite some protection from the elements, the conditions of growth are rugged. Temperatures vary greatly during a 24-hour period and during the course of the year. A desert-like aspect pervades the area, and indeed, plants struggle not as much with each other as with the physical elements of their environment. Where the wind obtains a purchase on older vegetated dunes, a blowout may occur. Elsewhere the sand shifts very slowly into small dunes which may become partly stabilized before they wander on at the prompting of the wind.

Trees are not common in this zone, but they do occur sporadically. Jack Pine is most characteristic, but eastern cottonwood, balsam poplar and a few black spruce also exist. In some places where sand has been blown completely clear to the underlying beach deposits, small groves of jack pine may take root (Fig. 4).

Over much of this area a wiry bunchgrass known as little bluestem is the most common plant. Along with creeping juniper and bearberry, it is considered to be the most usual dune building plant in protected areas (Cowles, 1889).

Four evergreen shrubs, however, most characterize the landscape: bearberry, oldfield common juniper, creeping juniper (Fig. 5) and woolly beachheather. Sand cherry, common chokecherry, russet buffaloberry and other deciduous shrubs also occur. This type of environment is best represented behind the Platte Plains foredunes. It is also found on Sleeping Bear Bay, Good Harbor Bay, South Manitou Island and elsewhere, particularly as a successional stage on very sandy "old fields."

Fig. 4. At the base of the Aral dunes, where the sand has been blown bare to underlying beach deposits, small copses of jack pine have become established.



The Sand Plains Forest

The inland edge of the deflated area ends in an uneven line of partially stabilized and partially rejuvenated horseshoe shaped dunes, in the lee of which a rather abrupt transition takes place to sand plains forest or to older vegetated dunes.

THE ORIGINAL FOREST

The composition of the sand plains forest ranges from open woodland mixed with the heath, described above, to climax forest near the inner or morainal margin. The original species have probably varied little from prehistoric time, but numbers of a given species have undoubtedly fluctuated tremendously in response to environment factors, mainly fire, logging, and clearing for agriculture.

The Platte Plains, at least, of the sand plain forests had been burnt-over when the first white settlers arrived nearly 120 years ago. Whether started by natural causes (lightning) or set by

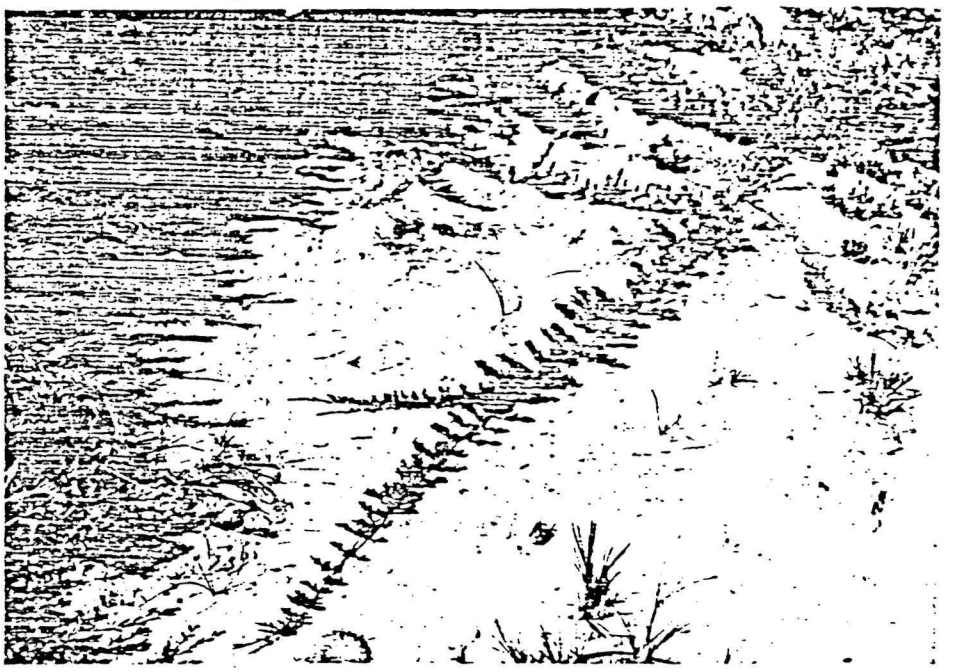


Fig. 5. Creeping juniper, one of the characteristic plants of the heath zone, advances into an area of open sand. Little bluestem grass, bearberry (lower left) and black spruce are other plant invaders.

Indians for hunting purposes or to encourage blueberry production is not known.

Nevertheless,

> *"... the sand ridge area was originally covered by a forest of pine and oak whose trees had reached considerable size. This forest had been burned before white settlers came to the region. Many of the dead trees were cut while still standing, and many of their stumps still remain. A few patches were not burned, perhaps being protected by neighboring bodies of water, and these give some idea of what the original forest must have been." (Waterman, 1922b)*

A representative segment of original sand plains forest is on the beach ridges and swales of Sleeping Bear Bay east of D. H. Day State Park. The vegetation changes rather abruptly from jack pine and heath, through red pine and jack pine, red pine and eastern white pine, eastern white pine with eastern hemlock understory to eastern hemlock and yellow birch and beech-maple forest on the slope of the wave-cut moraine. In the successional series jack pine seems generally to precede red pine which in turn precedes white pine, though the sequence is not invariable.

Logging has probably removed nearly all of the virgin red and white pine, and, without a doubt, jack pine, aspen, paper birch and red maple have been benefited by both logging and fires. Nevertheless, there is ample evidence to demonstrate a gradational sequence of species from the back edge of the blowouts across the filled embayments to the bases of surrounding morainal systems.

A SUCCESSIONAL TRANSECT

An excellent successional series occurs along a line beginning at the shoreline about two miles east of where the Platte River empties into Lake Michigan, thence proceeding east-southeasterly for over three miles to the Nipissing beach terrace in Section 30 (Geol. Fig. 17). Beginning at the beach and progressing inland beyond the foredune, the deflated zone and the active dunes, one encounters a series of beach ridges crossing the transect obliquely. Reindeermoss is the most abundant plant of the shoreward edge of this zone. Scattered jack pines, oldfield common juniper, chokecherry, bearberry, creeping juni-

per, small amounts of bracken fern and blueberry also occur. This is essentially heath but the jack pines, though small and widely spaced, indicate recent invasion of this zone by a pioneer forest type.

Inland, the ridges decrease in height and the swales become broad and filled with rushes and grasses. Though the swales were mostly dry in July of 1959, they are probably wet during the spring months and following heavy rains. Aspen, white birch and scattered balsam fir, red pine (Fig. 6), white pine and northern red and white oaks occur on the broad ridges, but jack pine remains preponderant. Near the southeast corner of Section 23, a broad flat area with closed stands of jack pine occurs, but east of it in Section 25 begins a series of dunes nearly a fourth of a mile wide. Michigan Highway 22 parallels this line of dunes from the north end of the Platte Lake Moraine northeastward to a place where the highway climbs from the lowlands to the outwash plain above. In these dunes, jack pine gives way gradually to white pine, red pine, northern red oak and white oak, red maple, quaking aspen and bigtooth aspen. East of the highway, the transition continues with white oak and pine dropping out, with aspen and white birch occurring in cutover stands, and with sugar maple, American beech, eastern hemlock, American basswood and white ash advancing into the plains from the morainal slopes. Similar transitions are found on South Manitou Island, Sleeping Bear Bay and Good Harbor Bay, but in none of these are the individual stages as well pronounced or the gradation as gradual.

In the understory a neat succession also occurs with reindeermoss giving way gradually to bearberry, creeping juniper and oldfield common juniper, thence to black huckleberry, blueberries, bracken fern and finally to characteristic plants of the hardwood forest understory.

Fig. 6. A red pine-aspen stand on the Platte Plains. The trees are young, but already the understory is opening up and receiving sunlight. Groundcover is mainly bracken fern.

DIVERSITY OF PLATTE PLAINS FLORA

The same factors that have made the Platte Plains complex geologically have affected the flora: namely, the Algonquin and Nipissing shore features, the interlobate Platte Lake Moraine, the impounded waters of the inland lakes, the draining or filling with marl of an old Otter Creek lake, the great dune complex near the northern end of the Plains, the beach and swale topography throughout and the constant increment of fresh sand along the bay shores.

SAND RIDGE FLORA

Principally the forests of the drier sandy ridges are composed of jack pine, red pine, big-tooth aspen, quaking aspen, red maple, paper birch, northern red oak and white oak. Less important is pin cherry, downy serviceberry, balsam fir and eastern hemlock. It is nearly impossible without more field work to determine which species are most numerous. Near the lake northeast of Platte Point, vast expanses of jack pine occur almost to the exclusion of other trees (Table 1). Beautiful groves in which red pine is dominant occur elsewhere. West of Otter Lake are nearly pure stands of paper birch, and in other places aspen of both species may predominate. White oak, fairly common between Platte Lake and Platte Point, is of somewhat scattered occurrence, and in places is completely absent. Northern red oak is of fairly wide distribution but is found mainly with red and white pine.

