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PART II

THE GLACIAL AND POST-GLACIAL HISTORY *of the* PLATTE AND CRYSTAL LAKE DEPRESSIONS BENZIE COUNTY, MICHIGAN

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, in the University of Michigan.

CONTENTS

ILLUSTRATIONS

[Plates]

[Figures]

[PLATE I. Air Mosaic of Northwestern Benzie County, Michigan.]

INTRODUCTION

Nature of Problem and Time of Field Work

Study of the Platte and Crystal Lake depressions, as a continuation of the work of Professor I. D. Scott on the origin and arrangement of the sand dunes in the Lake Michigan Basin, was begun under his direction during the summer of 1937. One month of reconnaissance work was completed in the area in 1937. The field work was continued throughout the summers of 1938 and 1939, and a short visit of two weeks was made to the area during the spring of 1939 in order to map the dunes in the Crystal Lake Bar Region.

Location and Size of Area

The area described in this paper is located in the northwestern part of the Southern Peninsula of Michigan, between the 44°37' and 44°47' parallels and the 85°56' and 86°16' meridians. It lies within Benzie County and includes an area of approximately 85 square miles in the northwestern part of the county. The section of the Manistee moraine found within the area forms two large depressions, each of which opens to the Lake Michigan Basin. These depressions formed large embayments in the shorelines of the high level Pleistocene Great Lakes. An inclusive study of the former shore lines situated in either depression must include those found in the other, because, during the early part of their history, a connection existed between the two embayments. Eleven lakes are within the area; of these Crystal Lake is by far the largest and covers the entire low part of the Crystal Lake depression. Of the nine lakes located in the Platte Lake depression, Big Platte is the largest. Round Lake, a pond, situated in the low sag in the moraine which separates the two depressions, occupies a portion of the connecting channel that formerly existed across the moraine. The area covered by lakes amounts to approximately 25 square miles, and the remainder of the area of this report is nearly equally divided into cleared or cultivated land and forest.

Methods of Study

No topographical map has been made of Benzie County, and the county road map was found to be too inaccurate for mapping purposes. The county platbook was very helpful for the general reconnaissance work, but inaccuracies of one-half mile, or even more, were noted in road locations and in the position of lake shores with respect to section lines. During the summer of 1938, a series of sketch maps and compass traverses was made for each critical position of the area. After the writer left the field in the fall of 1938, air photographs of a part of Benzie County were made available and these were fitted together to make a mosaic. A photostat copy of this mosaic (plate I) was then utilized as a base map.

Three instruments were used to determine the elevations of the abandoned shore lines. An ordinary hand level was employed for measuring up steep slopes and relatively short distances. During the summer of 1938, a wye-level was utilized in all traverses that involved distances of one-tenth mile or more. This wye-level was not available during the summer of 1939, and a telescopic stadia level, mounted on a Jacob's staff, was substituted for it. Nearly all traverses were made by using a light-weight, collapsible leveling rod in conjunction with one of the instruments mentioned above. The levels near Honor are based on the road profile of U. S. Highway 31, blueprints of which were furnished by the Michigan State Highway Department. Lake Michigan, however, served generally as a datum of reference, the elevation of the lake was determined from the gauge at the U. S. Coast Guard Station, Frankfort, Michigan. The traverses made in 1938 were checked the following summer when the preliminary level determinations of the U. S. Coast and Geodetic Survey bench marks located within the area were made available. In no case were changes necessary that involved more than one foot of error.

The relative age of the sand dunes within the area was determined by using the following criteria: (1) position and elevation; (2) extension or direction; (3) development: (a) simple ridges, (b) deformed ridges, (c) size; (4) soil profile. These criteria for age determination are discussed in a paper by Scott and Dow (17. Scott, I. D. and Dow, Kenneth W., 1937), and need not be emphasized here. Incidentally, the work of Scott, Dow (17. Scott, I. D. and Dow, Kenneth W., 1937), and Stevenson (21. Stevenson, Ellen B., 1931), in other parts of the Michigan Basin, shows that the largest dunes were formed during the Nipissing stage. This generalization seems to be a good one for the largest dunes found within the Platte and Crystal Lake depressions were also formed during the Nipissing stage.

Acknowledgments

The writer is indebted to several people for assistance in the preparation of this paper, and wishes to express his sincere appreciation to Prof. I. D. Scott of the University of Michigan, not only for the supervision and direction of the investigation, but also for his time and companionship throughout the several weeks he spent in the area; to Dr. R. A. Smith, State Geologist, for his kind cooperation, especially for making available recent airplane photographs of Benzie County and the services of the Department of Conservation, Geological Division, of the State of Michigan; to a fellow student, Kenneth W. Dow, whose friendship and generosity will long be remembered; and finally to Elizabeth Oliver Hosick and to Edward Calver, his brother, for their assistance in the field during the summers of 1938 and 1939.

Résumé of the Lake History Within the Michigan Basin

In any discussion of the post-glacial history of the Platte and Crystal Lake depressions, it is necessary to refer to four or five of the lake stages that once existed in the Lake Michigan Basin. Inasmuch as the history of the Great Lakes is complicated and authoritative agreement is lacking, it seems necessary to define some of these stages to avoid misunderstanding.

As the ice of the Wisconsin glacier retreated from the Valparaiso and Lake Border morainic systems, a body of water formed at the southern end of the Michigan Basin between the moraines and the ice front. This lake, Lake Chicago, stood at various levels, indicated by the shore features that were formed at each stage.

The Glenwood stage represents the first well defined level. It stood 55 to 60 feet above the present level of Lake Michigan (578' above sea level) and discharged through the Sag and DesPlaines Channels—the Chicago Outlet. During this time there seems to have been a readvance of the ice to form the Port Huron morainic system, but it is not known if this advance caused any change in level of the Glenwood stage (11. Goldthwait, J. W., p. 4, 1907). The 60 foot level, however, was maintained for some time after the retreat of the ice front from the Port Huron moraine (1. Alden, W. C., pp. 327-329, 1918), for remnants of the Glenwood beach have been found as far north as Sheboygan, Wisconsin, and the Manistee-Mason County line, Michigan (11. Goldthwait, J. W., p. 56, 1907; 15. Leverett, Frank, and Taylor, F. B., p. 354, 1915).

A period of low water followed the Glenwood stage, and the level of Lake Chicago fell to 590 feet, or about 10 feet above the present elevation of Lake Michigan (3. Baker, F. C., pp. 69-70, 1920). This is known as the Bowmanville low water stage. Its outlet is unknown but was possibly north of Green Bay (3. Baker, F. C., pp. 74-75, 1920). It is uncertain whether or not this low water stage is inter-Glenwood in age, or post-Glenwood and pre-Calumet. If inter-Glenwood, the glacier may have advanced again in order to raise the water to the 640 foot level. The outlet at Chicago was then cut deeper and allowed the level to drop to the 40 foot, or Calumet stage (620' above sea level) (3. Baker, F. C., 76-77, 1920). If, however, the Bowmanville is post-Glenwood, lake level must have risen to the Calumet stage. In a recent study of the beaches within the Chicago Region, the Bowmanville is interpreted as post-Glenwood (4. Bretz, J. H., p. 115, 1939).

During the Calumet stage, the outlet was again at Chicago, but the maximum size of this lake stage is unknown. Apparently the glacier readvanced as far south as Manistee, Michigan, and Manitowoc, Wisconsin, during Calumet time. The inner ridge of the Port Huron morainic system, the Manistee moraine, is thought to mark the position of this readvance. Both Alden and Taylor reported (1. Alden, W. C., p. 335, 1918; 15. Leverett, Frank, and Taylor, F. B., pp. 326 and

356, 1915) that the level of Lake Chicago dropped to the 25 foot, or Toleston stage, before the glacier retreated from the Manistee moraine. Before the Toleston level was established, however, there may have been another low water stage; the evidence for this still lacks authoritative interpretation and agreement (4. Bretz, J. H., p. 117, 1939).

The Toleston level was initiated by a "relatively abrupt drop" that lowered Lake Chicago to an elevation of about 600 feet (4. Bretz, J. Harlen, p. 109). This level marks the final stage of Lake Chicago—a body of water restricted to the Michigan Basin. It was followed by the Sag Low-water stage that evidently correlates with the Kirkfield stage of Lake Algonquin (3. Baker, F. C., p. 87, 1920. The glacier had retreated far enough, by this time, not only to allow the union of the waters of the Michigan, Superior, and Huron Basins, but also to uncover the low Trent Valley outlet. This allowed the level to drop well below the present elevation of Lake Michigan (15. Leverett, Frank, and Taylor, Frank, p. 410, 1915). Following the uplift of the Trent Valley, the water level was raised to the main, or three-outlet Algonquin stage, 25 feet above Lake Michigan (605 feet above sea level).

The closing stages of Lake Algonquin, periods of very low water, came into existence when the glacier melted from the region around Ottawa Valley and uncovered a series of low channels that drained the lakes into the Ottawa (Champlain) Sea (18. 19. 20. Stanley, George M., 1936, 1937, 1938). It has been postulated that the drop in lake level within the Huron Basin amounted to 500 or 600 feet (2. Antevs, Ernst, p. 718, 1939; 18. Stanley, George M., p. 1958, 1936). The fall in level within the Michigan Basin could not have been much more than 100 feet, or as low as the channel through the Straits of Mackinac would allow (20. Stanley, George M., pp. 966-974, 1938).

Continued uplift of the Ottawa Valley outlet brought about rising lake levels; and, when the outlet was elevated so high that the water again discharged at Port Huron, the Nipissing stage (596 feet A. T.) of the Great Lakes was initiated. The uplift continued in the region of the northern outlet, and finally the entire discharge was shifted to the Port Huron outlet. Apparently the Port Huron outlet has been functioning continuously since Nipissing times, the lowering of the water level from 596 feet to its present elevation (about 578 feet) having been effected chiefly by downward erosion of the St. Clair River. Before the waters of Lakes Michigan and Huron reached their present level, however, several transitional stages existed, of these the Algoma stage appears to have developed the best beaches.

The present knowledge concerning this record of events, still incomplete in its details and insupporting evidence, leads to a somewhat confused and uncertain history of the ancient lakes within the Michigan Basin. From the many events that have been established, however, it appears that each high-level stage was followed by a period of low water. With the possible exception of the first stage, the Glenwood rising water, or a flooded condition, accompanied the Calumet, Toleston, Algonquin, and Nipissing stages.

TABLE I

Elevations (feet above sea level) of shorelines within the Platte and Crystal Lake depressions, Benzie County, Michigan.

Locality	Algoma	Nipissing	Algonquin
Point Betsie Sec. 4, T. 26 N., R. 16 W. Sec. 33, T. 27 N., R. 16 W.	594. Terrace and base of bluff on Nipissing dunes, .5 mile southeast of lighthouse. 598. Top of gravelly beach just north of lighthouse. 590. Terrace and base of bluff on Point Betsie moraine.		621, 623, 621. Top of three bars west of State Highway 22, just north of Point Betsie road.
North side of Point Betsie moraine. Secs. 25, 26, 36, T. 27 N., R. 16 W.	595, 596. Top of low beaches behind modern dunes. 590. Low point in front of cut terrace.	602. Cut terrace. 606. Top of beach .5 mile east of cut terrace.	616. Beach east of log cabin owned by Mrs. F. A. Calkins. 614. Top of gravel bar near Bert Bancroft's farm, north of Round Lake.
Secs. 5, 6, T. 26 N., R. 15 W.		604. Base of bluff south side of Long Lake near house owned by J. R. Congden. 605. Base of bluff between Long and Rush Lakes.	616. Top of strong beach ridge south side of Rush Lake.
Platte River Point Sec. 20, T. 27 N., R. 15 W.	590-591. Flat area of about two acres west of morainic bluff.		606-607.5. Cut terrace on south side of moraine (no definite shoreline found).
South from L. Mich. along west ¼ sec. line, sec. 21, Lake Twp., to Mud Lake, Secs. 20, 21, T. 27 N., R. 15 W.	593. Top of beach in front of cut terrace. 590-591. Base of bluff east side of moraine. 588. Base of cut bluff on Nipissing dunes.	602. Top of terrace on which dunes are perched. 605. Top of beach ridge, east of Mud Lake.	
North shore of Platte Lake. Sec. 27, T. 27 N., R. 15 W.	595. Top of beach near lake; Boys' Camp.	604. Top of weak beach in front of bar. 605. Top of strong bar; entrance to Boys' Camp. 605. Top of strong beach in back of bar. 605. Base of cut bluff near intersection of Platte Lake road and Highway 22.	616. Beach east of road 0.1 mile south of intersection Platte Lake road and Highway 22.
Platte Lake near Breeze Shores Resort 2.5 miles southeast of intersection of Platte Lake road and Highway 22. Sec. 36, T. 27 N., R. 15 W.	595. Gravelly beach about 6 feet above Little Platte Lake.	605. Top of spit at its junction with the moraine on southwest side of moraine. 599. Cut terrace and base of morainic bluff.	
South shore of Platte Lake, near Youkan Resort. Secs. 1, 2, 11, 12, T. 26 N., R. 12 W.	594. Top of low beach near Platte Lake.	599, 610. Base and top of strong gravelly beach, south of road to Rettig's Green Cottages. 600. Base of wave cut bluff. 604, 607. Top of two beaches west of road to Bay Point Resort.	616. Terrace and base of bluff .5 mile west of Youkan Resort.
Junction of U. S. Highway 31 and South Platte Lake road. Sec. 7, T. 26 N., R. 14 W.		600*. Top of bar west of Algonquin bar.	614*. Top of sandy beach. 610*. Top of bar composed of fine gravel and sand.
Honor. Sec. 8, T. 26 N., R. 14 W.			620*. Terrace in the Village of Honor.
Near Junction of Little Platte Lake road and Highway 22. Sec. 25, T 27 N., R. 15 W.	593. Top of low beach near Little Platte Lake.	601. Base of cut terrace 0.3 mile southeast of junction. 607. Top of gravelly beach 0.5 mile southeast of junction.	613, 614, 615. Top of three beaches or bars just east of road junction. 610.5 Top of terrace in front of bars.
Aral Secs. 1, 11, 12, T. 27 N., R. 15 W.	592. Base of cut bluff on Nipissing dunes .75 miles south of Otter Creek.	605. Top of marl pit one mile southeast of Aral. 607. Top of gravelly beach 0.5 mile east of Aral. 605. Top of spit at point of junction with cut bluff.	611.8. Shore line (cut terrace) northeast of Aral. 608. Top of off-shore bars, northeast of Aral. 613. Base of high bluff one mile southeast of Aral. 621. Top of bench where spit joins the bluff.

*Elevations based on road profile on U. S. Highway 31.

Terminology

The history of the Glenwood, Calumet, and Toleston Lakes is derived from the Chicago district. The writer found no evidence in the Platte-Crystal Lakes locality to distinguish the Toleston from the Algonquin stage, even though a low water period may have existed between them. In fact, Taylor considered the Toleston beach north of Manistee to be identical with the Algonquin, and that the Algonquin passed into the same plane as the Toleston at or near Herring Lake (15. Leverett, Frank, and Taylor, Frank, p. 428, 1915). Consequently the name "Algonquin" has been used in preference to 'Toleston"; and all references to the "Algonquin Stage" will imply the main, or three-outlet, stage of that lake. The "Nipissing Stage" refers to the level of Lake Nipissing at the two-outlet (Port Huron) stage of that lake. The term "Algoma Stage" indicates a lake level, transitional between the Nipissing and the present Great Lakes, that developed strong beaches and wave-cut terraces at the elevation of approximately 592 feet in the Platte-Crystal Lake area.