Only eastern hemlock of the upland species is found far out on the plains. Occurring behind the blowout dunes of the southwestern part of Platte Plains, it reaches nearly to the Lake Michigan shore. A boxelder tree, observed only once in the entire study area, was found in this same habitat.

THE ASPEN ASSOCIATION

Near the morainal borders of the Platte Plains one is struck by the absence of pine as compared to the outer reaches of the Plains and by the great increase in the aspen association. This consists primarily of big-tooth aspen, quaking aspen and paper birch with lesser amounts of balsam poplar and pin cherry.

These trees are, of course, common components of the sand plains flora and are thus successional. They are also pioneer trees of disturbance areas, rapidly invading all types of soil in advance of later climax stages. Fire is undoubtedly the chief benefactor of these trees, though they are found to a small extent in old fields and heavily logged-over area.

On the Platte Plains they form a definite zone between the maple-beech forest and the sand plains forest. Through most of this area, this forest type may have been encouraged by disturbance of the maple-beech forest; but it seems also, at least on the more moist inner margins of the Platte Plains, to be a natural successional stage between the xeric sand plains forest and the maple-beech forests of richer soils.

TABLE 1. Composition of two 10,000 square foot samples on the Platte Plains. The upper is in the NW¼, Sec. 13, T27N, R15W. The lower is in the middle of the N½, N½, Sec. 25, T27N, R15W on flat, sandy ground.

Tree Species	Number of Trees	% of All Trees	Diameter Breast High in Inches 1-3	4-6	7-12	13-24	24+
Jack Pine	68	86.1	38	15	15	—	—
Red Maple	3	3.8	3	—	—	—	—
Pin Cherry	3	3.8	3	—	—	—	—
Big-tooth Aspen	2	2.5	—	1	1	—	—
Balsam Fir	2	2.5	2	—	—	—	—
Red Pine	1	1.3	—	—	1	—	—
	—		—	—	—	—	—
TOTAL TREES	79		46	16	17	0	0
	% OF TOTAL		58.2	20.1	21.7	0	0
Red Pine	39	33.6	9	11	19	—	—
Trembling Aspen	23	19.8	23	—	—	—	—
Big-tooth Aspen	22	19.0	20	1	1	—	—
White Pine	18	15.4	1	6	11	—	—
Red Maple	9	7.8	4	2	3	—	—
Red Oak	3	2.6	—	1	2	—	—
Shad Bush	1	0.9	—	1	—	—	—
White Oak	1	0.9	1	—	—	—	—
	—		—	—	—	—	—
TOTAL TREES	116		58	22	36	0	0
	% OF TOTAL		50.0	19.0	31.0	0	0

PLATTE MORAINE FLORA

The Platte Plains interlobate moraine demonstrates more clearly than the surrounding sand plains the successional trends that are operative. Though disconnected from the surrounding morainal systems, it has, nevertheless, acquired four common species of the morainal forests: American beech, eastern hemlock, American basswood and eastern hophornbeam. The four species are, however, mixed rather thoroughly with northern red oak, red and white pine, red maple and aspen. Significantly, sugar maple is absent, nor does it occur anywhere away from morainal margins on the sand plains. Witch hazel, found commonly elsewhere only on the wave-cut morainal bluffs overlooking the Bar Lake Embayment, is a common large shrub on the section of moraine between Platte and Little Platte lakes.

SWALES AND DEPRESSIONS

A good share of the Platte Plains is below 600 feet in elevation, and much of this is only a little above the 580 foot elevation of Lake Michigan. Consequently, the majority of the swales are wet at least periodically, and this adds to the diversity of the flora. A complete successional series of swales could be worked out from water filled ponds through cedar swamps. In general the swales of the northeastern half of the plains tend towards nearly dry, bracken-filled depressions, grassy meadows, juncus bogs, leather-leaf bogs (some very dry), cattail marshes, shrub bogs (hazel alder, red chokeberry, mountain holly, willow, rose, low birch, redoiser dogwood, sweetgale, common winterberry and poison-sumac) and a few open ponds. In the southwestern portion, cedar bogs, alder thickets, and tamarack bogs are more frequent. Swamp forests of American elm, black ash, red maple, paper birch, balsam poplar and balsam fir are less common. Considerable deciduous swamp forest is found in the valley of the North Branch of the Platte River.

LEATHERLEAF BOGS

The prevalence of leatherleaf in many of the bogs of the northeastern half of the Platte Plains might be considered a successional stage perpetuated by fire, since this plant is not likely to be exterminated by fire, and because it makes a hasty recovery following fire (Gates, 1942). Leatherleaf, on practically dry ground, often rings grassy meadows north of the Platte Lake Moraine.

GRASSY MEADOWS

It is north of the Platte Moraine that the grassy meadows are best developed though they occur also to the south. Amongst and along the northern fringe of stabilized dunes which parallel Highway 22, the meadows alternate with leatherleaf bogs or occupy the center of the bogs. These meadows are small and usually rounded in outline. It is in the long, broad, low swales that the best developed meadows occur (Fig. 7). Some are upward of three-fourths of a mile long and 300 yards wide and in one ". . . a remarkable growth of *Lobelia cardinalis* (Cardinalflower) covered one acre of meadow with its scarlet flowers." (Waterman, 1922b).

SWAMP AND BOG FORESTS

Of forest types the swamp and bog forests are the smallest in areal extent though they are widely scattered across the sand plains and around the margins of lakes and streams. They are practically nonexistent on moraines and dunes, but seven species occurring commonly in swamp and bog forests; northern white cedar, American elm, balsam fir, white pine, red maple, paper birch and mountain maple, are found in such situations. The intimate association of white cedar and mountain maple throughout the area is interesting. On South Manitou Island the massive northern white cedars occur on the moraine near the south edge of the island just in the lee of, and on, the back slope of the perched dunes. And the numerous ghost forests of the region suggest that the growth of cedar in such

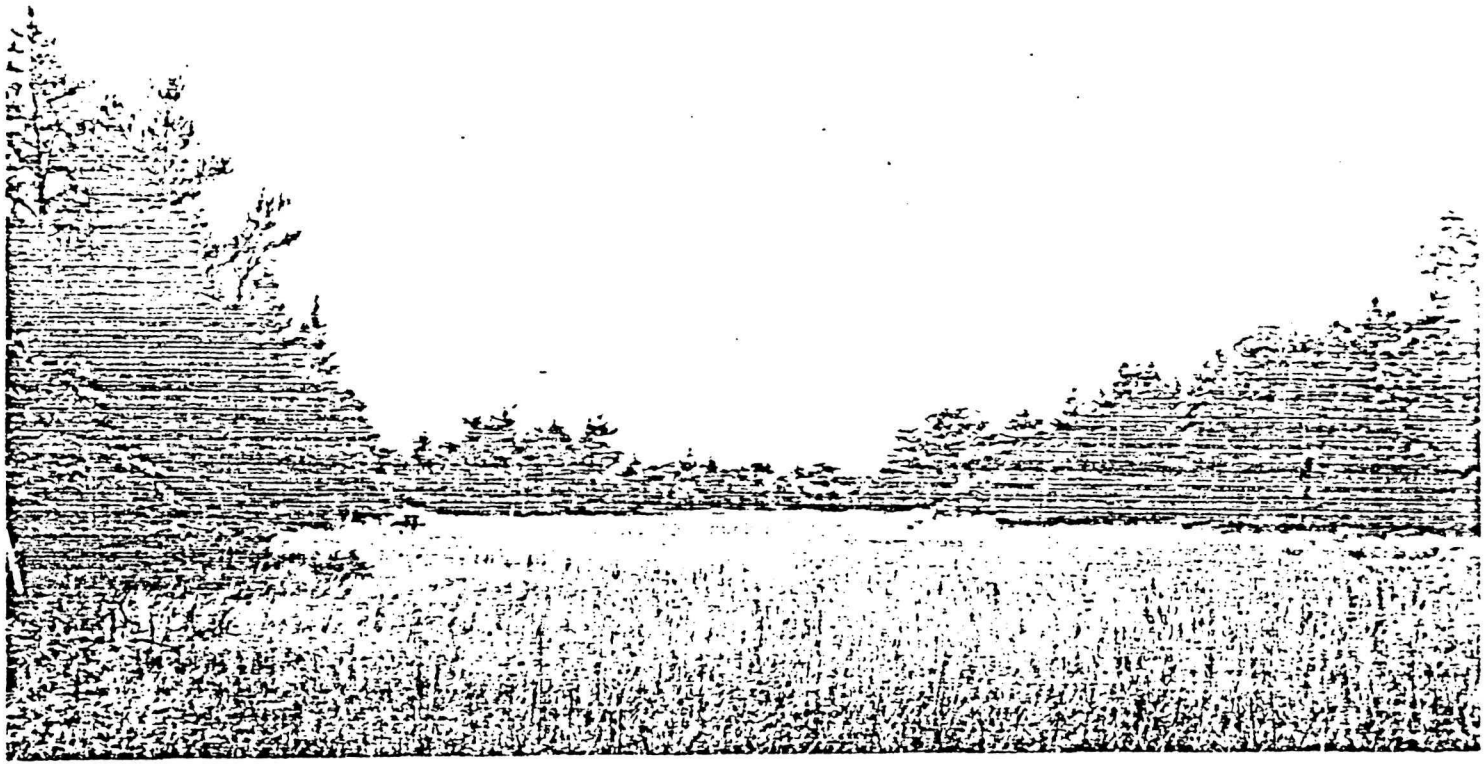


Fig. 7. The grassy meadows of the Platte Plains occur in the low swales between ancient beach ridges, the latter now grown up to jack pine forest.

situations has been a long continuing phenomenon, particularly on the perched dunes. Three other species: black spruce, black ash, and tamarack occur almost exclusively in bog or swamp forests though in the Otter Creek drainage some rather large tamaracks occur on dry sandy soil. The largest single stand of bog and swamp forest occurs east of the Platte Lakes (Fig. 8). Beginning east of Bay Point on Platte Lake it swings eastward in a wide arc along the old Algonquin beach lines turning finally northwest to the east side of Sylvan Point on Little Platte Lake. Much of the area is under water, and sphagmum and a host of the usual bog understory plants abounds.