Post-Glacial Uplift

Both the Platte and Crystal Lake depressions lie within the area influenced by the post-glacial uplift. The abandoned shore lines of lakes Algonquin and Nipissing are horizontal south of the Herring Lake depression, located five miles south of Frankfort, Michigan, but are tilted north of that depression. The line along which uplift to the north took place is known as the hinge line. Taylor locates the Algonquin hinge line "about at Herring Lake" (15. Leverett, Frank, and Taylor, Frank, p. 456,

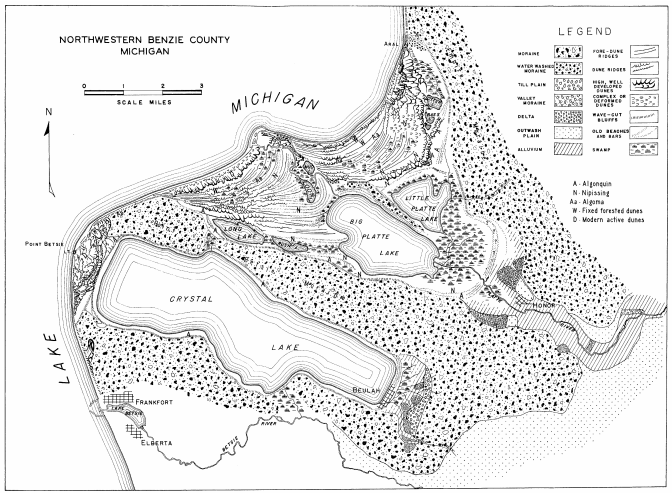
1915). However, in a detailed study of the Herring Lake depression, the zero isobase of the Algonquin beaches is described as lying "just to the north of the depression" (17. Scott, I. D., and Dow, Kenneth W., p. 437, 1937). The hinge line appears to have functioned and to have remained in the same location since Algonquin times.

In the area of horizontality the elevation of the Algonquin water plane has been established as 603-605 feet (15. Leverett, Frank, and Taylor, Frank, p. 430, 1915), and the level of the Lake Nipissing water plane as 595-597 feet (15. Leverett, Frank, and Taylor, Frank, p. 458, 1915.) Within the Platte depression, the Algonquin water plane stands at an elevation of 612-614 feet, and the Nipissing level at 600-602 feet. Shore features listed in Table I indicate an uplift of nine feet for the Algonquin level, and five feet for the Nipissing. Below the Nipissing another well defined plane was found at the elevation of 590-592 feet. The shore features of this level (also listed in Table I) definitely do not correspond to the modern shore of Lake Michigan and, consequently, have been considered to represent the Algoma Stage of Lake Michigan. (15. Taylor, Frank, p. 332, 1915). The level of this stage lies half way between the Nipissing water plane and the mean level of Lake Michigan. In the Manistique area, on the north shore of Lake Michigan, the Algoma beach was also found to occupy a position half way between the present level and the level of Lake Nipissing (21. Stevenson, Ellen B., 1931). South of the hinge line the abandoned strand lines are horizontal, the Algoma beach in that area is described in Part I of this publication.

The data in Table I were compiled from an area that lies more than seven but less than fifteen miles north of the hinge line. It was found that the variation in elevations of the beaches, taken at their crests, was greater than the amount of tilt. Also, it was found that the highest portions of the Algonquin beach lie about six miles closer to the hinge line than do the lowest portions. The Nipissing beach, moreover, exhibits no discernble tilt in a distance of five miles perpendicular to the hinge line, within the Platte depression.

The Algonquin beaches and bars within the Platte and Crystal Lake depressions vary in elevation from 613 to 623 feet at their crests. The average of eleven elevations, determined in different localities, is 617 feet. In contrast with this, the average of elevations taken at the base of four Algonquin wave-cut bluffs, is 613 feet. The elevations of twelve Nipissing beaches and bars, determined at their tops, average 606 feet, but the average at the base of nine Nipissing cut bluffs gives 602 feet. Likewise the averages of elevations of eight beaches or bars and seven bluffs formed during the Algoma stage are 595 and 591 feet respectively. It is surprising and perhaps significant that each pair of averages differ by four feet whereas the extreme variation, the difference in elevation between the highest beach and the lowest cut bluff, for the Algonquin, the Nipissing, and the Algoma stages is 12.5, 11, and 10 feet respectively. It is apparent that the average of elevations taken at the tops of bars and beaches, which vary in height depending upon the coarseness of material and their position, gives too high a value for the elevation of the water plane.

Likewise, the figure determined by averaging the elevations of wave-cut bluffs does not give the elevation of the water plane because the base of bluffs is normally above the still water level. Before the true elevations of the former water planes can be established, an extensive study of modern shore features and their relationship to existing water planes must be made. At present, the approximate elevations of the former lake stages may be considered to be not in excess of the elevation at the base of the wave-cut bluffs.



[PLATE II. Areal Map Northwestern Benzie County, Michigan.]

EARLY GLACIAL HISTORY OF NORTHWESTERN BENZIE COUNTY

Description

From the City of Manistee northward to Sleeping Bear Point, a number of depressions are located on the inner margin of the Manistee Moraine. These depressions are surrounded by moraine except on their western, or Lake Michigan sides. Platte and Crystal Lakes lie within two of these depressions, which are separated by a double morainic ridge.

The Point Betsie moraine (pl. II) is a true interlobate moraine of the knob and basin type and was formed by deposition of till from both the Crystal Lake and the Big Platte Lake lobes. The moraine extends from the Lake Michigan shore southeastward for about twelve miles. Throughout its length it has an elevation of from 780 to 830 feet, except in two sags, or depressions, that cross it. One depression, the Round Lake Basin, located south of the western extension of Long Lake, is nearly a half-mile wide; the other depression, a minor sag located about one mile northwest of the eastern end of Crystal Lake, is a quarter-mile wide and more than 100 feet above the lake. The Round Lake sag afforded a

connection between the two depressions during the higher stages of the glacial lakes that existed in this district. In a number of localities throughout the length of the moraine, the two ridges, each formed by a different lobe, may be recognized as individual features.

The northern ridge of the Point Betsie moraine forms the southwestern boundary of the Platte Lake depression and the Empire moraine the eastern boundary. This depression was formed by two lobes, or ice tongues, that advanced toward the southeast, and is, therefore, separated into two parts by a morainic ridge that extends southeastward from the mouth of the Platte River to the southern end of Little Platte Lake, a distance of approximately five miles. This interlobate moraine is a single, discontinuous ridge much smaller than the Point Betsie moraine. It rises in elevation to 790 feet, or nearly 100 feet above Platte Lake. In the part of the ridge which lies between the Platte Lakes, five small pits have been opened for gravel, but no gravel has been removed in several years.

PLATE III. A. View of the outwash plain at Honor; the Manistee moraine is in the distance.

PLATE III. B. The north side of the Platte River valley showing delta, left, and outwash plain, right.

The valley of the Platte River eastward for about six and one-half miles from Honor, where it joins the main part of the Platte Lake depression, is approximately a mile in width (pl. II). Its floor is flat and many alluvial fans are on either side. About a mile east of the edge of the map, the valley abruptly becomes "V" shaped. In the wide part, two patches of moraine (?) lie transverse to the valley. The one to the east forms a ridge of low hills that rise perhaps 15 feet above the valley floor. This ridge, composed of unstratified sand, has a layer of till one foot in thickness at the surface. The "moraine" to the west is much smaller and consists of three or four low hills not more than eight feet high. It is composed of unstratified sand. It is indeed doubtful whether or not these transverse ridges are moraines, although their irregular surface—low sags and swells—suggests a till deposit. It is entirely possible, however, that these ridges may have been formed as crevasse fillings in a stagnant block of ice that once occupied the Platte Valley.

The Manistee moraine is well developed in the vicinity of Honor, rising above the outwash plain which lies to the east (pl. Ill, A). The outwash drainage was to the east in this local area; but once out of the valley, the melt waters of the glacier drained to the southwest where they emptied into Lake Chicago near the city of Manistee (14. Leverett, Frank, p. 61, 1911; 15. Leverett, Frank, and Taylor, Frank, pp. 305 and 308, 1915). The outwash plain rises to an elevation of 740 feet at Honor.

At the head of the Platte depression where the river valley joins it just west of Honor, remnants of a delta were found nearly 80 feet above the level of Lake Algonquin and 60 feet below the out-wash plain (shown on pl. Ill, B). The surface of the remnant lying north of Honor is flat and slopes gently toward the northwest (pl. IV, A). The elevation near the eastern margin of the delta where it joins the outwash plain was determined as 691 feet; and near its western edge, 685 feet. The upper part of the delta is composed of relatively coarse gravel, but no fore-set bedding could be detected in the gravel pit located one-half mile west of Honor on the north side of the Platte Valley due to slump of the steep sides of the pit which obscured all bedding below the upper-most horizontal layers (pl. IV, B). A distributary channel, between the outwash plain and the moraine north of Honor, leads from the Platte Valley to the outer edge of the delta (pls. II and V, A). On the south side of the river, another part of the delta was found to be at a corresponding elevation. Here, however, the delta has been dissected by numerous gullies and the upper surface is no longer continuous (pl. V, B). Another patch of delta within the broad valley of the Platte River is on the south side of the valley one and one-half miles southeast of Honor. Its elevation is approximately 70 feet above the valley floor, or at the general level of the two parts just west of Honor.

The Crystal Lake depression is bounded on three sides by the Point Betsie moraine. The southern ridge of the moraine extends along the northeastern edge of the embayment, curves around the eastern end of Crystal Lake, and extends along the southwestern shore to the outlet. West of the outlet it continues to the shore of Lake Michigan as the Frankfort moraine. A small till plain is within the Manistee moraine at the eastern end of the Crystal Lake depression (pl. II). The undissected parts of a delta, found 40 feet below the level of the till plain, rise to an elevation of 690 feet. The surface of the delta slopes very gently to the west. No exposure of the bedding was found, but in form, appearance, and elevation, this delta is similar to the one west of Honor and is correlated with it.

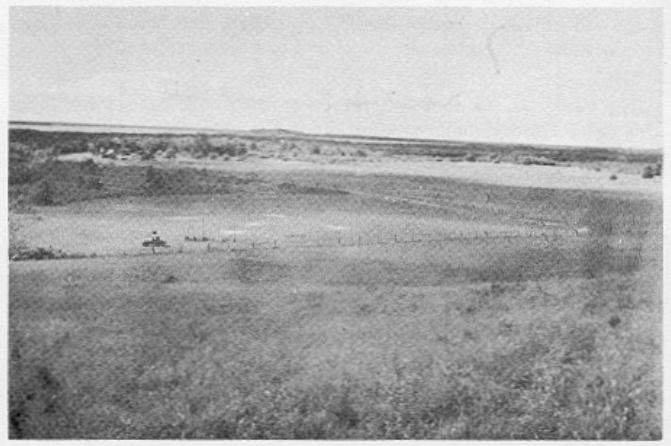


PLATE IV. A. The flat surface of the delta as it appears from the outwash plain. In the distance: Big Platte Lake, left; Little Platte Lake, right. The view is toward the northwest.

PLATE IV. B. The gravel pit in the delta west of Honor. Excepting the flat lying beds near the top, the bedding is concealed by slumping.

Interpretation

The glacial and river deposits of the Crystal-Platte lakes depression may be used to reconstruct the events which must have occurred for their formation. The glacier tongues of ice from the main Lake Michigan Lobe advanced forward into preexisting valleys or depressions. One lobe completely filled the valley now occupied by Crystal Lake, and two lobes advanced into what is now the Platte Lake depression and pushed onward into the valley occupied by the Platte River. There the ice front halted and the part of the Manistee moraine in this area was formed. The melt water from the glacier drained, in general, toward the southwest and furnished the sediment for the outwash plain.

The wide part of the Platte Valley was filled with stagnant ice and as the glacier melted (retreated) a lake was impounded at the head of the depression between the moraine and the ice front. The portion of the glacier which had advanced into the pre-glacial valley east of Honor may have been covered by outwash material and remained there as inactive ice. The surface of this stagnant block melted sufficiently to allow the drainage from the outwash plain to empty into the high-level lake which occupied the Platte depression. The deposition of sand and gravel resulted in the formation of the delta, remnants of which are located near Honor. The delta in the Crystal Lake depression may have formed in a like manner, as the outwash drainage escaped into the depression through the valley occupied by Cold Creek. The extent of the lake that existed within these depressions when the deltas were built is not known, and no other shore features were discovered to indicate a water-plane 80 feet above the Algonquin level. Inasmuch as the delta at the head of the Crystal Lake depression stands at virtually the same elevation as the delta near Honor, it would seem likely that the ice front had retreated at this time to a position at least as far west as the Round Lake sag in the Point Betsie moraine.

PLATE V. A. Looking north across the surface of the delta; a shallow distributary channel can be seen in the middle distance.

PLATE V. B. Delta on the south side of Platte Valley with the Manistee moraine in the background. Dissection of the delta becomes more pronounced to the west (right).

It may be observed in passing that these deltas may be important in the correlation of the morainic systems and the early glacial lakes. A high terrace in the Herring Lake depression, six miles south of Frankfort, stands at an elevation of about 675 feet; the writer observed a terrace, apparently in the same relative position, in the Arcadia depression four miles south of Herring Lake.

Whether these delta-like terraces were formed in individual lakes, impounded between the moraine and the glacier as the ice front retreated from the Manistee moraine, or in one of the higher stages of Lake Chicago has not been determined. If future studies establish the fact that the terraces belong to a higher stage of Lake Chicago, it will be necessary to revise the time relationship between the higher levels of Lake Chicago and the Port Huron morainic system.

PLATE VI. A. Airplane view of Point Betsie looking northeast.

PLATE VI. B. Truncated Nipissing dunes near the southern boundary of the Crystal Lake bar region. The modern fore-dune ridge has developed in front of the Algoma terrace.

LATER GLACIAL HISTORY OF CRYSTAL LAKE DEPRESSION

General

During the Algonquin stage, the Crystal Lake depression was connected with the waters in the Michigan basin by three channels. The Betsie River valley was flooded for several miles upstream from its mouth at Frankfort, and a connection existed between it and the Crystal Lake depression at the low sag in the Frankfort moraine, now occupied by the outlet of Crystal Lake. Likewise a connection with the waters that flooded the Platte Lake depression was made through the Round Lake sag in the Point Betsie moraine, on the north side of Crystal Lake. The bar between Crystal Lake and Lake Michigan was not in existence and the waters of Lake Algonquin had free access to the depression from the west (pl. VI, A).

Wave and current activity during Algonquin times constructed bars across the opening of all these connecting channels and isolated Crystal Lake from the main body of water in the Michigan basin. The natural level of Crystal Lake used to be, therefore, the level of Lake Algonquin, and many shore features formed within the depression cannot be distinguished with certainty from the Algonquin features. Apparently the water stood at the Algonquin level until historic times. In the fall of 1873, the Betsie River Improvement Company, organized by Mr. Archibald Jones, supervised the digging of a channel through the Algonquin bar at the present outlet of Crystal Lake. This was part of an ambitious plan that would have permitted the passage of small sized lake steamers from Frankfort harbor to Crystal Lake, by way of the Betsie River and the outlet channel (5. Case, William L., n. d.). No attempt was made to control the outrush of water when the channel was cut through the bar, and within a very short time the lake level dropped nearly 20 feet. Within a year, the Betsie River Improvement Company was declared bankrupt and the plan was never completed. Several years later a dam was constructed across the outlet and the water of Crystal Lake was raised to somewhere near its former level. However, the early dams were of wooden construction and the level of the lake fluctuated with the whim and fancy of the residents in the area. The concrete dam now in use was constructed about 1915, and since then the water level has been controlled at an elevation of approximately 602 feet, or eight feet below its natural (Algonquin) level.

Both the north and south shores of Crystal Lake are bounded by steep morainic bluffs that rise to elevations of over 200 feet. The zone between the modern shore and the wave cut bluffs varies in width from forty feet to two or three hundred feet or more. The widest part of the terrace is at the western end of the lake. A description of the shoreline of Crystal Lake can be found in *Inland Lakes of Michigan* (16. Scott, I. D., 1921); detailed studies of wave and current activity along the south shore of the lake were reported by Prof. O. F. Evans (7, 8, 9, Evans, O. F., 1938, 1939). Therefore in this report brief mention is made of two areas, the outlet bar and the bars at Beulah, and detailed descriptions are given of two important localities: the Round Lake basin and the Crystal Lake Bar region.

Wave and current activity along the southern shore near the outlet was sufficiently strong during Algonquin times to construct a bar nearly a half-mile long which completely blocked the "Outlet" channel. When the waters within the Betsie River valley receded, this bar was an effective dam for the water within the depression. No permanent outlet stream was maintained across the bar before the modern channel was dredged in the early

seventies. Wave activity had over-balanced the erosional effect of the outlet drainage and the bar was built too high for a stream to cross. The bar was not a perfect dam, since the water seeped through it and drained into the swamp between the Crystal Lake depression and the valley of the Betsie River (5. Case, William L., n. d.).

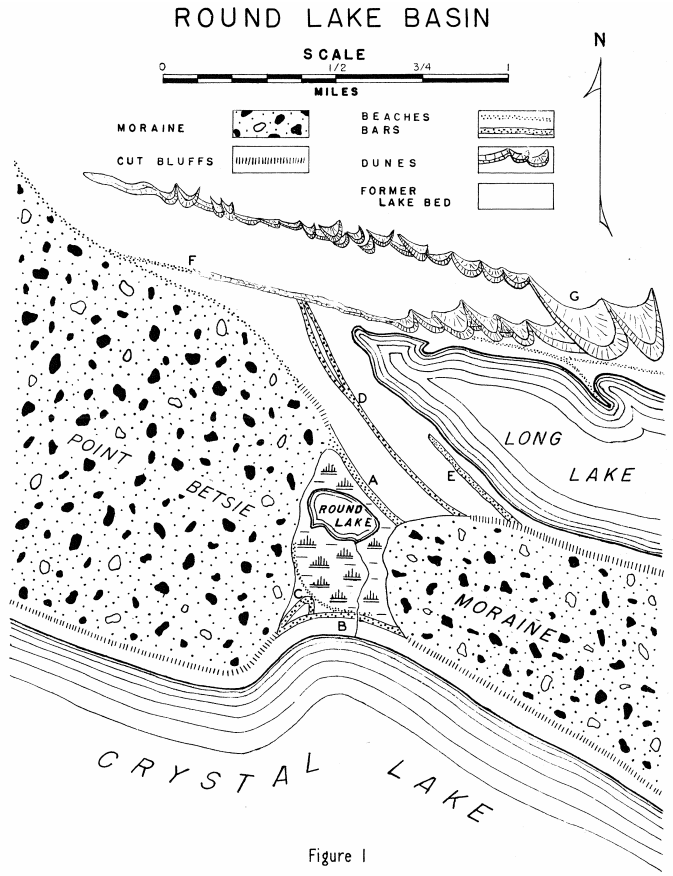
At the eastern end of the lake, three bay-head bars formed when the water in the depression stood at the Algonquin level. These were probably constructed during the Algonquin stage of Lake Michigan before the bar which closed the western end of the depression was completed. It must be remembered, however, that the natural level of the lake was the Algonquin level. The town of Beulah has been built on these bars which extend across the depression and join the wave-cut bluffs on either side. The opening across which Cold Creek flows is located near the southern limit of the bars. While the lake remained at the Algonquin level, the water flooded the lagoon to the east, which was drained with the lowering of Crystal Lake. In recent years, truck farming has been carried out successfully within this former lagoon.

ROUND LAKE BASIN

The Round Lake basin, located between the Platte and Crystal Lake depressions, occupies a part of a low sag, or break, in the Point Betsie moraine a quarter mile south from the western end of Long Lake. This break afforded a channel between the two depressions during the Algonquin stage before a gravely bar developed across its northern end to separate the Crystal Lake depression from the Platte depression. Although a bar also developed across the southern end of the channel, along the Crystal Lake shore, the connection between Crystal and Round Lakes was never completely closed while the water of Crystal Lake remained at its natural (Algonquin) level. Early maps of this region show the basin as a bay of Crystal Lake.

The gravelly bar, "A", figure 1, which forms the drainage divide between the Platte and Crystal Lake depressions, extends southeastward from a cut terrace just north of Round Lake to the main part of the Point Betsie moraine. The top of this bar rises to an elevation of 614 feet and was formed during the Algonquin stage by wave and current activity acting upon the northern side of the moraine, i.e., within the Platte Lake depression. At the present time, Round Lake stands at an elevation of 604 feet, or two feet higher than Crystal Lake into which it drains by means of a small creek. This creek cut across an Algonquin bar, "B", figure 1, which extends across the southern end of the basin. The crest of bar "B" rises to an elevation of 624 feet at the points of juncture with the moraine, but its central part stands at an elevation of about 615 feet. Near the western attachment of this bar a peculiar hook is found which rises to the same elevation (624 feet) near its attachment. In this locality the part of the Algonquin bluff facing Crystal Lake extends in a direction determined as N. 35° E., and the hook continues as an extention of this shoreline in approximately the same direction (N. 30° E.) about 500 feet. From this point it recurves to the east and south and is covered by the later bar, "B", that extends N. 50° E. from the bluff.

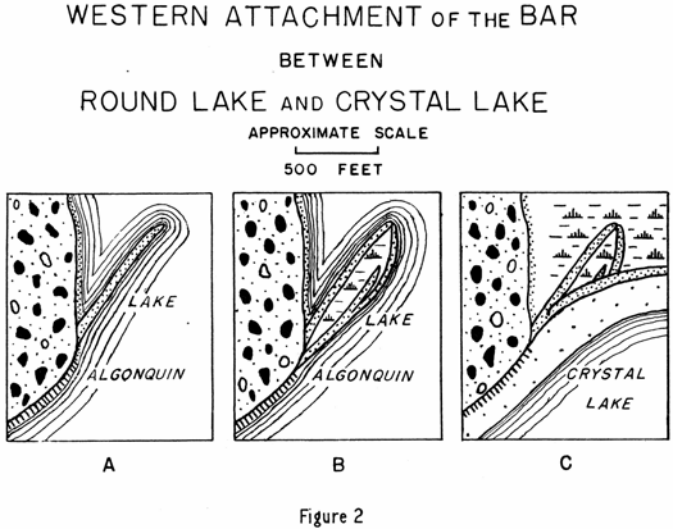
The three stages that may be represented in the development of this peculiar hook are illustrated in figure 2. A simple spit, A, built in a northeasterly direction from the morainic bluff which limits Crystal Lake marks the first stage of its development. It seems unlikely that cross currents existed within Round Lake basin sufficiently strong to effect the recurving of this spit to form a hook. Consequently a second spit, constructed in front of the first, is suggested as a possible explanation. The second spit was compound and extended from a point southwest of the juncture of the first spit with the moraine to the termination of the first spit (B, fig. 2). Only the northern tips of the compound spit remained after waves and currents within Crystal Lake depression eroded the morainic headland in this area (C, fig. 2) and built the third spit or bar which closed the southern opening to Round Lake basin, (B, fig. 1).



[Figure 1. Map of Round Lake Basin.]

Although the bar, "B", figure 1, is several feet higher than the gravel bar which limits the basin on the north, (A, fig. 1), it must have been formed after the northern bar was completed since the drainage within the basin escapes into Crystal Lake. Continued wave activity within the Crystal Lake depression throughout the time that elapsed between the Algonquin stage and the artificial

lowering of Crystal Lake is considered to have been sufficiently strong to build the bar to its present elevation. A portion of the western end of this bar is covered by low dunes that unquestionably developed subsequently to the drop in lake level. Within the Round Lake basin, a beach was found at an elevation of approximately 610 feet. On the Crystal Lake side of the bar, a gravelly shingle beach is at the same elevation. These two beaches were evidently formed at the natural level of Crystal Lake.



[Figure 2. Suggested development of bar between Round and Crystal Lakes.]

CRYSTAL LAKE BAR REGION

This is the first comprehensive survey of the Crystal Lake Bar Region, although brief mention of the area was made by W. G. Waterman, in 1917, and by I. D. Scott, in 1921. The general outlines of the region as contained in these reports follow.

Waterman's description reads:

> The topography as well as the character of these deposits and the identification of Algonquin beaches, show that in Algonquin times Crystal Lake was connected with Lake Michigan toward the north by channels passing west of Long Lake, toward the south through the valley of the present outlet, and to the west through the then unfilled valley which now contains Crystal Lake. During this time a broad harbor bar was built across this valley between the western ends of the glacial ridges. This bar, which is approximately two miles long and three-quarters of a mile wide, now cuts off Crystal Lake from Lake Michigan, and accounts for the name given to this region. At present the western outline of the bar is convex, but probably when first formed the glacial ridges extended much farther into Lake Michigan, and as they have been cut back the bar assumed its present shape. (22. Waterman, W. G., p. 199, 1917.)

In the same article, Waterman described a beach just north of the lighthouse at Point Betsie and identified it as a "relic of Nipissing times" (22. Waterman, W. G., p. 200, 1917).

Scott's description is somewhat more detailed:

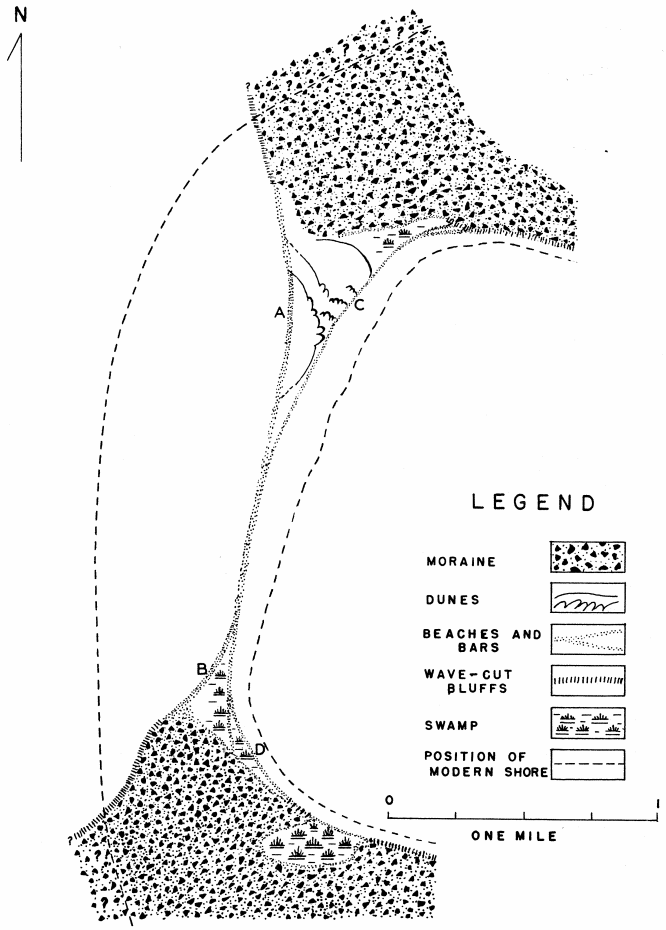
> A study of the west end of the lake discloses the fact that Crystal Lake is a lagoon. The material of the land forms is nothing but sand. Adjacent to the Crystal Lake shore the subsidence in level exposed a portion of the terrace three to four hundred feet in width which, in general, slopes gently towards the lake but is modified to some extent by low dunes of recent formation. Beyond are the steep lee slopes of the great dunes between which, near their eastern limit, may be distinguished portions of a double bar at the Algonquin level. The dunes, heaped in confusion to heights of one hundred feet or more, extend to the Lake Michigan shore, three fourths of a mile to the west, and the zone stretches in a nearly north-south direction between the two morainic boundaries of the Crystal Lake depression, a distance of about two miles. Most of the dunes are fixed in position, due to a vegetal covering, except near the Michigan shore where they are moving landward. In several locations the vegetation has been removed either by cutting or fire, and extensive "blow outs" in the dunes are evidence of renewed movement. This great zone of sand is clearly a bar formed during Algonquin times, since the Nipissing beach has been located in places on its front slope, but the usual concave outline is reversed along the Michigan shore. The explanation is that the limiting morainic ridges formerly extended farther into Lake Michigan as headlands and a normal bar of concave outline developed between them. However, subsequent erosion has caused a general recession of this shore as shown by the extensive cliffs, but greater in amount at the northern headland, causing a convex curvature and somewhat irregular outline of the bar. (16. Scott, I. D., p. 172, 1921.)

The top of the "Nipissing" beach north of the Point Betsie lighthouse mentioned by W. G. Waterman and evidently implied by I. D. Scott has an elevation of 598 feet. The beach can be traced to the Algoma wave-cut terrace on the moraine that forms the northern boundary of the area and is unquestionably post-Nipissing in age. The writer found no beach of Nipissing age in the Crystal Lake bar region, and is in agreement with Taylor's description of the Nipissing beach in this area: "Around the west end of Crystal Lake the beach has been cut away." (15. Leverett, Frank, and Taylor, Frank, p. 445, 1915.) The only evidence of Lake Nipissing found within the bar region is the great accumulation of sand that has been blown into a complicated series of high dunes.

The present convex outline of the western shore of the bar region resulted from not only the recession of the morainic ridges, but also from the accumulation of large quantities of sand on the westward side of the concave Algonquin bar. This material was derived largely from the limiting morainic bluffs, but it should be remembered that the western part of the bar, once lake bottom, was exposed by the drop in water level from the Algonquin to the present stage, and by several feet of post-glacial uplift.

The amount of wave recession that occurred on these headlands cannot be determined with accuracy. The 24 foot subaqueous (below water) contour extends parallel to the Lake Michigan coast approximately 1,500 feet off shore. The 32 and 50 foot contours are not parallel to

the shoreline and indicate greater recession on the Point Betsie moraine than on the Frankfort moraine. The northern, or Point Betsie, moraine may have extended as much as several thousand feet lakeward; the amount of recession the Frankfort moraine has undergone is probably about 1,000 feet. The following table was compiled with reference to the Lake Michigan coast chart No. 77 (1938 edition) published by the U. S. Lake Survey Office.