SUCCESSION FROM LAKE TO MORAINE

Already discussed in detail has been the successional stages from sandy beach to climax forest. In the Platte Lake bog and swamp forest another classic successional stage from open water to climax forest exists. Beginning with the shallow shoreward waters of either Platte or Little Platte Lakes and progressing easterly to the moraine above Honor many of the stages outlined by Gates exist (Gates, 1942; Fig. 9).

CEDAR SWAMPS

Northern white cedar swamps are a highly characteristic forest type of this region. Because of widespread past cutting they exist largely as dense, cutover stands, but large stumps on a par with the virgin trees on South Manitou Island indicate their former size. Otter Lake is fringed by a ring of white cedar, and north of the lake along Otter Creek is a thick cedar swamp. So dense may be the cover that practically no sunlight filters to the ground, consequently little of the plant growth characteristic of cedar swamps is found.

In lowlands and swales north of Rush and Long Lakes, white cedar is a fairly common species, as it is also in other wet swales of the Platte Plains west of the mouth of the Platte River. The massive white cedars of South Mani-

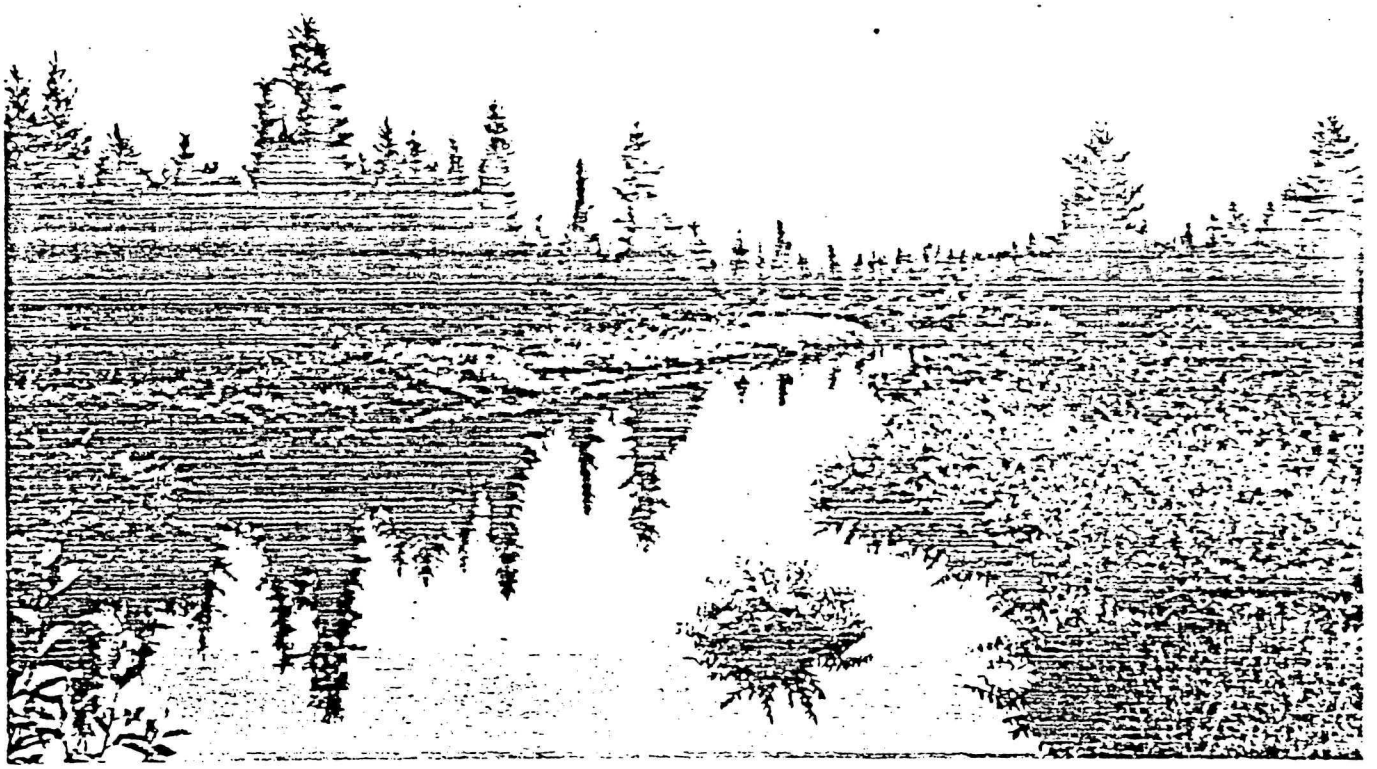


Fig. 9. The tamarack-spruce bog east of the Platte lakes is the largest of its kind in the study area. The plant in the water (right foreground) and along the edge of the stream is swamp loosestrife.

tou Island (to 4 feet d.b.h.), as noted, occur not in a swamp but on moist dunes and moraine. Along much of the exposed shore bluff cedar is also found, making it a species of wide environmental tolerance.

CONDITIONS OF SUCCESSION

On the four major bays of the study area, plant succession begins on the recently exposed increment of sand at the water's edge and works inward through more mature soils to the foot of the moraines. Vegetational succession also occurs following fires, and following the abandonment of agriculture in old fields. As conditions vary in each of those successional types so do the component species.

SUCCESSION ON WAVE-CUT MORAINES

General Description

A fourth type of succession has a peculiar relationship to the various lake stages from Lake Algonquin to the present. This is succession on wave-cut moraines. Because of the great time spread involved, the succession in places is essentially complete, though often the more usual maple-beech forest has not resulted. Instead, a hemlock-hardwood type has developed. One of the steepest and most dramatic of these bluffs angles southeast from Pyramid Point overlooking Shell Lake. The southwest face of the Sleeping Bear moraine, the Point Betsie Moraine, the Otter Creek Bluff and the Platte Moraine are other examples. The morainal bluffs of Sleeping

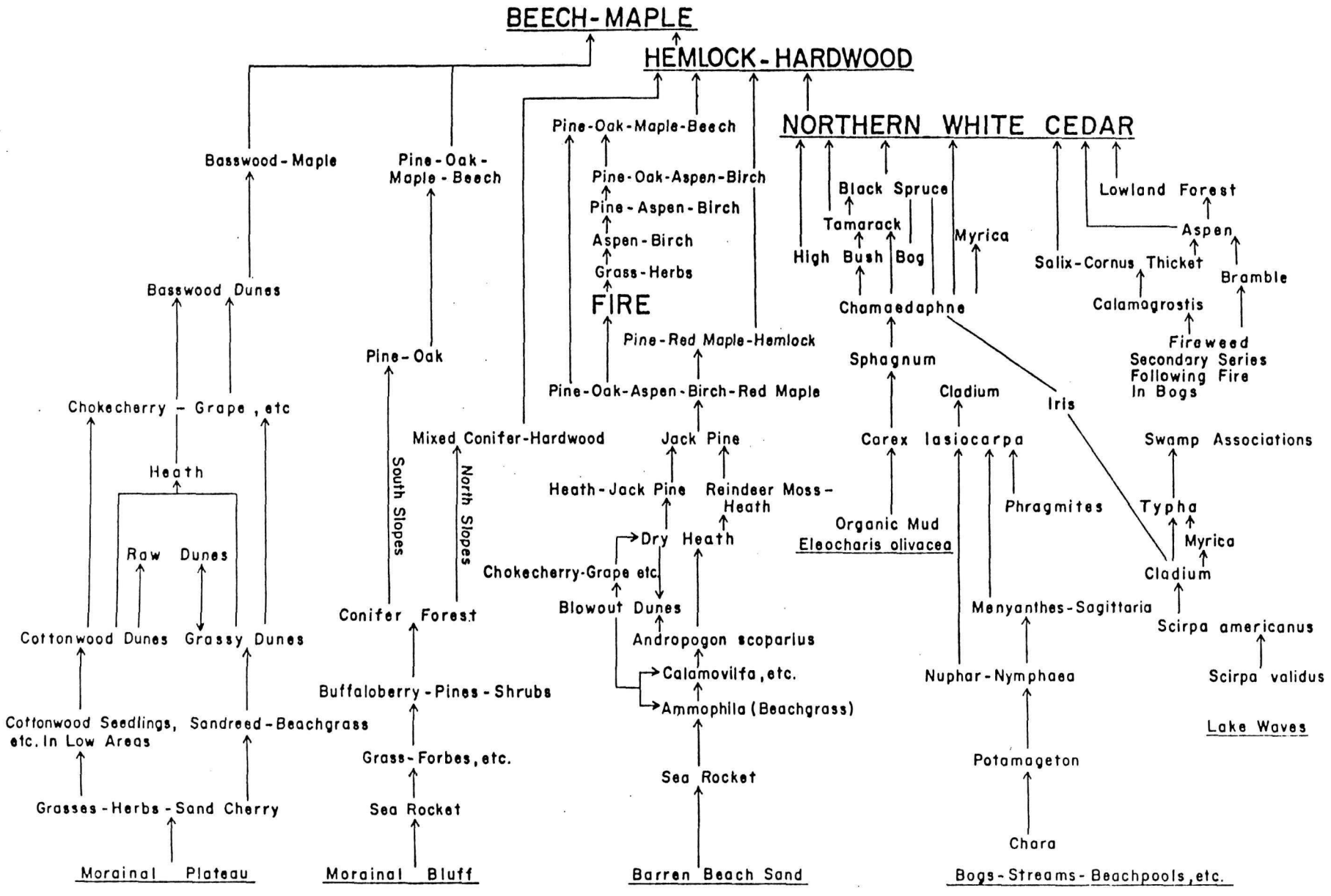


Fig. 9. General trends in the study area for several typical successional series. *The series for the morainal plateau and beach sands implies a progression from the plateau edge or shoreline inland The mesic or acquatic series under Northern White Cedar is taken entire from Gates (1942) There may be some question whether Northern White Cedar and Hemlock-Hardwoods tend towards Beech-Maple except as a moist to dryer series .*

Bear Dunes and of South Manitou Island are still being so actively eroded by Lake Michigan as to be largely without vegetation.

THE EMPIRE BLUFFS

Nowhere are the successional processes more clearly revealed than on the Empire Bluffs. Storm waves generated on Lake Michigan are still ravelling away a part of this moraine which is in places 300 feet high and locally topped by nearly 200 feet of perched sand dunes. At the point of the bluffs in Section 25 the steep slope is only scantly clad with grasses, herbs, and bushes. Progressing southward, such bushes as buffaloberry become more frequent and occasionally small trees begin to enter the vegetational make-up. From the middle of the shoreline in Section 36, a forest, mainly of conifers (balsam fir, red pine, white pine, and some white cedar), begins to descend the slope obliquely from the top of the bluff reaching to the beach along the north edge of Section 1. Slumpage, indicating the instability of these slopes, has caused the trees to lean crazily at many points and in one place erosion has cleared a wide swath on the bluff about 100 yards wide. South of this point, near the middle of the shore, in Section 1, the conifer stands are more stable and the trees are larger. It is at about this point that a subtle change takes place.

The foredune of the Platte Plains continues northerly from Otter Creek where it comes in contact with the wave-cut bluff of the Empire Moraine. For nearly half a mile on the gently concave shoreline north of Otter Creek it persists with scarcely any abatement in size. Eventually, however, the trough between it and the bluff becomes pinched off and, finally, near the middle of the shoreline in Section 1, the dune itself ceases as the depositional and erosional processes achieve a state of equilibrium. North of this point the bluffs are still subject to erosion.

TABLE 2. Composition of two forest samples. The upper is of an area approximately 10,000 square feet on the steep, wave-cut face of the Empire Bluffs in the NW¼, SW¼, Sec. 1, T27N, R15W. The lower is a 10′ to 30″ wide transect down the trough of a stabilized blowout dune from the lake shore to the crest of the dune in the NW¼, Sec. 13, T28N, R15W. The large number of species in both samples is typical of those environments.

Tree Species	Number of Trees	% of All Trees	Diameter Breast High in Inches 1-3	4-6	7-12	13-24	24+
Sugar Maple	38	24.2	26	9	2	1	—
Beech	29	18.5	*10	12	7	—	—
White Cedar*	23	14.6	18	3	2	—	—
White Birch	22	14.0	16	5	1	—	—
Hophornbeam	12	7.8	6	5	1	—	—
Red Oak	11	7.0	1	2	7	1	—
Balsam Fir	5	3.2	2	2	1	—	—
Pin Cherry	4	2.6	4	—	—	—	—
Black Cherry	4	2.6	2	—	—	2	—
Hemlock	2	1.3	—	—	1	1	—
White Pine	2	1.3	—	—	1	1	—
White Ash	1	0.7	—	1	—	—	—
Round Leaved Dogwood	4	2.6	4	—	—	—	—
TOTAL TREES	157		89	39	23	6	0
	% OF TOTAL		56.7	24.8	14.6	3.8	0

*The White Cedar, found in a low swale, is somewhat atypical

Balsam Fir	43	47.8	37	5	1	—	—
Big-tooth Aspen	11	12.2	—	2	9	—	—
White Birch	6	6.7	2	2	2	—	—
Beech	7	7.8	7	—	—	—	—
Sugar Maple	5	5.6	1	2	2	—	—
Red Oak	3	3.3	1	—	2	—	—
White Ash	3	3.3	—	2	—	1	—
Hophornbeam	3	3.3	1	2	—	—	—
Hemlock	3	3.3	3	—	—	—	—
Black Cherry	1	1.1	—	—	—	1	—
Shad Bush	2	2.2	1	1	—	—	—
Red Pine	1	1.1	—	1	—	—	—
White Pine	1	1.1	—	—	1	—	—
White Cedar	1	1.1	—	—	1	—	—
TOTAL TREES	90		54	17	17	2	0
	% OF TOTAL		60.0	18.9	18.9	2.2	0

TENSION BETWEEN SPECIES

On the bluff behind the foredune, the conifers begin to merge gradually into a mixed conifer-hardwood type. The tension between species struggling for dominance is clearly demonstrated in the 100 foot square sample taken behind the foredune from the edge of the trough up to morainal slope (Table 2). Though balsam fir is abundant, it figured only meagerly in the overstory; and red and white pine have nearly disappeared. The appearance of sugar maple, American beech and eastern hemlock permits no doubt as to the direction of the successional stage. A similar tension between species occurs on other wave-cut or very steep morainic ridges and on the dune forests of the Bar Lake

Embayment. Though the pattern has undoubtedly been distorted somewhat by human interference, the image is still clear. The following sample for the Bar Lake Dunes, taken from the crest of an old dune to the low sand bluff over the beach, demonstrates a somewhat advanced, but similar, condition (Table 2). The large number of northern white cedars is explained by a low swale just inland from the bluff and is somewhat atypical.

The Morainal Plateaus and Dunes

STERILITY ON ACTIVELY WAVE-CUT BLUFFS

The cutting away of the interlobate moraines projecting into Lake Michigan has been described under the geology section. The striking shoreline vistas of the study area have been the result. At Pyramid Point and the Empire Bluffs, lake erosion is abating; but for three miles along the front of the 400 foot high Sleeping Bear Moraine it is a very active reality (Fig. 10). Vegetation is practically nonexistent and the environment ranks with the wet beach in the severity of the conditions imposed upon plant life. Sand grains are actually carried bodily up the steeply inclined slope and it is probable that the dehydrating and abrasive effect of the wind and sand, as much as the rate of shoreward erosion, has limited plant growth.

CONDITIONS AND PLANTS OF THE PLATEAU

Atop the bluffs the great power of the wind is once again evinced in plateau-like grading of the exposed moraine (Fig. 10). Blowing in freely off Lake Michigan from three-quarters of the compass, the wind is constantly deflating the morainal till and is again responsible for the paucity and uniqueness of the plant growth. The net effect is best seen in the sand cherry striving to thrive in this inhospitable environment (Fig. 11). Its prostrate form and fan-like shape, and its general direction of growth toward the east-northeast, offer mute testimony to the influences of sand and prevailing winds.

A common species of this environment is the harebell, a plant often lifting its blue flowers to well over a foot in height. On the wind swept moraine, however, it is seldom over six inches high, and is often no more than two or three.

Plants with broad leaves would be subject to severe dissection, buffeting by the wind and abrasion by the wind driven sand. Thus, it is interesting to note that two of the common plants of this impoverished but interesting flora are the white camass and the harebell. The former, incidentally, is also dwarfed along the plateau edge and has long, linear, grass-like leaves. The harebell has a small rosette of broad, round leaves resting upon the ground, but above these the leaves are linear, offering almost no wind resistance. Their habit of spreading by underground roots has probably made it possible for them to migrate windward to the very edge of the bluff. Inland the force of the wind diminishes; and, in low basins east and northeast of the Sleeping Bear, vegetation of various sorts has become established. Eastern cottonwood, chokecherry, buffaloberry, grasses, herbs and other plants have taken root. These are generally the plants described for the beaches, foredunes and deflated areas of the Platte Plains and elsewhere.