CRYSTAL LAKE BAR -- ALGONQUIN STAGE

Figure 3

[Figure 3. Crystal Lake Bar Algonquin stage.]

TABLE II

Distance, in feet, from the shore that subaqueous contours are encountered in the region of Crystal Lake Bar.

	Subaqueous contours		
	24 ft.	32 ft.	50 ft.
West of the Frankfort moraine	1,500	3,000	6,500
West of Crystal Lake Bar	1,500	2,000	3,500
North of Point Betsie moraine	1,500	3,500	10,500

ALGONQUIN STAGE. Early in Algonquin times, the area now occupied by the Crystal Lake Bar was under water. Wave and current activity filled the western end of Crystal Lake depression with sand and gravel eroded from the morainic headlands that are north and south of the area. The depth of water that covered this region is not known with certainty, but certain evidence seems to prove that the deposition of Algonquin sediment was made on top of a submerged ridge of drift that existed between the Lake Michigan basin and the Crystal Lake depression. Evidence for this drift ridge is not found at the surface, but records from a number of wells that have been drilled in the bar area indicate its presence. Throughout the area, the water-bearing layers are encountered at depths less than 30 feet below the level of Crystal Lake. At this depth, a seam of peat which varies in thickness from one inch to several feet is penetrated. A thick deposit of clay is below the peat. In a deep well at the Three Pines Inn, the clay was found to rest on bed rock at a depth of 500 feet (el. of well 615 ft.).[1] The contour map of the bottom of Crystal Lake shows a large area in the western part that has a depth in excess of 150 feet. In general this part of the lake varies in depth from 160 to 165 feet but, is 175 feet deep in one locality.[2]

The first Algonquin baymouth bar to be formed across the western opening of Crystal Lake depression was a low gravelly ridge that extended in a north-south direction from the wave-cut bluff on the western side of the Frankfort moraine to the Point Betsie moraine, a distance of nearly two miles. This bar was concave toward the Lake Michigan basin ("A" and "B", fig. 3). It should be noted that only two relatively small portions of this bar are to be found. The remnant in the northern part of the area, "A", is a low ridge 1,400 feet in length and 100 feet in width that rises but three feet above the Hat area directly east of it. The portion of the bar in the southern part of the region, "B", is much stronger and better developed than the northern remnant. The cut-bluff of Algonquin age which extends in a northeasterly direction from the western end of the Frankfort moraine can be traced for nearly half a mile to the point of attachment of the broad gravelly bar. From the point of its southern terminus, the bar can be traced one-half mile in a northeasterly direction where it merges with a bar concave to the east (C-D, fig. 3). The bar is nearly 200 feet wide at the point of attachment but narrows to 70 feet just south of the junction with the second bar. Its lee slope (east) is steep, but the bar is low and does not rise much more than six feet above the low flat directly to the east.

Further evidence that the Algonquin bar first to form across the western end of the Crystal Lake embayment was constructed by wave and current activity on the lakeward (west) side is found in a series of three sand ridges which lie to the east of the main Algonquin bar in the northern part of the area, (A-C, fig. 3). The ridge farthest north is a foredune and can be traced eastward until it disappears beneath the strong bar built by currents within the Crystal Lake basin (C-D, fig. 3). The second ridge may have been originally a sand beach which has later undergone wind deformation, accompanied with additional sand accumulation on its easterly extension. Both in front of and behind this ridge of blow-outs other small dunes are found as indicated on the map. The third ridge is a typical sandy beachridge at its extremities but has suffered deformation in the central part. Here five blow-outs have formed small parabolic dunes of apex type which rise to elevations of 10 to 15 feet above the plane on which they are found or above

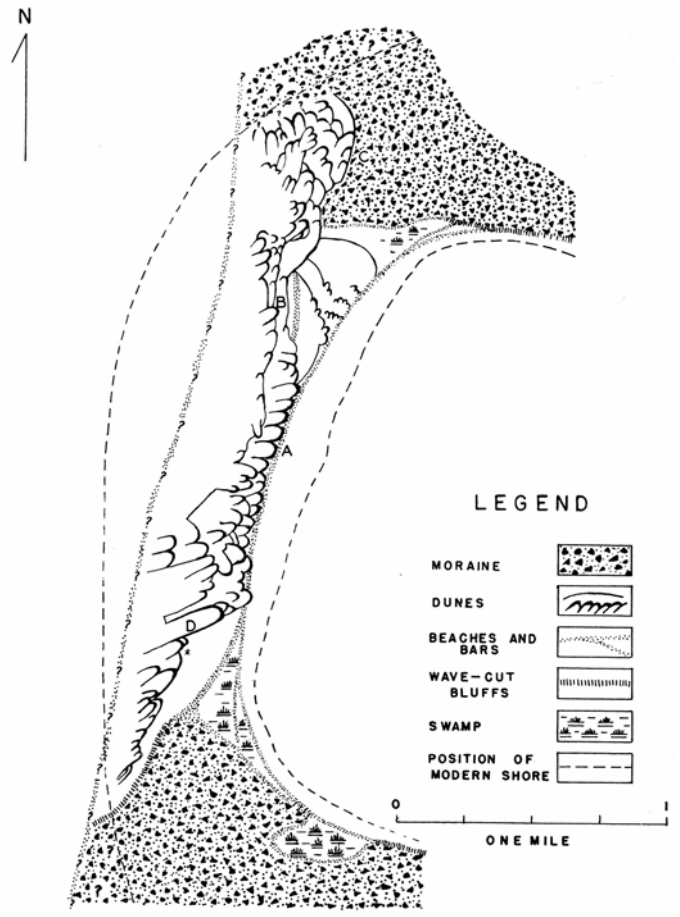
their bases. Each ridge is concave to the west and has an eastward-facing lee slope. These ridges were completed before the development of the main Algonquin bar which isolated Crystal Lake.

Following the development of the main bar, concave to the west, which separated Crystal Lake from Lake Michigan, a double bar, concave to the east, was constructed by the wave activity within the Crystal Lake basin (C-D, fig. 3). Throughout most of its length this bar is a single ridge, but it is forked near its attachments. This bar has the same elevation as the Algonquin remnants (A-B, fig. 3) and may have been formed, at least in part, during Algonquin times. No accurate dating of its formation is possible because the water level of Crystal Lake remained at or near the Algonquin level until recent times. Near the northern attachments the two parts of the bar are approximately six feet high and are strikingly similar in their development. The fork to the west, the first to form, extends southwest nearly 0.2 of a mile before it is joined by the bar in front of it (fig. 3). The moraine eastward from the attachment of these bars ends abruptly in a bluff, the bottom of which is a cut terrace at the Algonquin level. This bluff can be traced westward from the attachment of the west forked bar a distance of 60 feet. This indicates wave attack and shoreline adjustment before the double bar formed and possibly antedates the main bay mouth bar which closed the westward opening of the depression. To the west, the moraine decreases in elevation and an Algonquin beach must have been present at the foot of this gently rising moraine. State Highway 22 follows this shoreline for nearly a quarter of a mile westward, however, and the beach, as a distinct shore feature, has been destroyed. At the southern end, the bar first to form is scarcely five feet high, and its exact extent in a northerly direction cannot be determined. The point of juncture with the bar which lies to the east has also been destroyed by the construction of Highway 22.

The writer has no adequate explanation for the development of triple bars across the eastern end of the depression, near Beulah, for the three-staged development of the bar between Round and Crystal Lakes, or for the three important bars of the Algonquin level represented in the area between Crystal Lake and Lake Michigan. There is no evidence that the level of Crystal Lake was lowered following Algonquin times until the recent artificial reliction which exposed a sandy terrace three to four hundred feet wide between the forked bar and the new shoreline. Small dunes have been developed on the exposed terrace throughout the entire length of the bar. No definite form or arrangement is evident in these dunes, although they are best developed on the northern part of the area, between the Nipissing dunes and the point of juncture of the forked bar, a distance of nearly three-quarters of a mile (fig. 4). Sand has been piled in dunes that form a ridge 10 to 15 feet high on top of the bar; small "blow-outs" have formed and increase the height of the ridge three to five feet locally. In the southern portion, dunes three to five feet high have developed on the bar. It is probable that these dunes were formed after the level of Crystal Lake was lowered in 1873.

[1]This information was received from Mr. Hugh Mitchel, well driller, Frankfort, Michigan.

[2]From a map prepared in 1935, by Robert L. McNamee, Ann Arbor, Michigan



CRYSTAL LAKE BAR--NIPISSING STAGE
Figure 4

[Figure 4. Crystal Lake Bar Nipissing stage.]

NIPISSING STAGE. A great series of dunes was formed in this region during the Nipissing stage (fig. 4). In the central part of the area, many of the dunes have advanced across the Algonquin shore and their lee slopes were formerly washed by the waves of Crystal Lake. In the southern end of the region, the dunes are found in front (west) of the Algonquin shoreline. The greatest advance of the Nipissing dunes is found at the northern end of the bar area. Here the dunes migrated at least one-half mile and now rest on the south slope of the Point Betsie moraine, C, figure 4.

Two well defined periods of dune development are best shown in the central part of the area. Here the more easterly of the two ridges is made up of a series of parabolic dunes which have an average height of more than 100 feet (A, fig. 4). The lee slope of this ridge is straight for nearly three-quarters of a mile, and a beach of the higher level of Crystal Lake is at its base.

Apparently the waves and currents within Crystal Lake were sufficiently active to keep the shore in adjustment and the usual scalloped outline found on the leeward side of a parabolic dune ridge was not developed.

The elevation of these earlier Nipissing dunes decreases toward the north, from 100 feet at the point where the ridge leaves the shoreline of Crystal Lake to 40 feet directly west of the remnant of the Algonquin beach (B, fig. 4). In this locality the character of the dunes changes into a ridge nearly as steep on its windward side as on its lee side. The ridge is, however, made up of a series of parabolic dunes that have one very short spur and one greatly elongated spur. The dunes again increase in height northward where the dune area has advanced over a part of the Point Betsie moraine. At locality "C", near the northern end of the ridge, the crest rises eighty feet above the moraine.

The second, or inner, ridge of dunes can be traced from the large parabolic dune, "D", at the southern end of the central part of the dune area, northward for two miles. In general, these dunes are smaller and lower than the dunes to the east, as their lee slopes rise generally 40 to 60 feet above the base. However, "D", the largest of the Nipissing dunes, is found within this ridge. This exceptional parabolic dune rests upon an earlier older Nipissing dune (fig. 4) and rises at its apex 230 feet above the Algonquin Lake bed directly south of it.

The dunes of Nipissing age in the southern part of the area, south of the large parabolic dune, "D", are not separated into two distinct ridges, although they rank in size and height with the first, or outer, ridge of the central dune area. The southern end of this dune area has been truncated by a later shore, the ridge ending abruptly in a wave cut bluff (shown on pl. VI, B). Thus the original extent of the dunes to the south is unknown, since it is impossible to trace them to the Nipissing beach. Likewise in the northern part of the area, some of the dunes have been cut away through the recession of the morainic bluff that has occurred since Nipissing times.

Nearly all the Nipissing dunes are covered by forest and no recent "blow-outs" were found on them. The only place where the sand is moving at the present time is on the wave-cut bluff at the south end of the dune series. Several logs have been placed in a horizontal position, one above the other, in a futile attempt to control the sand movement on the face of this bluff (shown on pl. VII, A). The southern and eastern part of the Nipissing dune area are covered by a heavy climax forest of beach, maple, and hemlock, with some yellow birch. The central part of the area has been cleared, or burned, but is again fixed with second growth forest trees (22. 23. 24. Waterman, W. G., 1917, 1922).

ALGOMA STAGE. The Nipissing dunes in the central part of the region have been truncated on the windward side by a wave-cut bluff (A, fig. 5); the elevation at the base of this bluff (592 to 594 feet) identifies it as an Algoma beach of post-Nipissing age. The cut bluff can be traced for nearly three-quarters of a mile but passes beneath recent dunes both to the north and to the south.

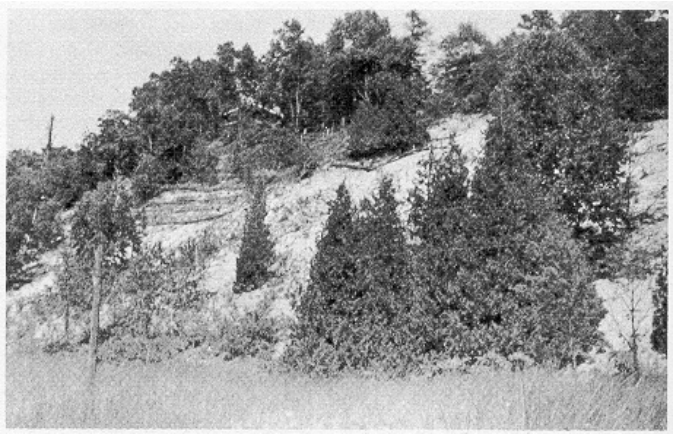


PLATE VII. A. Detail of truncated Nipissing dune ridge showing attempt to control sand movement.

PLATE VII. B. Looking southwest along the Algoma beach that ends at the Point Betsie Lighthouse.

A strong gravelly spit or beach (B, fig. 5) which was developed during the Algoma stage extends from the morainic headland at the northern limit of the area southwestward for nearly a mile; at that point it has been truncated by the waves of the present level of Lake Michigan (pl. VII, B). How much farther this spit was developed southward from the Point Betsie lighthouse, its present terminus, is not known. The material which composes this Algoma beach ranges in size from sand to shingle. Its surface is protected by a coating of flat, rounded stones, one to two inches thick and three to six inches in diameter (pl. VIII, A). The wind has removed the sand from the surface of the bar, exposing the stones to sand blast, which has formed typical ventifacts (one-, two-, three-sided stones) of many.

During Algoma times the westward side of the Crystal Lake bar region was in part a shallow bay partially cut off from the main lake by a bar or spit that extended southward from the moraine to the north. A layer of marl, three-quarters of an inch in thickness, exposed in many places where deflation has removed the upper layer of sand, indicates shallow, still water within the bay. This marl bed was found in several localities south

of the lighthouse and also back of the Algoma beach northeast of the lighthouse (pl. VIII, B). No dunes found within the area can be definitely dated as of Algoma age. Perhaps some of the modern wooded dunes south of the active dune area were developed during or just following the Algoma stage, but neither their position nor their soil profile gives any indication of antiquity.