THE SLEEPING BEAR DUNES

East and north of the morainal plateau are the remarkable Sleeping Bear Dunes. These dunes are almost entirely without the dune forests which characterize Betsie Point, the Empire Moraine and South Manitou Island. It could be no other way for the dunes are still advancing, reputedly at a rate of six feet per year (Waterman, 1922a). Large areas are entirely without

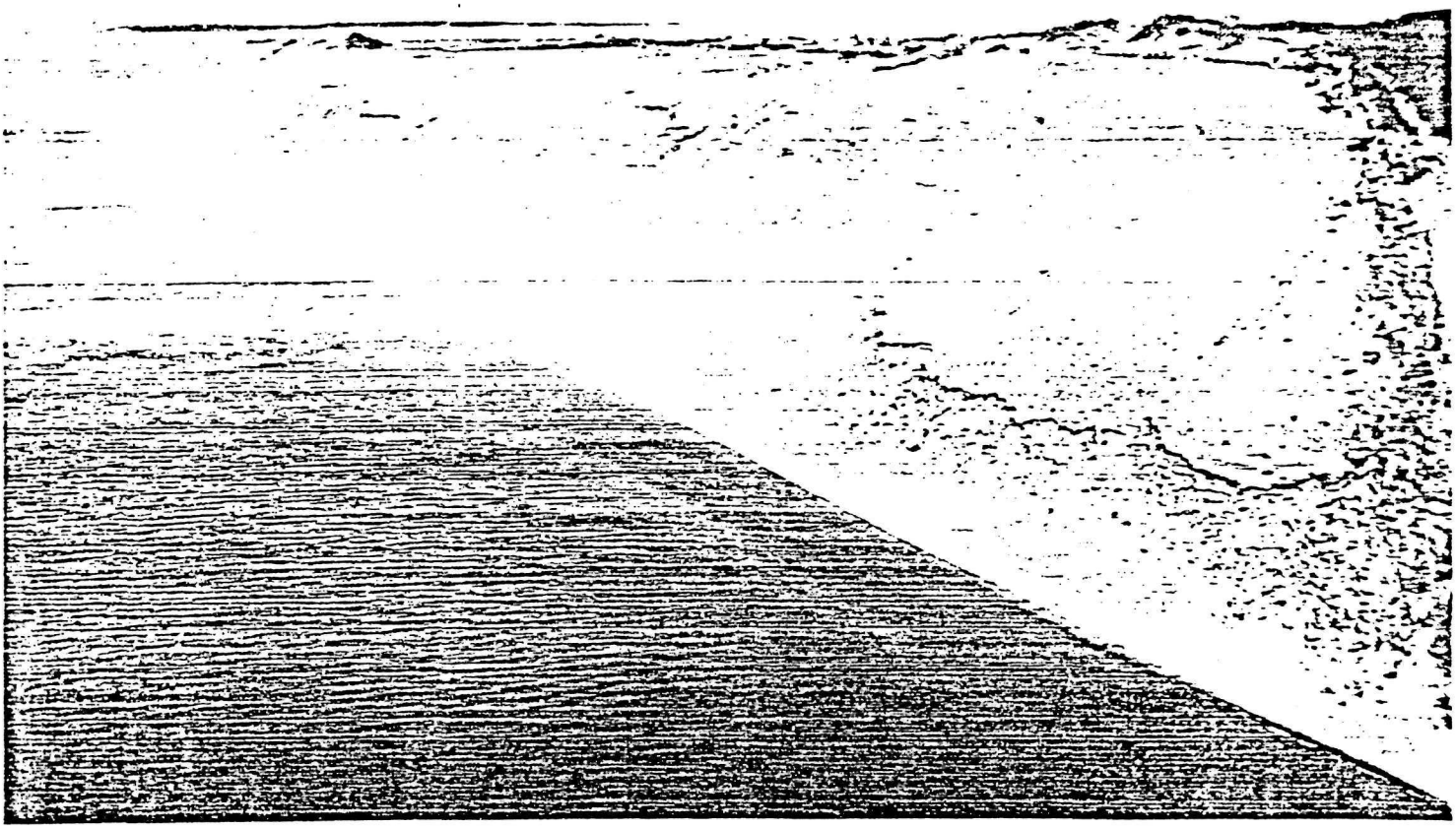


Fig. 10. The continually eroding face of the Sleeping Bear Bluffs is sparsely vegetated. It is like the beach in the severity of limitations placed on plant growth.

Fig. 11. Atop the Sleeping Bear morainal plateau the wind-trained and sand blasted sand cherries lie prostrate on the deflated surface of the moraine.

Fig. 12. The cottonwoods on the Sleeping Bear Dunes are important dune builders, capable of making sufficient growth to stay above the accumulating sand.

plant growth. Much of the vegetation that appears to be growing on the dunes is, in reality, growing on deflated areas of till or beach deposits.

The sand that rides the winds up the steep face of the Sleeping Bear Bluffs and the sand gathered up by the wind atop the plateau moves eastwardly to that point beyond which, because of various circumstances, the wind cannot presently move it. In this manner are the dunes built and so do they continue to grow and spread. Because of their temporal instability, dunes present great difficulties to successful plant stabilization. In the study area they rank with the beaches and the morainal bluff of the Sleeping Bear in this regard.

> *"Perhaps no topographic form is more unstable than a dune. Because of this instability plant societies, plant organs, and plant tissues are obliged to adapt themselves to a new mode of life within years rather than centuries, the penalty for lack of adaption being certain death."*

> *". . . the advance of a dune makes all things new. By burying the past, the dune affords to plant life a world for conquest, subject almost entirely to existing physical conditions." (Cowles, 1889).*

PLANT LIFE OF THE DUNES

Because the winds blow across the dune complex from three-quarters of the compass, the outlines of the dunes are not clear cut but gently molded by the shifting of the sand in different directions. Between dune crests there are low areas of only slightly compacted sand through which walking is a laborious process. Sand grains are significantly larger in these depressions than near the crests of the dunes, suggesting that the smaller grains have been removed by the wind and that gravitational forces are operative: the larger particles are not wind borne but as the smaller grains around them are carried away they are free to roll and be loosely sifted from the slopes into the depressions. Plant growth is virtually absent in such places.

The plants of dunes are the plants of the middle beach, the upper beach and the foredune. Beachgrass and sandreed are both widespread, and are so continuous in places as to give the appearance of grassy meadows. Pitcher's thistle occurs quite abundantly atop the plateau where the first incipient dunes begin. With it are sand cherry, Canada wormwood and other plants.

THE COTTONWOOD DUNES

Though beachgrass is the most abundant plant on the dunes, the most conspicuous is the eastern cottonwood (Fig. 12). Both species are important dune builders, both are dependent upon moving sand for their existence: the beachgrass because it cannot grow in any other situation and the cottonwood because it escapes competition.

The life history of a cottonwood dune is interesting and deserves attention. The seeds of the cottonwood, produced in tremendous numbers, are minute in size and transported by the wind. They need a moist environment in which to sprout if they are to prevail. Such an environment is provided by the damp basins in the dunes, excavated by the winds often to the underlying beach rubble. Here, with a variety of other plants, the small trees take root and flourish. As the dunes move into the depression, those plants which cannot adjust die out. The cottonwoods, however, grow upward at a sufficient rate to keep above the sand, thus creating a barrier and causing a dune to accumulate. The trees cannot spread laterally by rhizomes as does sand reed, but adapt themselves to changing conditions by the continued prolongation of the trunk.

> *"Thus a group of cottonwoods which germinated when conditons were more favorable and have been able to withstand the severe environment of the dune complex, cannot appreciably extend their area, nor can they live for many years. New trees cannot take their place, because of the inability of the cottonwood seed to germinate in the higher exposed portions of the complex." (Cowles, 1889).*

Fig. 13. The size of the dead cedars of the Sleeping Bear Dune ghost forest can be inferred by comparing them to the figure of the man climbing up the face of the blowout.

THE SLEEPING BEAR DUNE

The Sleeping Bear region receives its name from a single and singular dune perched atop the very edge of the morainal plateau. Named from an Indian legend, the dune stands nearly 100 feet above the plateau and is a conspicuous landmark when viewed from the lake. The dune has been rejuvenated by the winds and is, in fact, in the process of being completely destroyed by them. As the dune has moved inland it has buried enormous cedar trees, comparable in size with those of South Manitou Island (Fig. 13). Now exhumed by the winds, these dead giants bear mute testimony to the power of wind and sand.

BOTANICAL EVIDENCE OF FORMER DUNES

In the dune country, white cedar seems to grow best on the lee slopes of dunes that are in the process of stabilization, often forming a fringe between the dune and the hardwood forest. This is the case on South Manitou Island and on the Empire Dunes. Inland from the Sleeping Bear Dune there is no deciduous forest; there is only the impoverished vegetation of the morainal plateau already described. On the lee slope of the dune only a few small white cedars now persist. These are wholly unlike the giants that preceded them. Numerous thin layers of humus-rich soil indicate periods of dune stabilization followed by rejuvenation. At the extreme south end of the plateau on Schauger Hill, a similar humus-rich layer containing charcoal occurs, overlying several feet of dark colored sand. Above this layer are several more feet of fresh, light colored sand. Along the inland margin of the dune complex are several dunes in various stages of stabilization suggesting an origin earlier than the higher active dunes currently encroaching upon them. Finally, the large dunes of the Bar Lakes Embayment (up to 140 feet high) are completely stabilized, except for some minor rejuvenation, with a forest indicating advanced succession. Wave action is currently wasting away these dunes and indications are that they were laid down at a time when both the Sleeping Bear and Empire Moraines extended further lakeward than they do today, forming a bay much like that between the mouth of the Platte River and the Empire Moraine.

The evidence seems strongly to indicate that the Sleeping Bear Dune, the Bar Lake Dunes and the Empire Dunes, as well, were created during an earlier lake stage. Continued erosion of the Sleeping Bear Moraine has rejuvenated and destroyed these earlier dunes from which successive dunes are being created in the form of the current dune complex. These in turn have undoubtedly overridden older dunes in their path. That white cedar no longer seems as important as it formerly was on the lee slopes of advancing dunes is undoubtedly significant, but in what way is uncertain unless it has a bearing on climatological factors.

RELIC FORESTS

Further evidence of the relative instability of even stabilized dunes in the face of a receding shoreline is seen in the relic forests set atop the 200 to 300 foot high morainal plateau on old sand dunes. All about them the dunes have been destroyed through rejuvenation and the forests remain as isolated remnants of a past dune complex. The margins of these islands of vegetation are composed of dense hedges of oldfield common juniper, rose, and particularly buffaloberry which on the lakeward sides acts as an effective sand binder. Beyond this is an almost impenetrable thicket of balsam fir, white spruce (in the study area observed only on South Manitou Island) and white cedar. Poison ivy is very abundant. Inside this evergreen border basswood, paper birch and trees of the maple-beech forest occur (Fig. 14).

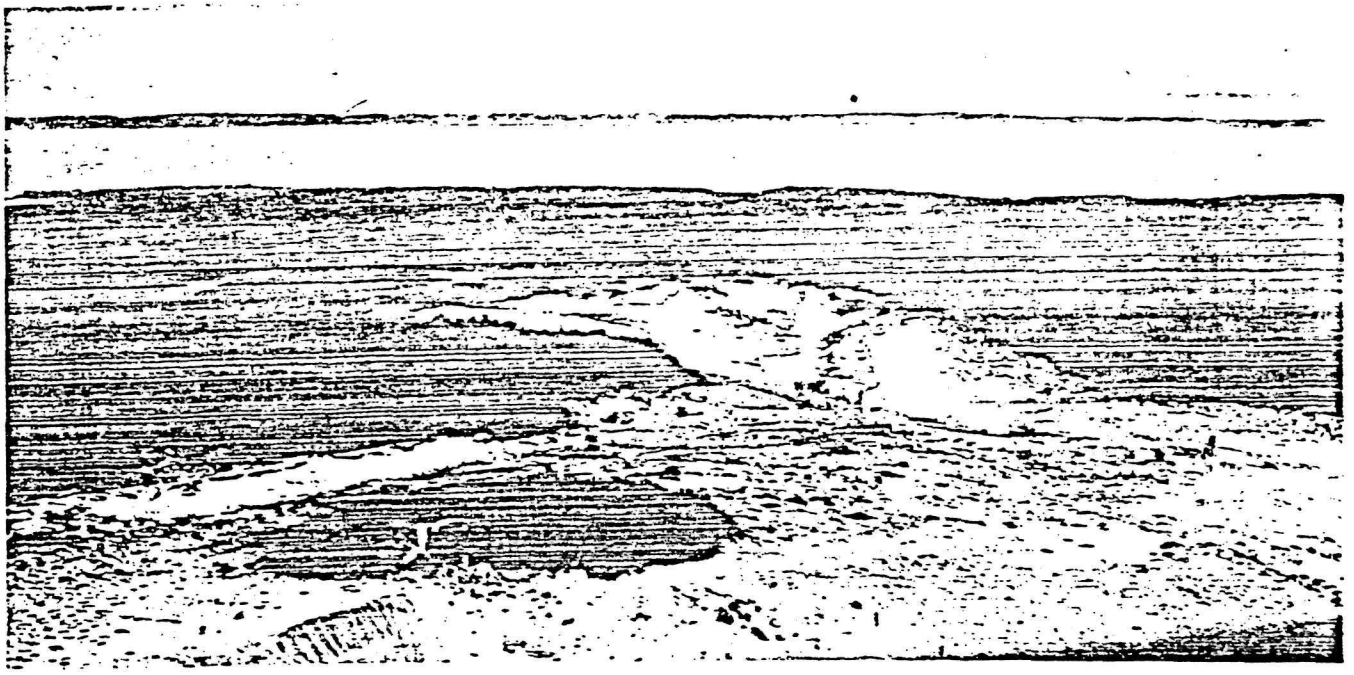


Fig. 14. A relic forest on the west side of South Manitou Island is a remnant of a series of vegetated perched dunes that were rejuvenated and blown further inland.

THE BASSWOOD DUNES

Rather extensive dune forests occur on Betsie Point, the Empire Moraine and on the inner margin of the morainal plateau of South Manitou Island. In the two latter instances the dunes are perched high above the lake on morainal deposits. The vegetation of these perched dunes differs from the pine-oak forest of the dune complex of the Platte Plains. The characteristic tree is the American basswood, so much so that the dunes have been called the "basswood dunes."

> *"The conditions that determine the development of these wonderfully characteristic flora are very obscure. The basswood dunes are always very steep and relatively near the lake." (Cowles, 1889).*

They lie adjacent to the maple-beech forests of the moraine, of which the basswood is an integral part. That they are successional is certain as a sample plot along the Empire Dunes indicates (Table 3). Beech forms part of these dunes forests near their morainal border, but

TABLE 3. Composition of a 10,000 square foot sample on the extreme inland slope of the Empire dunes in the center of Sec. 25, T28N, R15W.

Tree Species	Number of Trees	% of All Trees	Diameter Breast High in Inches 1-3	4-6	7-12	13-24	24+
Sugar Maple	16	53.3	3	4	7	1	1
Slippery Elm	6	20.0	—	2	4	—	—
Hophornbeam	3	10.0	1	—	1	1	—
Beech	3	10.0	1	—	1	1	—
Basswood	2	6.7	—	—	—	2	—
	—		—	—	—	—	—
TOTAL TREES	30		5	6	13	5	1
	% OF TOTAL		16.7	20.0	43.3	16.7	3.3

UNDERSTORY PLANTS
Marginal Woodfern (*Dryopteris marginalis*)—not common.
American Yew (*Taxus canadensis*)—covers about half of the understory.
Northern White Cedar (*Thuja occidentalis*)—several seedlings in the yew.
Grasses (sp.)—some.
Merry-bells (*Uvularia* sp.)—a few.
Wild Leek (*Allium ampeloprasum*)—common.
False Solomon's-seal (*Smilacina racemosa*)—large and vigorous.
Solomon's-seal (*Polygonatum pubescens*)—a few plants.
Trillium (*Trillium* sp.)—common.
Wood-nettle (*Laportea canadensis*)—common.
White Baneberry (*Actaea pachypoda*)—several plants.
Blue Cohosh (*Caulophyllum thalictroides*)—a very few plants.
Prickly Gooseberry (*Ribes cynosbati*)—a few plants.
Sugar Maple (*Acer saccharum*)—only a very few seedlings.
Enchanter's Nightshade (*Circaea quadrisulcata*)—a few.
Wild Sarsaparilla (*Aralia nudicaulis*)—fairly common.
Anise-root (*Osmorhiza longistylis*)—abundant.
Alternate-leaved Dogwood (*Cornus alternifolia*)—two plants.
Elder (*Sambucus* sp.)—several plants.

upon progressing deeper into these dunes, the beech drops out completely. Other trees found with the basswood in varying numbers depending on location and other factors are slippery elm, hophornbeam, white ash, paper birch, white pine, white cedar, balsam fir and hemlock. American bittersweet and frost grape are moderately abundant and typical of these dunes. An understory plant encountered only in the dune forests with any frequency is the American spikenard and the abundant occurrence of Canada yew on these dunes is one of their most striking features. The southern section of the Empire Dunes is completely stabilized with basswood dunes in which a general succession from conifer of the bluffs through beech-maple forests occurs. The northern section lies on the eroding point of the bluffs and dune building and rejuvenation continues to a certain extent with four or five blowouts occurring.

Atop the bluffward edge of the dunes are several shrubs and vines forming an almost impentrable barrier to the hiker. They are American cranberrybush, redozier dogwood (in unbelievably dense stands) chokeberry, frost grape, American bittersweet, rose, and more than enough poison ivy. In one place the bluffs have been eroded away to the very crest of a dune leaving a knife-edge ridge dropping off 400 feet to Lake Michigan and inland into a pit about 50 feet deep filled with the most luxuriant tangle of vines, bushes and trees imaginable.