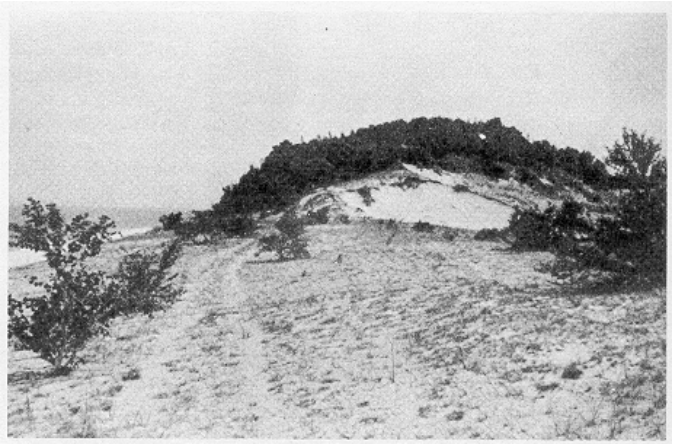
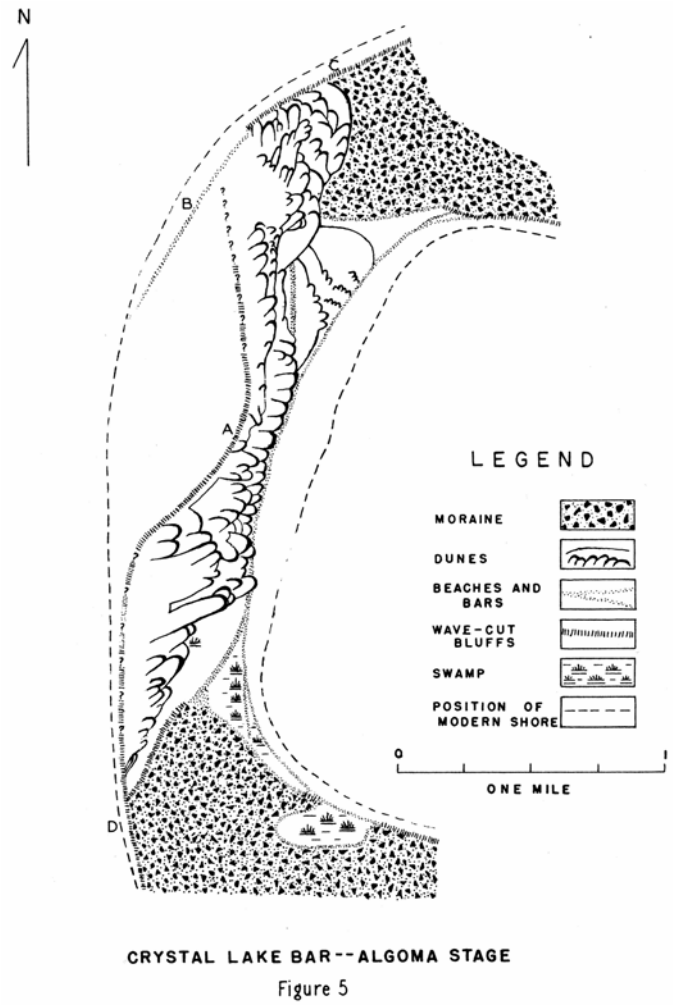


PLATE VIII. A. Looking northeast along crest of the Algoma beach, showing modern dunes that have covered the beach.

PLATE VIII. B. Marl layer three-quarters of an inch thick, one-quarter mile southwest of Point Betsie Lighthouse.

The limiting morainic bluffs both north and south of the bar region have been truncated by the waves of Lake Algoma. A cut terrace extends along the lakeward side of the Point Betsie moraine at an elevation of 592 feet (C, fig. 5). The western end of the terrace is narrow, perhaps twenty feet wide, but it gradually widens toward the northeast. At the eastern end of the morainic bluff the terrace is two to three hundred feet broad. The Frankfort moraine, south of the bar region, (D, fig. 5) was also truncated by Algoma waves, but the terrace at the foot of the bluff is covered by a foredune ridge (pl. IX, A). This information is given to amend Taylor's statement that the Point Betsie moraine has been truncated by the present lake (15. Leverett, Frank, and Taylor, Frank, p. 427, 1915).

PRESENT STAGE. Following the fall in level from the Algoma to the present level of Lake Michigan a great series of dunes was formed. In the southern part of the bar region these dunes have been preserved because a vegetal covering protected the sand from further blowing. A complex "blow-out" (M, fig. 6) developed directly windward of the large Nipissing dune (N, fig. 6) to a height of nearly 80 feet at its apex.



CRYSTAL LAKE BAR--ALGOMA STAGE
Figure 5

[Figure 5. Crystal Lake Bar Algoma stage.]

In the central part of the region, however, in an area approximately half a mile wide and a mile long the dunes are developing and being remodelled at the present time (M, fig. 6). The several patches of relic wooded dunes preserved there indicate one and possibly two dune ridges that have been almost entirely disrupted by recent sand movement. The scattered relic dune patches are too small to indicate the stage of development of the dunes. Evidently the vegetal covering on earlier ridges was destroyed by fire, and a mass movement of sand resulted in the formation of the present large festoon dunes that reach a height of 100 feet.

The westward part of the active dune region is a flat sand plain on which a number of low dunes are developed. A low dune ridge parallels the shore from the south end of the active dune area northward to the lighthouse (fig. 6). Many small "blows" are on this ridge, but elevations above 20 feet are uncommon. In the lee of this dune ridge are several parabolic, apex type, dunes that were blown up from the sand plain, and not

developed from a foredune ridge. The plain consists of a layer of sand about four feet in thickness that rests upon a thin layer of marl which has been described. Evidently this sandy plain may have supported a plant cover which when destroyed allowed the wind to blow the sand and pile it on the leeward side of the exposed areas. The zone of deflation of the windward side of these dunes has been lowered to below the present water table and small ponds are in the bottom of the wind furrows (shown on pl. IX, B). This deflation doubtless occurred during a very low stage of Lake Michigan.

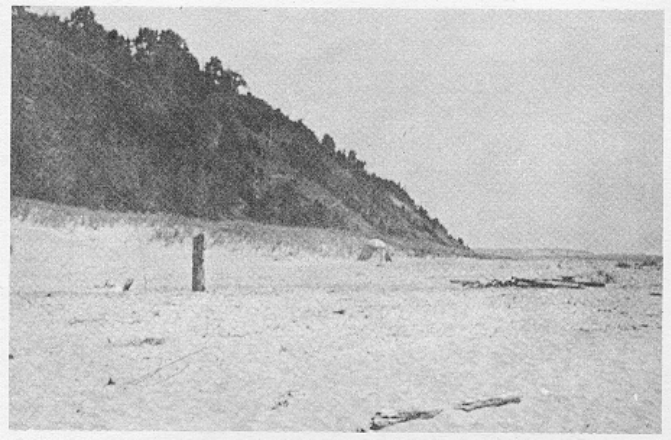


PLATE IX. A. Truncated Frankfort moraine; the southern boundary of the Crystal Lake bar region.

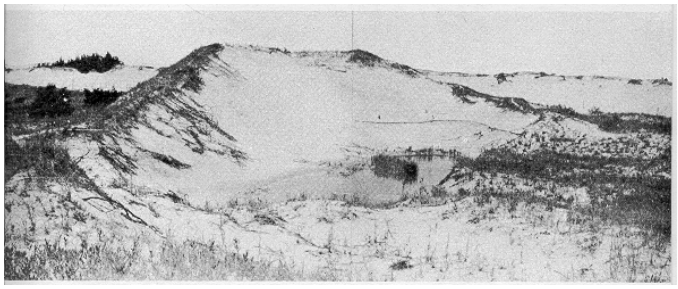
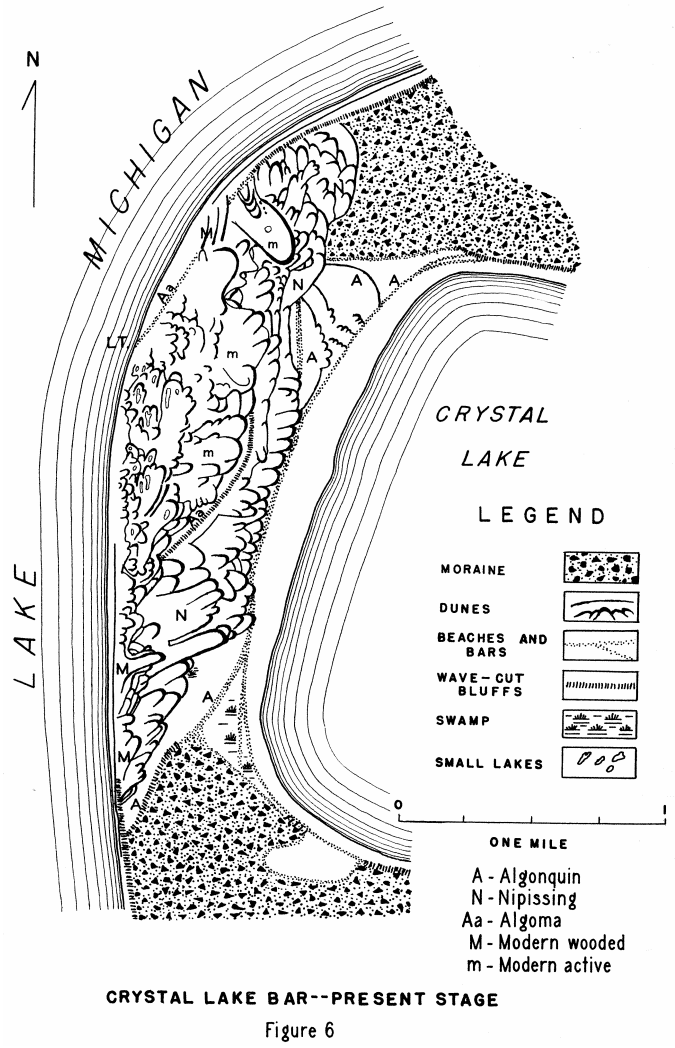


PLATE IX. B. Small parabolic dune blown from the sandy surface of the bar region, one-half mile southeast of the Lighthouse.

Further evidence of fire is found one-half mile northeast of the lighthouse, within the deflation zone just south of the three relic dune ridges (fig. 6), where nearly an acre of pebbles (pl. X, A), which undoubtedly represents old lake bottom, has been exposed. Perhaps a third of the pebbles have been broken or cracked; some of them appear to have exploded and the fragments scattered over several square feet. The fragments of some were collected and fitted together again (pl. X, B-C). No one particular kind of rock seems to be affected; stones of granite, gabbro, diabase, diorite, gneiss and quartzite are among those most commonly fractured. Evidently the stones were cracked during the fire that destroyed the vegetation in the region and are not all Indian fireplace stones. Three hundred feet west of the area of rock fragments, a thin layer of charred wood is exposed and three pine stumps were found in it.



[Figure 6. Crystal Lake Bar Present stage.]

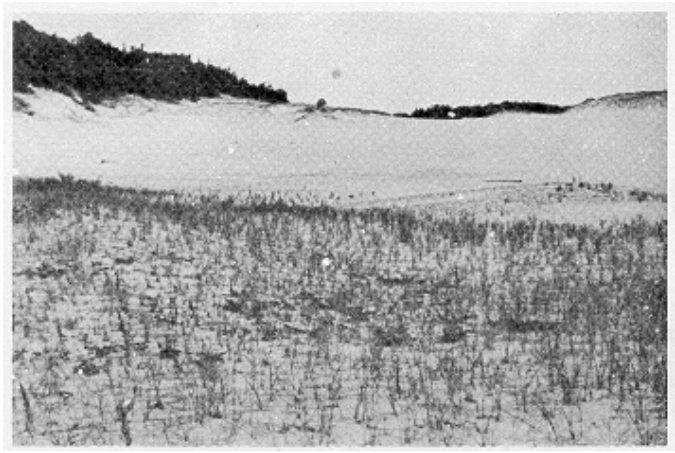


PLATE X. A. Gravelly deflation zone one-half mile northwest of Point Betsie Lighthouse.

LATER GLACIAL HISTORY OF PLATTE LAKE DEPRESSION

General

The Platte Lake depression contains nine lakes; six are drained directly or indirectly by the Platte River, and three are drained by Otter Creek, (pl. II.) The Platte River enters the embayment at Honor, in the southeast corner, and flows northwestward into Big Platte Lake. About three-quarters of a mile northwest of the outlet of Big Platte, located at the northern end of the lake, the river turns and flows south for nearly half a mile before it enters the crescentic shaped Loon Lake. A small creek, the outlet of Mud Lake, empties into the river about a quarter mile upstream from this point. The outlet of Loon Lake is at the northernmost extension of the lake, and the Platte River continues its northerly course to Lake Michigan, a distance of nearly two miles.

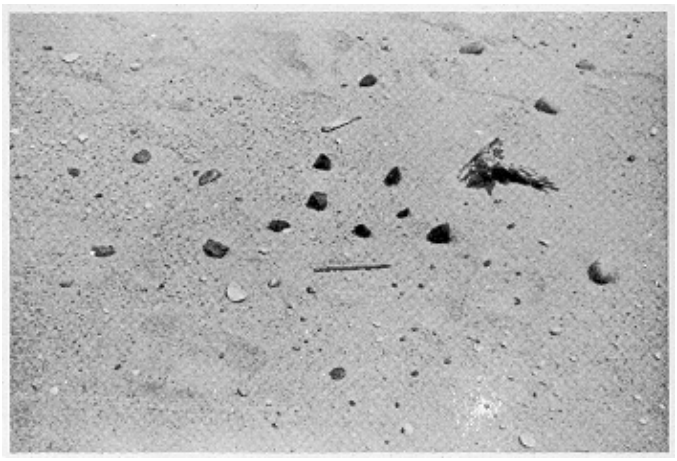


PLATE X. B. Detail of deflation zone showing fragments of "exploded" beach pebbles.

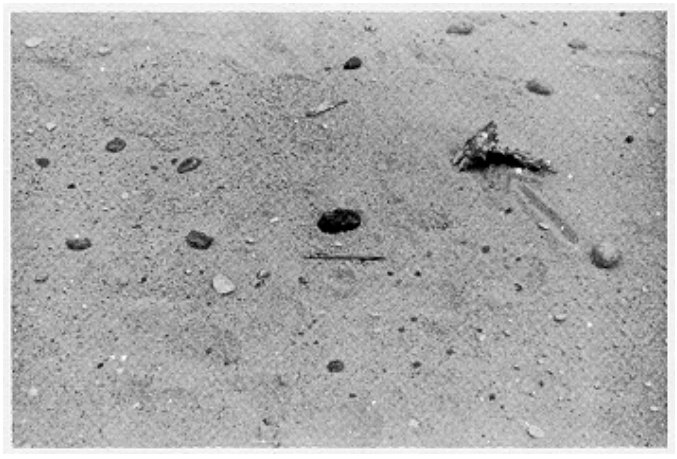


PLATE X. C. Same as B, the fragments of one stone have been gathered and fitted together.

Long Lake, the highest lake in the area, drains eastward into Rush Lake through a cedar-tamarack swamp. Rush Lake, filled with reeds and rushes, is nearing extinction; it is so shallow that waves have little effect on the shore. Its outlet drains eastward through a cedar swamp that separates Rush from Big Platte Lake. Little Platte is but one foot higher than Big Platte, into which it empties by way of the Dead Stream and the Platte River. This lake is very shallow and has a low and swampy shoreline. The following table gives the elevations of seven lakes located within the area studied.

TABLE III

Elevations of lakes within the Platte and Crystal Lake Depressions

	Feet above sea level
Crystal Lake	602.0
Round Lake	604.4
Long Lake	599.6
Rush Lake	599.6
Mud Lake	585.3
Big Platte Lake	587.4
Little Platte Lake	588.6

(Elevations determined during July and August, 1938.)

PLATE XI. A. Morainic "island" east of the Platte River mouth.

PLATE XI. B. Active dune area southwest of Platte River Point. The wind furrow in the fore-ground has been deepened below the present groundwater surface. A small pond is distinguishable in the zone of deflation.

Deer, Bass, and Otter Lakes are drained by Otter Creek, which empties into Lake Michigan at Aral. The "town" of Aral, once a flourishing community of perhaps a hundred or more people, is now represented by one summer cottage owned by Mr. Beaver Edwards. A fourth lake in this series, now extinct, is shown clearly on the airplane mosaic (pl. I).

The Platte interlobate moraine divides the depression into a double embayment. The western embayment contains all the lakes drained by the Platte River excepting Little Platte Lake which empties into the Platte River southeast of the moraine. The ridge is not continuous but is composed of three segments: (1) A narrow ridge two and one-half miles long and one-quarter mile wide that lies north and east of Big Platte Lake, (2) a high ridge east of the Platte River, near its mouth, and (3) a small, low patch of till within Benzie State Park.

The single ridge composed of sandy till that lies north and east of Big Platte Lake contains several patches of kame material that have supplied gravel for local use. Each of the six pits visited was small and overgrown with grass, weeds and small trees which made it impossible to observe the bedding; however, local residents report the beds to be contorted and crumpled. This condition may indicate a final readvance of the glacier before its complete withdrawal. Other evidence for a readvance of the glacier within the depression is found east of Honor, where two small "valley moraines" appear to extend across the valley of the Platte River (pl. II). If these deposits, which rise to a maximum of 15 to 20 feet above the valley floor, are moraines, they were formed subsequent to the main Manistee moraine, which rises more than 200 feet above the river at this location. (See discussion, under Early Glacial History.) From its southeastern terminus, which was covered by water during both Algonquin and Nipissing stages of the Great Lakes, the Platte moraine rises gradually toward the northwest. The nearly uniform increase in elevation is continuous for one and one-half miles to "Mt. Minnie," the highest knob, which rises 90 feet above Platte Lake or to approximately 680 feet North of Mt. Minnie the moraine decreases in elevation and a cut bluff 30 to 40 feet high extends for nearly one-half mile in an east-west direction. (pl. II.) The elevation of the cut terrace at the base of this bluff identifies it as a Nipissing shore feature.

A smaller remnant of the Platte moraine lies east of the mouth of the* Platte River. This ridge, nearly a quarter of a mile long, parallels the present shoreline and rises 70 feet above Lake Michigan (shown on pl. XI, A). The ridge is not more than 200 feet wide and both its north and south sides rise as cut bluffs. The material, exposed on the north bluff, is boulder-clay. Lake Michigan Coast Chart No. 78 (edition 1938) shows shallow water, less than 18 feet in depth, extending lakeward from this morainic remnant for a distance of more than a mile. Apparently the moraine has been gradually worn away by wave attack.

The third remnant of the Platte moraine lies between the two segments just described. It is located within Benzie State Park, a quarter-mile northwest of the main part of the moraine. This portion is sandy and was worn down and washed by the waves of Lake Algonquin. The northern and eastern sides of this till area have been covered by parabolic dunes developed by northerly winds during the Nipissing stage, which rise approximately 20 feet.

ALGONQUIN STAGE

Excepting small island areas, the entire triangular depression between the Point Betsie Moraine on the south and the Empire Moraine on the northeast with the apex of the triangle west of Honor was a bay of Lake Algonquin.

In general, the Algonquin shoreline can be traced eight miles eastward along the north side of the Point Betsie moraine from a point near Lake Michigan to the delta remnant at the head of Platte Lake depression. Throughout this distance a bluff with a wave-cut terrace characterizes the former shore. A prominent bay-head bar (east of Big Platte Lake) connects the Pointe Betsie moraine with the Empire moraine to the north. The shore development found in the area is similar to shore development at Beulah near the head of the Crystal Lake depression. From the northern attachment of the bar about a mile east of Little Platte Lake to Aral, a distance of five miles, high (200 feet or more) wave-cut bluffs on the Empire moraine predominate. These bluffs, however, are interrupted in two localities which will be discussed later.

The interlobate moraine which divided the depression into two parts formed a series of islands in the middle of this large bay of Lake Algonquin. The morainic segment between the Platte Lakes was the largest island. Along the southwestern side of this ridge, a well-developed beach ridge was found to have an elevation of 616 feet. In front of this beach, a bar (elevation 608 feet) can be traced eastward until it joins the morainic cut bluff which extends more than a mile southeastward. On the opposite side of the ridge, the Algonquin level is represented by a cut terrace which has an elevation of 610 feet. This terrace, which can be traced along the entire length of the moraine, gives way at the north to a beach, the top of which rises to 613.5 feet. The Nipissing beach truncates the Algonquin shore on the north side of this "island."

An Algonquin cut terrace extends along the south and east sides of the morainic segment which forms Platte River point, but no definite shore was found in this locality. The elevation of this terrace (605 to 607.5 feet) does not represent the true elevation of the Algonquin lake stage. Nipissing dunes developed by southwesterly winds have extended across a portion of the terrace and have obscured the shoreline.

The third morainic segment in Betsie State Park, between the two described, was narrow and probably low. The waves of Lake Algonquin wore away the sandy till and washed over this part of the moraine.

The bar which separated Platte Lake depression from the Algonquin bay occupied by Crystal Lake (see discussion of Round Lake Basin and "A" fig. 1) closed the northern entrance of Round Lake channel. Northeast

of the bar, a strong gravel ridge, "D" figure 1, extends three-quarters of a mile in a northwesterly direction from the cut bluff on the Point Betsie moraine. The northern extension of the bar is double, or forked, and has been covered by dunes. The bar appears to be best developed north of "D," but south of this point for nearly a quarter of a mile the original shape has been destroyed through the removal of gravel. Parallel to the shore of Long Lake, a gravelly spit "E," 606 feet high, joins the cut bluff, the base of which has an elevation of 604 feet. This spit and terrace are not Algonquin features but a later Nipissing shoreline adjustment.

After the development of the bar "D" an Algonquin spit "F" figure 1, was constructed (by wave and current activity of the main body of water) from the moraine west of Round Lake eastward along the north shore of Long Lake. Near the west shore of Long Lake, this spit, evidently truncated the double bar, "D." Traced eastward from its attachment to the Algonquin beach (elevation 616 feet) on the north side of the Point Betsie moraine, "F" merges into a ridge of low dunes. This dune ridge, Algonquin in age, rises 25 to 30 feet above Long Lake (elevation 600 feet); it has been partially covered by larger, higher Nipissing dunes, "G," that rise 50 to 70 feet above the lake. Farther east the Algonquin dunes reappear (pl. II) and extend southeastward nearly three-quarters of a mile as a single ridge. Situated between the lee slope of the dunes and Long Lake is an Algonquin shoreline which may be an extension of "F" (fig. 1). The two little peninsulas on the north shore of Long Lake are spits developed from this beach. As the current activity continued, bars and spits were built eastward past the north shore of Rush Lake. (See pl. II.) The underwater extension of this shoreline forms the larger peninsula on the west side of Big Platte Lake.

From the Round Lake basin eastward for a distance of five miles, the bluff on the north edge of the Point Betsie moraine rises abruptly from a wave-cut terrace. The bluff, continuous throughout the distance, had two periods of formation. During the Algonquin stage waves actively eroded the northern side of the moraine and reduced the minor irregularities to form a cut bluff. Two segments of this Algonquin shore are to be found: (1) The terrace south of Rush Lake, which has an elevation of 616 feet, and (2) a smaller remnant along the south shore of Big Platte Lake which stands at 615.7 feet. On either side of these features, recession of the bluff cut at a lower lake level, the Nipissing, has removed all traces of the former, higher lake stage. (See pl. II.)

South of the easternmost, extension of Big Platte an Algonquin beach lies at the base of the moraine and extends eastward for more than a mile to the head of the Platte depression. Here the shore line turns sharply to the north as a bay-head bar. The swampy area bordering the Platte River east of this bar must have been a lagoon during the Algonquin stage, similar to the lagoon at Beulah. The distance the water flooded the Platte valley upstream is indeterminable. Within the village of Honor a river terrace about one hundred feet wide stands at an elevation of approximately 620 feet. This terrace, the only one found within the valley, is present only in this one locality. It is correlated with the Algonquin stage.

The eastward part of the Algonquin bay-head bar stands at an elevation of 610 feet and is continuous with the Algonquin beach found on the north side of the Point Betsie moraine. The bar, composed of fine gravel and sand, can be traced for two miles in a northerly direction to its attachment on the eastern side of the Empire Bluffs moraine. The true character of the bar north of the river has been obscured by the construction of a highway; even the critical locality, the point of attachment, has been destroyed. To the east of this locality an earlier Algonquin spit was found to extend nearly a mile southeastward from the moraine. Near its attachment, this spit is four feet high but it gradually decreases in elevation toward the south; a thick stand of second growth timber and underbrush in this locality made it impossible to determine the extent southward (see pl. II).

From the attachment of the Algonquin bay-head bar northward, the Algonquin stage is represented by a wave-cut bluff which extends northward for one and one-half miles from a point a quarter of a mile south of Little Platte River. The bluff reaches its maximum height just north of the river and rises to more than 200 feet above the lake plain. The cut bluff is interrupted by the development of three low, broad spits north of Little Platte Lake. These spits average 613 to 615 feet in elevation and rest on a terrace—lake bottom—610 feet in altitude. The southern extension of these spits has been truncated, nearly at right angles, by a terrace of Nipissing age, just north of the swampy peninsula in Little Platte Lake. The elevation of the terrace was determined at 601 feet.

The cut bluff is well developed on the Empire Bluffs moraine east of Bass and Otter lakes and northward to Aral and conditions are similar to the cut bluff south of Long and Rush Lakes: The Algonquin bluff has been reworked and worn away by a later lake stage. The bluff is approximately 250 feet high east of Otter Lake, but the morainic hills rise more gently in the vicinity of Aral, and a beach with its off-shore terrace was developed there. This beach may be traced westward to near the present shore, where it has been truncated by the later lake stages. (See pl. II.)

Within the Platte depression Algonquin dunes were developed in only two localities: (1) Southeast of Otter and Bass Lakes on the east side of the depression, and (2) north of Long Lake in the western part of the area. Near Bass Lake the dunes comprise two ridges which are generally less than 20 feet in height but in places rise to a maximum of 30 feet. These ridges disappear beneath high Nipissing dunes to the south, although the easternmost ridge reappears. This ridge of parabolic dunes extends one-half mile southward, where it is again covered by the younger dune ridge. The soil profiles have a much deeper color in the Algonquin dunes than in the larger Nipissing dunes. The dunes which lie

directly north of Long Lake, have a still darker color, and the surface sand has been cemented by limonite, or iron oxide, to a depth of three quarters of an inch. No iron cemented sands were discovered in the Algonquin dunes in the eastern part of the area, but they are present in the sand beaches which lie between these dunes and the moraine.

NIPISSING STAGE

The most important shore line changes within the depression occurred during the next lower Nipissing lake stage, and in favorable localities, these changes were accompanied by the development of large parabolic dunes. Bars were constructed across both the western and eastern part of the embayment to form a lagoon which included the lake basins now occupied by Long, Rush, and both the Platte Lakes. A somewhat smaller lagoon in the northern part of the area, now partially filled by Otter, Bass and Deer Lakes was also formed.

Along the northernmost part of the Point Betsie moraine, a wave-cut terrace is found at an elevation of 602 feet. The terrace which extends in a direction S. 85° E. truncated the Algonquin beach at an angle of 40° (shown on pl. II). The shoreline continues easterly for one-quarter mile as a gravelly beach ridge, the top of which has an elevation of 606 feet, but at that point it is lost beneath a dune ridge. Northwest of Big Platte Lake, (south of the Loon Lake swamp, pl. II), however, the eastern extensions of some twenty sand spits or hooks have particular interest. These were developed mainly by waves and currents from the west; in profile the steep lee slope of the hooks faces south. The apparent explanation of this development is that the long-shore currents, unhindered eastward from the Point Betsie moraine for a distance of three miles, were interfered with and deflected northward chiefly by the Platte moraine which extended as a low ridge to the Platte River, however, the current from the outlet of Big Platte Lake was a contributing factor in turning them. The discharge from the Platte River was sufficiently strong to prevent complete bars to form across the depression although the outlet channel was crowded eastward against the Platte moraine. Enormous quantities of sand may have been required to build these bars above the level of Lake Nipissing (Big Platte Lake has a depth of 80 feet and Loon Lake, of 40 feet). No information is available regarding the depth of the sand deposited in this region. It appears likely that deep water once existed west of Platte lake basin because high dunes, characteristic of the Nipissing shore, are not to be found in this locality. Probably the sand furnished by the waves and currents was only sufficient to fill the deep pre-glacial valley in this locality.

Throughout this area several foredune ridges were found among the Nipissing beaches. These ridges, 10 to 15 feet high, are uniform in development in the eastern part of the area, but, they become deformed toward the west (pl. II). It is only in the locality north of Long Lake that parabolic dunes formed and the best developed ones are adjacent to the Algonquin dunes. Two of these rise 40 or 50 feet and cover the Algonquin dunes to the south (see plate II just north of the bay shore of large lake), in general, the dunes consist of small, insignificant blows. In front of this ridge is an area of foredunes which have been thoroughly disrupted by "blow-outs" to form low dune ridges (15 to 20 feet, maximum elevation of the apexes).

During Nipissing times a narrow bay three and one-half miles long and about one-half mile wide, now occupied by Long and Rush Lakes, extended westward from Big Platte. This arm was bounded on the north by a low ridge which may represent the submerged part of an Algonquin bar or a bar formed during the fall in level of Lake Algonquin. The western end of the bay nearly coincides with the outline of Long Lake, and the Point Betsie moraine with its Algonquin cut-bluff formed the southern shore line. This bluff was remodeled, in part, during Nipissing times, because the Nipissing terrace extends along its base on the south side of Long Lake, and a bench was cut in the Algonquin terrace south of Rush Lake (shown on pl. II). From Rush Lake eastward, a long compound hook developed; its four stages of construction were traced and found to end in a swamp southwest of Big Platte Lake. From this swamp, a lagoon during the Nipissing stage, the Nipissing shore extends eastward as a cut terrace for two miles. This shore line, traced eastward, extends as a beach (top elevation 605 feet) around the head of the Platte depression. Where the shore turns toward the northeast to cross the Platte valley, the beach drops in elevation to 599 feet.

The eastern part of the Platte depression was separated from the Lake Michigan basin by a bar early in the Nipissing stage. Although the elevation of this bar northwest of Little Platte Lake between the Platte moraine and the Empire Bluffs moraine was not determined, the conditions at its western attachment exclude, any other interpretation of its age. Below the Algonquin cut terrace (elevation 610.7 feet), present along the northeastern side of the Platte moraine, between Big and Little Platte lakes, a Nipissing beach was found to have an altitude of 605 feet. The northern edge of the moraine has been truncated by a wave-cut bluff the base of-which has an elevation of 605 feet. To the east, the shore line leaves the moraine as a low, broad bar which may be traced more than a mile in a northeasterly direction to a place where it is covered by later Nipissing dunes. The beach adjacent to Little Platte Lake turns abruptly and joins the main portion of the bar, which indicates an adjustment of the shore of the lagoon behind the mid-bay bar. Beaches of this stage formed by the water within the Little Platte Lake basin were found to be nearly continuous around the basin. One locality, just north of the peninsula in the northeast part of Little Platte, is of particular interest. Here a cut terrace has truncated the underwater extension of the three Algonquin bars (see pl. II). From this terrace (elevation 599 feet) eastward, two spits developed and extend nearly to the small creek which

empties into the east arm of Little Platte Lake. The spits are eight feet high and rise to elevations of 603 and 607 feet respectively.