The Morainal Forests

GENERAL FOREST COMPOSITION

A large portion of the study area occurs on the interlobate and terminal moraines of the region, the adjoining outwash plains, or glacial drainage channels. It is on such sites that the northern hardwood forest is found. From this base it is pushing out onto the sand plains and onto the perched dune forests. It is undoubtedly the climax-type to which all other types are verging. The principal species in sample areas of all age and size groups is the sugar maple. American beech, the second most important species in total numbers is nonetheless, most numerous of trees above two feet in diameter. The area was originally ". . . a heavy forest known from its predominant trees as a Beech-Maple-Hemlock forest." (Waterman, 1922a).

In total numbers at present in the areas sampled, eastern hophornbeam is the third most abundant species followed by hemlock, white ash, black cherry and maple, however, most of the forest is cutover and this has altered not only species composition but relative numbers of a given species. Black cherry, for instance, appears to occur most abundantly on cutover stands of advanced age on the Sleeping Bear Moraine.

VARIATION AND NATURE OF FOREST TYPES

The forest cannot be considered as being of static composition even if human interference is not taken into account. Much of its charm derives from this fact. In one place striped maple may be a common tree in the understory, in another it may be absent. Witch hazel occurs abundantly in at least two locations, but is generally nonexistent in the forest understory. Yellow birch is a tree of the more mesic situations; consequently, in the generally well-drained dune forests and morainal areas of the Sleeping Bear Dunes region it is poorly represented. However, it is locally abundant in the low lying Otter Creek drainage and in the flatter, wetter portions of South Manitou Island.

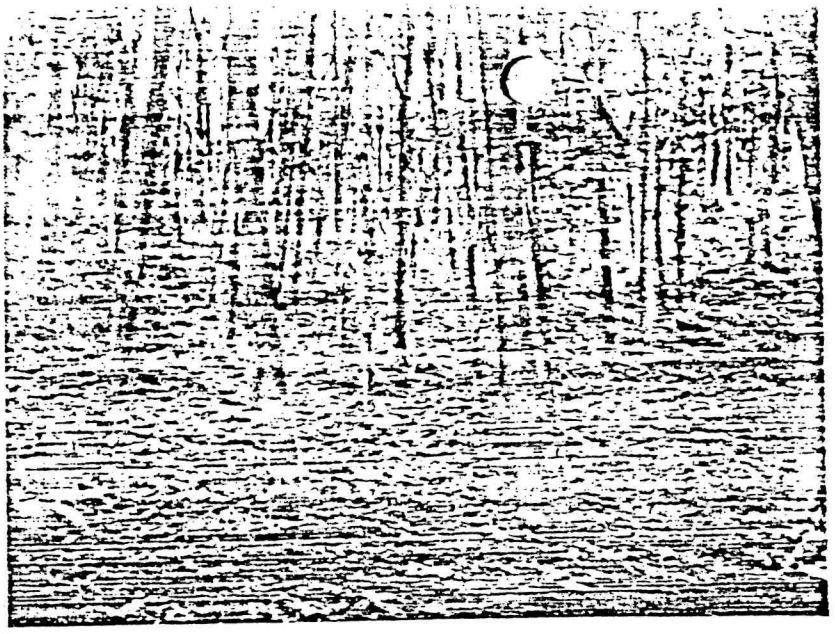


Fig. 15. In this vigorous stand of second growth hardwoods on South Manitou Island, sugar maple is by far the most common species.

SUGAR MAPLE

Sugar maple is the one tree that spans nearly every conceivable type of northern hardwood habitat (Fig. 15). In the areas sampled it was nearly four to one in abundance over beech, the next most numerous species. It is the most prolific seeder. In eleven samples where sugar maple is an important element of the forest cover, it comprised from 25% to 96% of all trees from 1 to 3 inches in diameter breast high. And in all cases except one, over 40% of all maple were from 1 to 3 inches d.b.h. A goodly number of young maples were dead, indicating strong competition for space.

AMERICAN BEECH, HOPHORNBEAM AND WHITE ASH

It is probably that if these forests were left undisturbed for a sufficient period of time, beech would be co-dominant with sugar maple in climax stands. As it is, beech is a third more abundant than maple in trees above a foot in diameter in the areas sampled. Near the south end of the Empire Moraine in a shallow ravine is what must be considered a stand of climax (if not virgin) forest in which beech is preponderantly the most abundant species. This small stand of trees is one of the many attractive features of the Sleeping Bear region. The understory is free of young trees; the stand is park-like and open and the forest floor is covered with a rich layer of decaying leaves.

Eastern hophornbeam is locally abundant, but undoubtedly is favored by cutting. Nearly 90% of 119 sample trees were under 7 inches d.b.h. and many were dying out in the more advanced second growth. White ash occupies an important place in the hardwood forests. Never abundant, it is nevertheless present in nearly all typical stands. Because of its great height and size it is conspicuous in the forest cover.

AMERICAN BASSWOOD, ELM AND NORTHERN RED OAK

Basswood occurs sporadically and is often poorly represented over considerable areas of morainal forest. It seems to thrive best in intermediate successional situations. Just as beech is uncommon on the perched dune forests of the north end of the Empire Moraine, so basswood is common. On parts of the wave-cut Empire Moraine and along Schauger Hill on the Sleeping Bear Moraine, it occurs commonly with hophornbeam as stunted and sand-blasted trees. Its habit of sending up several main stems is often pronounced and its size places it among the largest trees of the areas.

Slippery elm and American elm occur in dune forests, locally along the back edge of blowouts (Old Baldy Dune), in the small ravines of morainal forests, and along water courses of the area. A large American elm on the South Manitou Moraine attains a size of nearly 4 feet d.b.h.

One of the larger and more conspicuous trees of the northern hardwood forests is the red oak. Its occurrence in the forest is successional, however, and it is largely absent from the climax stands, or exists as large isolated relics. It occurs most abundantly on wave-cut morainal slopes that have passed through the conifer stage of development, and on steep morainic ridges where the soil is rocky and well drained. In the latter situation it may be the dominant

tree, though the presence of young sugar maple in the understory suggests its eventual fate (Table 4). Though it does not occupy as wide a range of habitat as white pine, its affinity for ridges, wave-cut moraines, and the sand plains likens it to this species.

TABLE 4. Sample area at top of rocky morainal ridge in the center of the SE¼, NW¼ of Sec. 8, T28N, R14W. Area is approximately 10,000 square feet. Evidence of past fire found on a decaying log. Understory poorly developed.

Tree Species	Number of Trees	% of All Trees	Diameter Breast High in Inches 1-3	4-6	7-12	13-24	24+
Red Oak	56	31.6	15	20	19	2	—
Sugar Maple	55	31.4	50	1	4	—	—
Red Maple	24	13.5	20	4	—	—	—
Beech	12	6.7	6	3	3	—	—
Striped Maple	10	5.6	9	1	—	—	—
Hophornbeam	9	5.0	7	2	—	—	—
White Birch	5	2.8	—	4	1	—	—
Big-tooth Aspen	3	1.7	—	1	1	1	—
White Ash	3	1.7	2	1	—	—	—
	—		—	—	—	—	—
TOTAL TREES	177		109	37	28	3	0
	% OF TOTAL		61.6	20.9	15.9	1.7	0

WHITE PINE, EASTERN HEMLOCK AND YELLOW BIRCH

Certain evidence would indicate that white pine once occupied a place of minor importance in the northern hardwoods forest of the region. However, excessive cutting and inability to regenerate in advanced successional stages has nearly eliminated it from this forest-type. A few large trees still occur on the south side of the Glen Lake Moraine near the top of the bluff. Elsewhere, a few isolated trees are all that remain. In the sand plains forests, however, it is an important species and is discussed more fully under that section.

The term "hemlock-hardwood forest" is sometimes used to refer to the forests of this region and is not inappropriate. Hemlock, however, exhibits perculiarities of distribution worthy of comment. Often nearly absent from well-drained morainal soils, it seems to thrive better in more mesic situations than either sugar maple or beech. On South Manitou Island it is best represented in the beach ridge and swale section of the island in association with balsam fir and yellow birch. This is midway between the pine-oak forest and the maple-beech morainal forest. On the Glen Lake Moraine it occurs rather abundantly in the steep ravine on the east side of the moraine. A good example is found on the bluff running southeast from Pyramid Point. It tends to invade the sand plains in advance of sugar maple and beech and may form an important understory in white pine. On the north end of the Bar Lake Dunes it is the principal tree in all size classes.

Yellow birch exhibits similar anomalies of distribution. On South Manitou Island it is rather common in the inner or western margin of the beach and swale topography, but declines remarkably on the moraine. On the lowlands east of the Otter Creek it is fairly abundant in a confined area. It is found locally on the Empire Moraine, the inner edges of the Bar Lake Embayment, the lower wave-cut slopes on the north side of the Glen Lake Moraine and elsewhere. It is of much less frequent occurrence than hemlock, but exhibits similarities in distribution.

OLD FIELDS

Agriculture in the study area is definitely on the wane. In consequence a goodly percentage of land is, for purposes of the report, referred to as "old fields". Roughly this covers any type of cleared land going back to some stage of forest succession. Many of these old fields were formerly apple orchards, and consequently apple trees remain as one of the common exotic species in the area. When the fields occurred on barren sand the usual sand progression occurs: namely reindeer moss, oldfield common juniper, grasses, spotted beebalm (which is abundant in some fields), staghorn sumac, pin cherry and on to climax forest. Around Glen Haven, black locust has established itself as a successful exotic in old field associations. Old field common juniper is particularly significant in sandy soils at the west end of Sleeping Bear Bay and on South Manitou Island.

Old fields introduce elements to the flora largely lacking elsewhere. They also have a definite aesthetic appeal mingled with nostalgia especially where a few old buildings remain.

South Manitou Island

The flora of South Manitou Island is generally that of the mainland, but several botanical features are of more than passing interest.

VIRGIN FOREST

Near the southwestern side of the island, just at the edge of the moraine and old perched dunes, is an area of approximately fifty acres of virgin forest. It is composed mainly of hardwood trees around 100 feet high. One massive elm, well known to island visitors, has a diameter of nearly four feet at breast height. The cedars of the grove are especially imposing, reaching four feet d.b.h. though not as high as nearby sugar maples, basswood, and white ash. The undergrowth seems to match the trees in size, individual plants appearing much larger and more luxuriant of foliage than in nearby cutover areas.

STATUS OF JACK PINE

Of the many islands in northeastern Lake Michigan, jack pine is found only on South Manitou. Its distribution along the eastern or bay side is similar to its mainland distribution. It lies between the beach heath and pine-oak forest. Atop the morainal plateau on the northwestern side of the island it occurs as a narrow outer fringe to the ordinary outer fringe of balsam fir and white cedar. Nowhere else in the study area does it occur on morainal deposits or lie so high above the level of Lake Michigan.

MAN'S ALTERATION OF THE FLORA

Fires and logging (the island became a fueling station for wood burning lake steamers about 1840) have taken a heavy toll of the original forests. Farming later cleared much of the island outside of the perched dunes and higher moraine though only two or three hayfields are cultivated at present. All these factors may help to account for the large amount of open land on the north shore dunes. These dunes are covered with juniper, grasses and reindeer moss, or are in the process of being rejuvenated by the winds.

SUCCESSION ON THE ISLAND

In the successional stages from the halfmoon bay to the maple-beech forests of the moraine, three trees are better represented generally than on the mainland. These are balsam fir, eastern hemlock and yellow birch. Both balsam fir and hemlock occur rather abundantly with the usual sand plains species, with yellow birch coming in about the older beach ridges and blending with maple and beech before the moraine is reached.

UNUSUAL SPECIES

The principal form of rock in the moraines is limestone and on South Manitou this fact appears to be responsible for the unusual occurrence of three species of ferns.

> *"These are the walking fern (Camptosorus rhizophyllas), the green spleenwort (Asplenium viride) and the northern Holly fern (Polystichum lonchitis.) There are no other known stations for the latter two species in the Lower Peninsula of Michigan and the only other known station in this region for the walking fern is the Alpena area. The walking fern at the Manitou Island site completely covers entire sections of rotting logs." (Thompson, et. al.)*

The large nodding trillium *(Trillium flexipes)*, absent from the mainland of the Leelanau Peninsula, is found in the virgin forest where it forms vari-colored hybrids with the red trillium *(Trillium erectum)*.

White spruce, not observed on the mainland, occurs sparingly along the stabilized bluffs of the south shore of the island and in the relic forests atop the morainal plateau.

Fauna

SIZE OF FAUNA

A hypothetical checklist of the wildlife of the Sleeping Bear region would show around 220 species of birds, about 48 species of mammals, 17 species of amphibians and 15 species of reptiles, perhaps 80 species of fish and a multitude of invertebrate forms. A number of these would only rarely, if ever, occur in the study area. Some would occur only in very scanty numbers. Others are shy and retiring and thus seldom seen. A large number are migratory or seasonal in their appearance, and a few are common and widespread. Probably none are so generally reduced in numbers as to be in danger of extinction in at least the foreseeable future, though many are in danger of local extirpation through diminishment of habitat.

Apart from the general enthusiasm that wildlife everywhere generates, some species are of particular interest for various reasons.

GULL ROOKERY ON SOUTH MANITOU ISLAND

On South Manitou Island's Gull Point is one of the larger breeding colonies of herring gulls found on the Great Lakes. On June 8, 1940 about 1,500 nests were reported by A. E. Staebler (Wood, 1951) and in 1958 and 1959 there seemed to be no diminution of numbers. Apart from the normal mortality caused by disease during the population concentration on the nesting grounds and from predation by cats, dogs, and red foxes, the colony deserves protection from molestation from the numerous boating parties that visit the island.

INSULAR FAUNA OF SOUTH MANITOU ISLAND

South Manitou Island, in general, is of more than passing interest. The southernmost of the several islands of northeastern Lake Michigan, it has, in common with the others, an impoverished fauna. Its insularity makes it especially valuable in studies of species dispersal and differentiation under conditions of isolation.

The results of past studies on the island indicate a land vertebrate population of 3 species of amphibia, 4 species of reptiles, 76 species of birds, and 9 species of native mammals as well as feral cats, the European hare and the Norway rat (Hatt, et. al., 1948). Two of the mammals, the fox squirrel and the muskrat were introduced by man, leaving only 7 species known to have reached the island through their own agency. This represents less than 15% of the mainland species. Of these, the raccoon and red squirrel are of uncertain occurrence leaving only the red fox, the eastern chipmunk, the deer mouse, the snowshoe hare and the cottontail as adventives. The cottontail is thought to have arrived by ice bridge from the mainland as late as 1925 (Hatt, et. al., 1948).

In the case of the birds only 10 species were known definitely to nest (Hatt, et. al.) but this number is far too low and simply indicates lack of sufficiently prolonged observation. The author saw, in the late summer of 1959, large numbers of bank swallow nests on the south shore bluffs as well as great numbers of swallows. Also an unidentified female duck (black or mallard) with young was observed on the inland lake. In addition three other birds not previously listed for the island, the horned lark, the yellow-shafted flicker and the ring-necked duck were observed.

BIRDS OF SHORELINE AND DUNES

The birds are one of the faunal highlights of the Sleeping Bear region. Their number is large and their habits and habitats are varied. Several interesting species are intimately associated with the open areas of beach, heath zone, shore bluffs, morainal plateau and dunes during the summer months.

Along the Empire Bluffs, Schauger Hill and the Sleeping Bear Moraine, South Manitou

Island and along the beaches elsewhere in the area a number of berry plants occur; buffaloberry, chokecherry, grape, sand cherry, redozier dogwood, high bush cranberry and others. Associated with these during the summer months are numbers of cedar waxwings. These soft-voiced, elegantly plumaged birds personify the shore bluffs, particularly the Empire Bluffs.

At the point of the Empire Bluffs is a boulder belt derived from the eroded moraine. This is one of the exceptions to sand and gravel beach. It is in this short stretch that one can nearly always depend on seeing spotted sandpipers. Above the boulders, the 400 foot high bluff is clothed with grasses, herbs and scattered bushes. This is the almost exclusive domain of the vesper sparrow.

Atop the windswept Sleeping Bear morainal plateau and in the active dunes, the vesper sparrow shares its habitat with the horned lark, the goldfinch and the marsh hawk. The presence of the goldfinch in this assemblage is due almost entirely to a single plant species, the Pitcher's thistle. This plant, a Great Lakes shoreline endemic, grows abundantly on the parts of morainal plateau. Its seeds are the source of its attraction to the goldfinch.

Along the lakeward face of the dunes one may commonly see Caspian terns, American mergansers and herring gulls resting on the beach. The piping plover has been seen here also, as well as on South Manitou Island, and is known to have nested on Betsie Point (Cotrille, 1957).

FOREST BIRDS

A large number of birds are associated with the various forest types of the study area. In the hardwood forests three species are typical. They are the red-eyed vireo, the redstart, and the ovenbird. Various warblers, thrushes, flycatchers and woodpeckers are well represented. Two of the most colorful birds of the area are found in this habitat: the rose-breasted grosbeak and scarlet tanager. The latter is often seen in the forested Empire Dunes.

Loons still occur on the lakes of the Platte Plains. Marsh and swamps habitat favorable to reptiles, amphibians, grebes, herons, ducks, rails and shorebirds is found in most of the embayments. Areas noted for high wildlife populations are the pond at the northwest end of West Glen Lake, the Otter Creek marsh, the delta of the Platte River on Platte Lake and the several swamp ponds north of Little Platte Lake.

MAMMALS

Among the mammals a number are relatively common and often seen. Interesting in itself is the presence here of all three species of eastern tree squirrels. The red squirrel is most commonly seen in hemlock-hardwood stands. The grey squirrel is common in the hardwood forests, particularly where red oak occurs, and the rarer fox squirrel seems to occupy much the same—if more open—habitat.

Raccoons are not uncommon. The author watched two foraging in the shallow water of the marsh pond at the northwest end of West Glen Lake. The pond is in plain view of, and adjacent to, a heavily traveled highway. Woodchucks were seen on several occasions in the Platte Embayment. Eastern chipmunks are common in forested regions and are replaced by thirteen-lined ground squirrels on open land. Deer were seen commonly in the morainal forests, and a red fox was seen on South Manitou Island.