Unlike the western portion of the Platte depression, the area northeast of the Platt interlobate moraine contains a grand display of Nipissing dunes. These dunes undoubtedly formed, for the most part, following the maximum elevation attained by Lake Nipissing. A double row of parabolic dunes extends from the Platte moraine to Aral, a distance of nearly seven miles. The highest dunes comprise the outer ridge; these rise between 60 and 70 feet from the Nipissing Lake bed, upon which they are mainly developed. The inner row, composed of somewhat smaller dunes, rises almost as high in some places; but these are dunes "perched" upon the windward slope of the earlier Nipissing series. In the vicinity of Bass Lake, the inner ridge has developed on top of the high outer ridge, and here the dunes reach their maximum height of nearly 100 feet. West of this locality an area of complex dunes exists; no definite linear trends were observed and no attempt was made to map them. Some dunes in this area rise 30 or 40 feet, but on the average, the dunes are only 15 or 20 feet in height.[1] It is possible that these are inland dunes developed on old lake bed.

In the area sometimes referred to as the Platte Plains, (23. and 24. Waterman, W. G., 1922) which lies between the Nipissing dune ridges north of Little Platte Lake and Lake Michigan, a series of fore-dunes was formed. Each ridge marks a stage of slightly lower water level initiated by land uplift or by actual drop in lake level and is, therefore, part of the transitional development from the Nipissing Great Lakes to the Present. This transitional period is also reflected in the gradual lightening of the color in the soil profiles from the high Nipissing dunes to the neutral colored sands which form the modern dunes. No definite age grouping is possible for the younger dunes of Nipissing age.

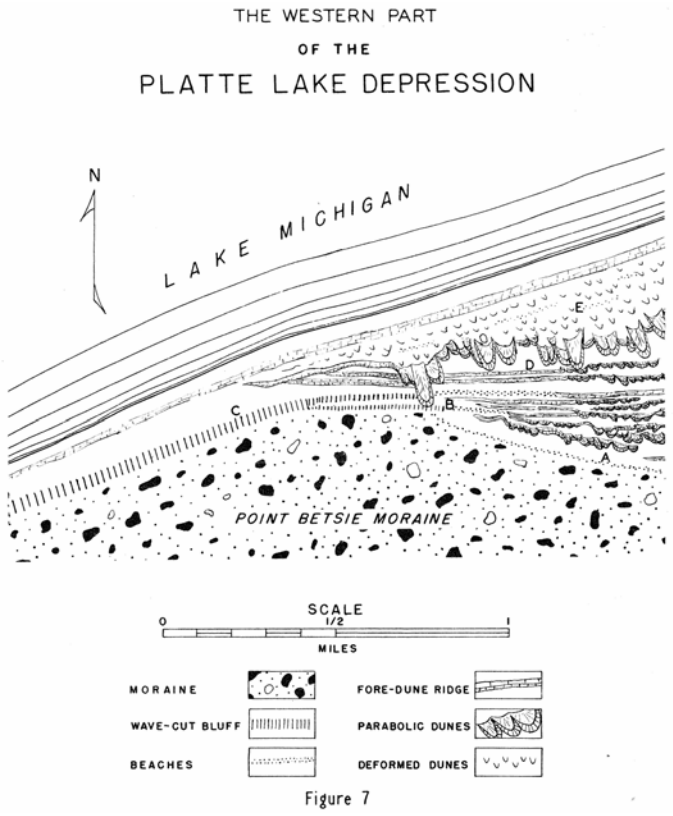
[1]A more detailed description of the Nipissing dunes which lie in the northern part of the depression is to be found in the discussion of the northeastern part of the depression.

POST-NIPISSING STAGES

Within the basin which contains the Platte Lakes, a beach exists below the Nipissing level. This shore line probably represents the Algoma stage, for its elevation was determined at 594.6 feet. The beach was found on both sides of the outlet channel of Rush Lake, along the south shore of Big Platte, from the outlet of Big Platte southeastward along the Platte interlobate moraine, and along the northeast edge of the Platte moraine.

During the Algoma stage, the water level within the Platte depression was sufficiently high to cover the modern swampy area adjacent to the Platte Lakes on the east forming one body of water. The fall in level of Lake Michigan from the Algoma stage to the present resulted in draining the shallow part of this lake and thus separating the two Platte Lakes. The basin between the Nipissing dunes and the Empire moraine now occupied in part by Otter, Bass and Deer lakes must have been flooded during the Algoma stage at least as far south as Bass Lake. Although no beach prominent enough to be assigned to the Algoma stage was recognized in the area, the elevation of Otter Lake is, at most, not five feet higher than Lake Michigan. Otter Creek, its outlet, is a slow-moving stream which winds through a swampy area for nearly two miles before it discharges into Lake Michigan at Aral. Through nearly half this distance the creek cuts through a bog that once was a fourth lake in this area, visible on plate I. For some time before and-after the year 1900, a dam was maintained across the narrow channel of the creek near its mouth, but nearly all traces of this dam and a lumber mill that once stood here have been destroyed.

The characteristics of the Post-Nipissing development on the lakeward part of the Platte depression may best be described in conjunction with a detailed account of three critical areas: (1) the westernmost part of the depression, (2) the Platte River point, and (3) the locality near Aral in the northern end of the depression.



[Figure 7. Western part of the Platte Lake Depression.]

THE WESTERN PART OF THE PLATTE LAKE DEPRESSION. The shore lines of four successive stages of the Great Lakes are clearly shown in this area located in the westernmost part of the Platte depression. The oldest beach, the Algonquin, has been truncated by the Nipissing and the Nipissing by the Algoma beach. This truncation resulted from wave cutting-cliff recession of the morainic headland. Below the Algoma level several minor beaches are found which indicate temporary

levels between the Algoma to the present stage of Lake Michigan.

The Algonquin beach, "A," figure 7, extends along the Point Betsie moraine as a beach ridge at an elevation of 616 feet (top of beach). This beach was truncated during the Nipissing stage by the cut bluff "B" at an angle of 15 degrees. The base of this bluff stands at 602 feet, and it can be traced eastward with no apparent change in elevation to a place where the shore line gives way to a beach ridge, the crest of which has an elevation of 606 feet. This beach continues 2000 feet eastward, where it merges into a fore-dune ridge. A number of low dune ridges, developed from deformed fore-dunes, are between the Algonquin and Nipissing beaches. Each ridge consists of a series of small, parabolic blows which rise 10 to 20 feet above the Algonquin lake bed. Traced westward, the Nipissing terrace was found to be truncated by the Algoma bluff "C"; the terrace at the base of this Algoma bluff, beautifully preserved here on the northwest side of the Point Betsie moraine, has an elevation of 590 feet. This shore line can be traced southwestward for approximately four miles to the Point Betsie Lighthouse, where it is truncated by the present level of Lake Michgian. The bluff on the lakeward side of the moraine rises well over 200 feet, and the cut terrace at its base varies in width from 20 to 400 feet. The broad portion is located at point "C," figure 7. To the east, between "C" and "B," the bluff continues as a bench cut into the Nipissing terrace, which passes beneath a modern dune. The shore line emerges on the east side of this dune as a beach ridge, the crest of which has an elevation of 595 feet. This beach extends nearly one-quarter mile to the east before it is covered by, or merges into, a fore-dune ridge as shown on figure 7.

Below the Algoma shore line two stages of dunes are represented. The older consists of two fore-dune ridges, "D," figure 7, which developed parallel to the Algoma shore. The sand has a neutral color although the dunes are covered by forest. These fore-dune ridges have been considered wooded modern dunes, but it may be that they more nearly represent Algoma dunes. The two ridges exposed in the area have a uniform height of 14 feet and are equally developed. To the east both ridges have undergone deformation and consist of a series of small "blowouts."

Lakeward, a modern dune ridge composed of adjacent parabolic dunes has developed to heights of almost 100 feet. This ridge is still in process of formation; very little vegetation is to be found on the windward slope. In some of the parabolas, however, dead pines have been exposed on the windward slopes. This condition is especially evident on the dune which extends to the Nipissing bluff and therefore has buried the trees on the wooded modern dunes (see fig. 7, west of "B").

To the north, a zone of deflation lies between the dune ridge and a modern fore-dune, (see fig. 7). This area contains several rows of fore-dunes that have been thoroughly dissected by wind. In limited areas, deflation has exposed several gravel beaches (pl. E fig. 7) which lie below the Algoma stage but are definitely higher than the present level for Lake Michigan. The elevations of the crests of four beach remnants were determined at: 588, 588.8, 588.7, and 589.2 feet. Within the deflation zone several shallow ponds exist in basins hollowed out by the wind during a low stage of Lake Michigan as shown on plate XI, B. Similar ponds are found on the westward part of the Crystal Lake bar region. Parallel to the shore line, a modern fore-dune extends from the Point Betsie moraine to the Empire Bluffs moraine; it is uniform in development throughout this distance and rises about 15 feet above the level of Lake Michigan.

THE AREA ADJACENT TO THE MOUTH OF THE PLATTE RIVER. The area near the mouth of the Platte River has particular interest in the study of dune development. All the Platte moraine in this locality was submerged during the Algonquin stage excepting an "island" which lay east of the Platte River mouth, (A, fig. 8). This moraine undoubtedly extended much further northward and suffered greatly by wave attack throughout the high level stages of Lake Michigan. Shallow water, less than 18 feet in depth, extends northward from the present shore for more than one mile (see U. S. Lake Survey Chart No. 78). Unfortunately no definite Algonquin beach can be found on either side of the "island," which rises in height about 65 feet above Lake Michigan. The north side exposed to wave attack has been truncated by the present level of Lake Michigan as shown on plate XI, A. To the south, the till remnant drops off nearly as abruptly as the cut bluff on the north. The morainic extension to the southeast, an Algonquin cut terrace that varies in elevation from 605 to 607.5 feet, has no definite shore line between it and the higher part of the moraine.

Two groups of Nipissing dunes are in this area. Northwest of Mud Lake three parabolic dunes of the apex type are over 90 feet in height. Developed in front (west) of them, a festoon dune ridge which rises generally less than 10 feet may be traced to the north and to the south into a typical fore-dune. Just south of the till "island" (A fig. 8) several Nipissing dunes have developed on the Algonquin cut terrace and rise to a height of 80 feet. The modern wooded dunes west of the Nipissing dune ridge (B fig. 8) rise 40 to 60 feet above the Algonquin terrace.

The Platte River, an extended consequent stream, flows in a meandering course only in its lower reaches below the short rapids located in the narrow channel between the end of the Nipissing beach and the Nipissing dunes northwest of Mud Lake (see C fig. 8 and pl. XII, A). These rapids result from gravel and boulders which were probably derived from the till remnant to the north. In this locality the river was apparently forced against the moraine by the northward-moving longshore currents in the old Nipissing embayment.

The present aspect of the Platte River mouth is in response to interference by man. Formerly the river discharged through the channel east of the two small islands, see figure 8. This opening gradually filled with

sand, supplied by longshore currents from the west; in the early 1920's a channel was dredged across the hook which then separated the river from Lake Michigan. This opening also filled with sand and a second channel was excavated about 200 feet farther west. The river was forced to flow through the new opening by an underwater barrier which was constructed in the old channel to deflect the current (shown on pl. XII, B). Apparently the discharge directed into Lake Michigan at right angles to the shore was strong enough to deflect the longshore currents out into the lake. A low sand hook which developed from the west to east now all but encloses the former mouths of the river (see pl. XIII, A). Hence, the attempt to shift the mouth of the Platte River 500 feet to the west resulted in the extension of the river toward the east, where it now discharges 500 feet beyond its original opening.

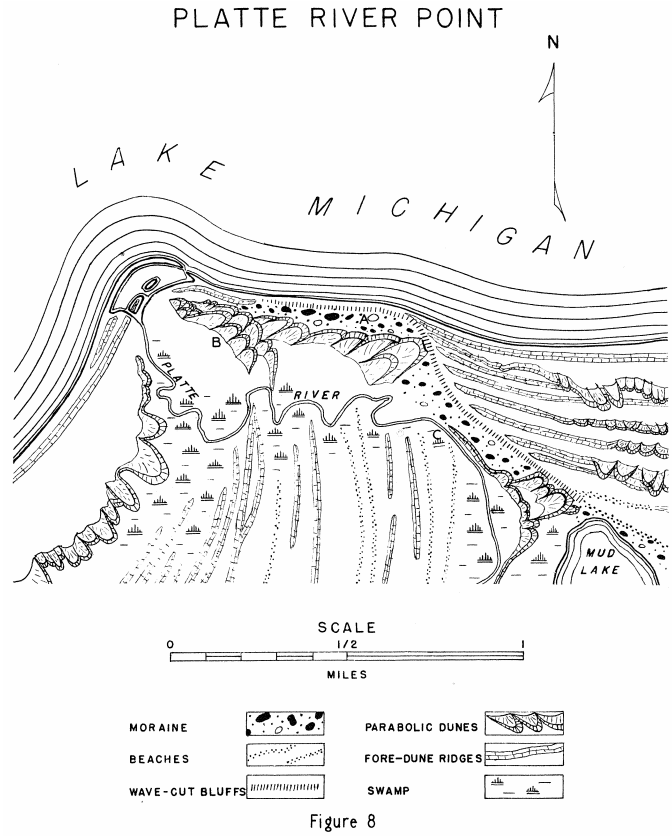


Figure 8

[Figure 8. Platte River Point.]

The shore of Lake Nipissing extended along the east side of the Platte moraine in this locality. Northeast of Mud Lake, this shore line has been preserved as a strong beach ridge which rises to 605 feet above sea level. From the present shore to the high Nipissing dunes blown across the morainic extension from the west near Mud Lake this beach has been worn away by the Algoma level, represented by a cut bluff and terrace (elevation 590 to 591 feet) which extends southeastward along the east edge of the moraine. At that locality the Algoma shore changes in direction and can be traced eastward as a beach ridge.

Between this beach and Lake Michigan, eight fore-dune ridges have developed. Six of these ridges have been interpreted as modern wooded dunes. It is self-evident that these fore-dunes are all post-Algoma forms, but they may be in part more closely related to the Algoma stage than to the present lake level. The western part of the ridges rise about 10 feet above the sandy lake plain and are relatively free from blows. To the east, however, the ridges have been deformed by northerly winds and the simple fore-dunes give way to dune ridges. Of the wooded dunes, the ridges farthest south have the highest parabolas; these rise 40 to 50 feet; the remaining ridges may rise to 30 feet at the apex of the larger blows, but are on the average much lower.

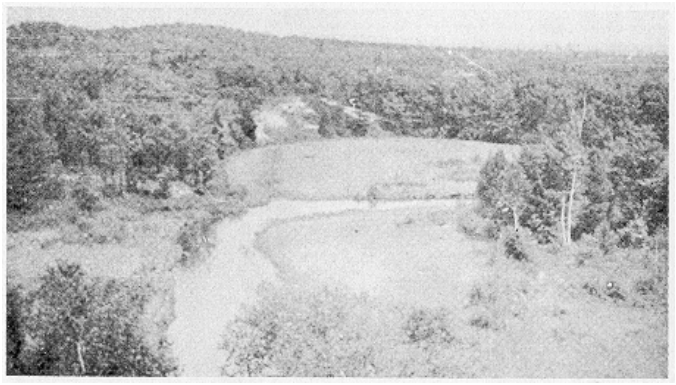


PLATE XII. A. The lower course of the Platte River showing its meander belt.

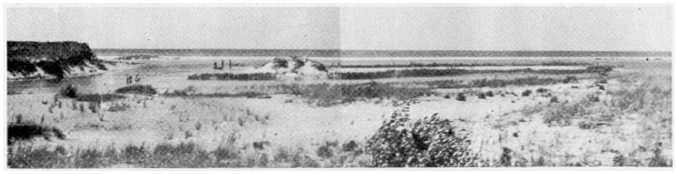


PLATE XII. B. View of the cut through the fore-dune ridge near the mouth of Platte River; the hooked spit shows in the middle distance.

PLATE XIII. A. View of the Platte River Point, looking northeast; the relationship between the former course of Platte River, the cut through the fore-dune ridge, and the hooked spit which developed around the mouth of the river are clearly shown.

PLATE XIII. B. Dune ridge east of Platte River Point, in the foreground; the Empire Bluffs, in the middle distance; Sleeping Bear Bluff, in the far distance.

Parallel to the shore two characteristic sets of modern dunes are in process of formation as shown on plate XIII, B. The dune ridge has covered part of the earlier fore-dunes. In this locality the ridge is quite low—less than 25 feet in height—but the corresponding ridge west of the Platte River rises in places to 80 and to 100 feet. The fore-dune adjacent to the shore supports a relatively thick stand of dune grasses.

THE NORTHEASTERN PART OF THE PLATTE LAKE DEPRESSION. All of the area shown in figure 9 south of the Empire moraine was covered by Lake Algonquin. The beach and offshore bar located on the edge of the moraine have elevations of 611.8 feet and 608 feet respectively (A, fig. 9). No shore line of the Nipissing stage was discovered on the lakeward side of the depression, but within the lagoon (B, fig. 9, and pl. II) now occupied by a swamp the Nipissing beach was found and has an elevation of 607 feet. A marl deposit one-quarter of a mile southeast of the part of the Nipissing beach shown in figure 9 in the northern part of the area has an elevation of 604.5 feet, and is believed to have been formed during the Nipissing stage.

It seems probable that the northern part of the depression was flooded during the early stage of Lake Nipissing. The high Algonquin bluff on the Empire moraine was reworked by the waters of Lake Nipissing. A slight drop in level exposed a broad fan-shaped area upon which a remarkable series of dunes formed (see pl. XIV, A). For the most part, the dunes are of the apex parabolic type and rise 20 to 30 feet in height. Just west of Otter Lake, shown in the southeast corner of figure 9, one ridge is superimposed on an earlier Nipissing dune ridge (fig. 9). Here the dunes rise to heights of nearly 100 feet, The highest dunes, however, are one-half mile south of Aral (C, fig. 9) and form an imposing, though small, row of dunes which were later truncated during the Algoma stage of Lake Michigan. The crest of this ridge rises 170 feet to an elevation of 760 feet above sea level.

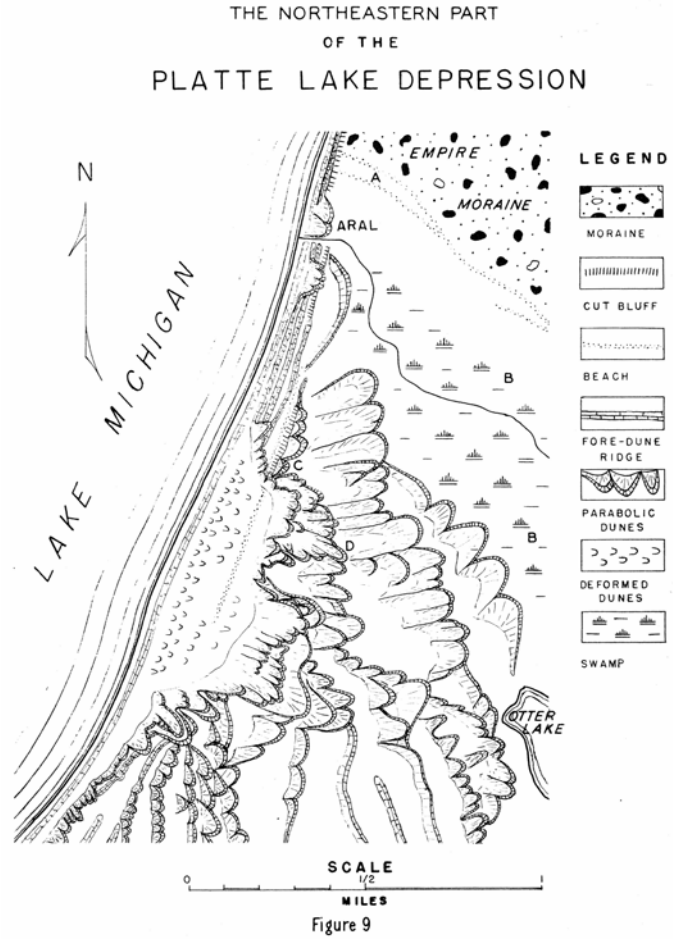


Figure 9

[Figure 9. Northeastern part of the Platte Lake Depression.]

A shore line composed in part of a cut bluff and terrace and in part of a gravelly beach ridge extends from the Empire moraine southward for a distance of nearly two miles. The base of the cut bluff on the lakeward side of the moraine and also its continuation south of Otter Creek has an elevation of 592.1 feet. The elevation of the cut terrace adjacent to the Nipissing dunes (C, fig. 9) was determined to be 592.3 feet. South of this point the shoreline has been covered by modern dunes which, for the most part, have migrated eastward and exposed a gravelly beach ridge (shown on pl. XIV, B). Two deformed fore-dune ridges south of the area of active blowing are believed to be Algoma in age because these ridges are in line with the Algoma shore features to the north.

The post-Algoma dunes north of Aral consist of two fore-dune ridges, one wooded and the other still in process of formation. The two recent blows at Aral reach a height of approximately 25 feet. South of Otter Creek, four parallel ridges lie below the Algoma cut bluff (fig. 9). The oldest ridge has covered a part of the Algoma shore line, but this fore-dune as well as the adjacent predune ridge have suffered very little blowing and are now fixed by forest vegetation. The crest lines are relatively straight and both ridges have symmetrical profiles; they rise about 15 feet high. The other two ridges in this locality are active modern dunes. The ridge to the east has undergone considerable deformation and excepting a

small portion may be considered to be a dune ridge (see pl. XV, A). It is an extension of the large, modern parabolic dunes which lie to the south. The grass covered fore-dune ridge parallel to the present shore has developed to a height of 15 to 18 feet above Lake Michigan (shown on pl. XV, B).

The active dunes in the central part of the area are the result of two periods of dune formation. The dune ridge may be traced from Otter Creek southward to a more or less continuous inner ridge of parabolas in the area of active blowing. This ridge, north and south of the region of active dunes, occupies similar positions (see fig. 9). The outer dune ridge and to a lesser extent, the inner ridge, are remodeled earlier (older) dunes which have had their cover of vegetation destroyed, although shore currents are actively supplying sand from the south and west. That some sand comes also from the Empire Bluffs, to the north, is shown by the southward deflection of Otter Creek which implies a shore current to the south (see pl. XVI). These dunes consist of complex parabolas composed of small wind furrows. Heights of more than 150 feet are common along the outer crest line. The largest of the dunes "D," figure 9, has had its apex removed and is the only true saddle type parabola in the area.

PLATE XIV. A. View from airplane across the Platte River Plains, foreground; the large modern dunes, south of Aral, middle distance; the Empire and Sleeping Bear Bluffs, far distance.

PLATE XIV. B. Dune area three-quarters of a mile south of Aral. From right to left: A. Lake Michigan, B. modern fore-dune ridge, C. complex dune ridge, D. Algona gravelly beach, and E. modern parabolic dunes.

PLATE XV. A. Dune ridge south of Otter Creek, Aral, looking southwest.

PLATE XV. B. Fore-dune ridge south of Otter Creek, Aral, looking southwest.

INTERRELATION OF WIND DIRECTION AND SHORE LINE EXTENSION WITH DUNE DEVELOPMENT

The study of both ancient and modern dunes within the limits of this investigation reveals significant facts related to dune development. It is a common belief that dunes "blow out" and are extended to the leeward direction of the prevailing winds. This conception is sometimes modified to the extent that the sand is said to be blown by the effective winds. Hence the elongation must take place in the direction of the effective winds which, though independent of the prevailing wind, may coincide with it. Evidence will be presented to show: (1) that the effective wind direction in any one locality may shift as much as 90 degrees over a period of time; (2) that the effective wind direction for any one period may be diametrically opposed in adjacent localities; (3) that the axes of the parabolic dunes are generally oriented perpendicularly to the shore line from which the dunes developed.

In the northern part of the Crystal Lake bar region the outlines of the Nipissing dunes clearly indicate development by south, southwest winds. But the large modern parabolic dune which buries some of the earlier Nipissing forms is developed by northwest winds (shown on fig. 6). Just north of Mud Lake near Platte River point, the Nipissing dunes formed under the influence of westerly winds, but the modern wooded fore-dunes were deformed by northerly winds (see fig. 8). The modern wooded dunes which lie east of the Platte River near its mouth were formed by winds from the southwest, although the modern fore-dune in this locality is being developed by northerly winds. Also, west of the Platte River, both the fore-dune and the parabolas of the dune ridge formed under the influence of northwest winds (see fig. 8). Hence, the effective wind direction in any one locality may shift as much as 90 degrees over a period of time.

The dune orientation indicates that the effective wind direction during any one stage varies in different localities. This is clearly shown by reference to table IV and plate II. The modern dunes show essentially the same relationship as the Nipissing dune orientation, although the directions of blowing differ in each locality.

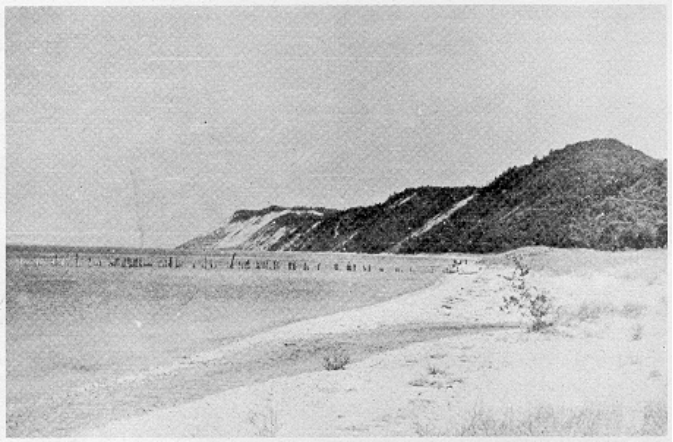


PLATE XVI. Mouth of Otter Creek, Aral. Longshore currents have deflected the creek southward; Empire Bluffs show in the background.

TABLE IV.

Effective Wind Direction Indicated by the Orientation of Nipissing Parabolic Dunes for Various Localities.

Locality	Approximate Wind Direction
Crystal Lake Bar	
1. Southern part	W.
2. Northern part	S. 30° W.
Platte Lake Depression	
1. North of Long Lake	N.
2. Northwest of Mud Lake	W.
3. East of Mud Lake	N. 30° W.
4. North of Little Platte Lake	N. 30° W.
5. West of Bass Lake	W.
6. Northwest of Otter Lake	S. 60° W.

From data in table IV it is evident that the dune development, or elongation, is independent of the prevailing wind direction. In general, the parabolic coastal dunes in the area studied are extended in a direction normal to the shore which furnished the sands for their formation. Hence, the effective wind direction is dependent upon the direction of the shore line and remains normal to it. The largest dunes in the area studied all open toward the west and may be explained by the coincidence of the prevailing wind direction with the "on-shore," or effective, winds.

CONCLUSIONS

The elevation at the base of wave-cut bluffs gives a more accurate approximation to the true water plane than does an average of elevations taken at the crests of beaches, bars, spits, and other shore features. By use of this method and accepting the tilt rate given by Leverett and Taylor, lower elevations for the Algonquin and Nipissing water planes could be derived.

The Platte and Crystal Lake depressions were pre-glacial valleys occupied by ice lobes during the formation of the Manistee moraine. Segments of the moraine bound both depressions except on their lakeward sides. Following the retreat of the glacier, glacial lakes flooded the embayments. Delta remnants near Honor and Beulah are 80 feet above the Lake Algonquin level and may indicate a local ice-blocked lake impounded within the depressions.

Crystal Lake Depression was separated from Lake Algonquin by bars which closed the three openings of the embayment. No later lake stages are found within this depression. On the lakeward side of the main baymouth bar, however, shore features of the later lake stages are developed. This baymouth bar, constructed on a submerged moraine, was enlarged in area by the combined effect of post-glacial up-lift, the fall in level of the Great Lakes and the accumulation of large quantities of sand.

In the Platte depression, Algonquin mid-bay spits partially separated the lagoon now occupied, in part, by Big and Little Platte Lakes. The separation was completed during the Nipissing stage, and, from that time on, a progression of the shore due to uplift and reliction resulted in the formation of more than twenty beach ridges. These ridges—beaches and fore-dunes—filled the western part of the bay. To the east, large quantities of sand accumulated on the lakeward part of the Nipissing mid-bay bar and formed large dunes.

Shore features found within the area studied indicate: (1) A period of cutting, or destruction, that accompanied the Algonquin stage; wave-cut bluffs form the major part of the Algonquin shoreline. The bars which formed at Beulah, at Round Lake, in the Crystal Lake bar region, and near Honor exhibit three periods of development. (2) Deposition, or construction, accompanied the Nipissing stage. Large quantities of sand accumulated in dunes; and in both the Crystal Lake bar region and in the eastern part the Platte depression, these dunes exhibit two periods of deformation. (3) The Algoma stage was a period of destruction; wave-cut bluffs formed on the lakeward side of the Nipissing dunes and the exposed segments of the morainic headlands. No dunes are definitely correlated with this period. (4) The

present stage of Lake Michigan has constructional shore features similar to features formed during the Nipissing times. In the Platte depression beach ridges between the Nipissing ridges and the present shoreline are due to the continuation of uplift and reliction. Dunes in this locality as well as the dunes in the Crystal Lake bar region exhibit two periods of formation.

The direction of dune development in Algonquin, Nipissing, and recent times indicates: (1) that the effective wind direction in any one locality may shift as much as 90 degrees over a period of time; (2) that the effective wind direction for any one period may be diametrically opposed in adjacent localities; (3) that the axes of parabolic dunes are generally oriented perpendicularly to the shore line from which the dunes developed.

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