

SHORELINES OF THE GLACIAL GREAT LAKES IN COOK COUNTY, MINNESOTA*

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ABSTRACT. Lateral tracing of shoreline features of the Glacial Great Lakes provides a better basis for recognition and correlation of ancient water planes than heretofore available in Cook County, Minnesota. In addition to the shore features of Lake Duluth, Lake Algonquin, and Lake Nipissing, previously identified in this area, five lower Algonquin shorelines, resembling those of Georgian Bay in Lake Huron, are distinguished and provisionally assigned local names. Possibilities appear good that a relation can be established between the lowest of these, the Deronda, and the Minong beaches of Isle Royale, thus ultimately providing a possible means of relating lower Algonquin levels in the Superior and Huron basins.

The degree of tilt displayed by various shorelines in Cook County is consistently lower than previously stated. The uplift in Cook County may have been more uniform than in other parts of the Superior basin indicating differential warping in the Earth's crust during the postglacial recoil rather than uniform tilting as a rigid plate over a wide area.

INTRODUCTION

SHORELINE features of ancient lakes in the Superior basin have been studied along the Minnesota coast most extensively by Lawson (1893) and Leverett (1929, pp. 57-71), and most recently in the Duluth area by Schwartz (1949, pp. 70-73). Lawson's field data were supplemented, analyzed, or interpreted by Upham (1894, pp. 56-66), Grant (1899, pp. 338-343), Taylor (1897), and Martin (1911, pp. 443-448) among others. These earlier workers, Schwartz excepted, dealt largely with data obtained along widely spaced profiles extending inland from the present shore.

In Cook County the lateral extent of shoreline features has been mapped wherever possible. This procedure was greatly facilitated by air photos, an advantage not available during earlier studies. Lateral tracing provides more certain identification of shoreline features as such, leads to recognition of distinguishing characteristics of particular shorelines, and results in more certain correlation of discontinuous features along an ancient water plane than can be obtained solely from transverse profiles.

The following shorelines are distinguished in Cook County, from highest to lowest: Lake Duluth; sub-Duluth; highest

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Lake Algonquin; a group of lower Algonquin shorelines locally named Lutsen, Marais, Tofte, Kodonce, and Deronda; and finally Lake Nipissing; and sub-Nipissing (fig. 12). Identification of the Duluth, Algonquin and Nipissing shorelines was earlier made by Leverett (1929, pp. 57-71).

This work constitutes part of a geological study of Cook County made largely by Frank F. Grout under auspices of the Minnesota Geological Survey. Appreciation is expressed for the aid and advice of Grout, George M. Schwartz, and Herbert E. Wright of the University of Minnesota. George M. Stanley kindly reviewed the manuscript and offered numerous suggestions based on his long experience with similar features in the

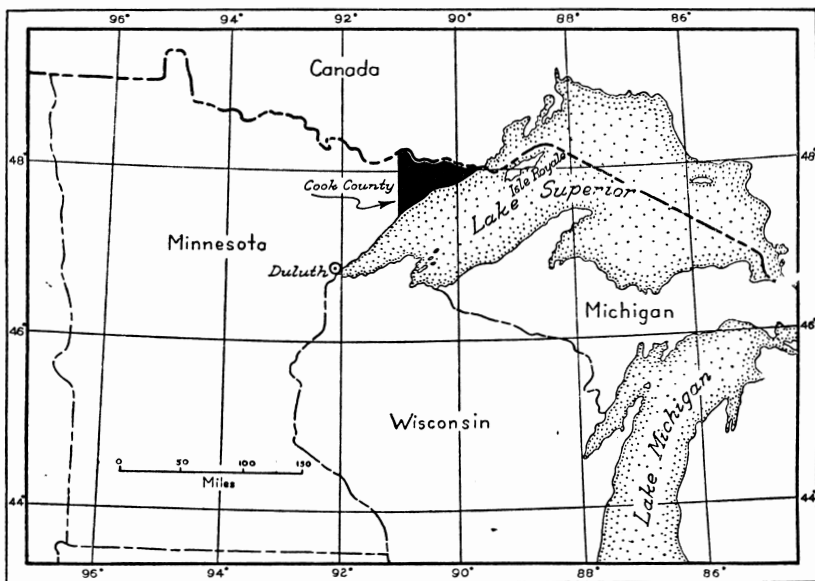


Fig. 1. Location map for Cook County.

Great Lakes region. Field work on the Pleistocene features of Cook County covered a period of approximately 3½ months during the summers of 1946 and 1947.

PHYSICAL SETTING

Cook is the northeasternmost county (fig. 1) of Minnesota (47° 55' N., 90° 30' W.). Its triangular shape is determined by the eastward convergence and eventual junction of the

Canadian border with the north shore of Lake Superior. Cook County borders Lake Superior for a distance of 80 miles as measured along a straight line bearing N. 62° E. The actual shoreline is considerably longer owing to irregularities (plate 1, fig. 1).

Over much of this distance the land attains elevations up to 1000 feet above the lake within a few miles inland. The hard rocks and steep slopes of this coast did not generally favor as strong development nor as good preservation of shoreline forms as in other areas.

SHORELINE FEATURES

Wave-cut cliffs.—This is the most abundant form along the ancient water planes. Most cliffs are 20 to 30 feet high, a few attain 50 feet, and some are laterally continuous for miles as, for example, along the Nipissing water plane east of Grand Marais. A flattish tread mantled by gravel or shingle lies below the cliffs in many places. The highest and sharpest cliffs are cut in platy rhyolite and red clay till. Those formed in diabase and basalt are mostly lower and less continuous.

Beach ridges.—Abandoned beach ridges are easily identified and provide convincing evidence of former lake levels. Unfortunately, they are limited largely to lower shorelines, the Deronda, Nipissing, and sub-Nipissing. This arises in part from a flattening of the coastal slopes at the lower levels.

Most Cook County beach ridges are composed of fine pebbly gravel, but some consist of well-worn boulders averaging 1 foot in diameter (plate 2, fig. 2). Beach ridges are usually larger, more numerous, and coarser near the mouths of streams because of debris supplied therefrom. Heights of a few feet are average, 5 to 8 feet is not unusual, and one ridge at Deronda Bay attains 9 feet. Individual ridges have widths of 5 to 20 feet, and multiple assemblages are 75 to 100 feet wide. Favorable conditions of a gently sloping shore, abundant loose debris, and strong wave action prevailed at Deronda Bay where 20 pebbly ridges are found within the first 50 feet, vertically, above Lake Superior (fig. 10). Good beach ridges were also formed near Grand Portage, at Wauswaugoning and Horseshoe bays, and at Paradise Beach.

Beach ridges may be built in a relatively short time during storms. Although providing good evidence of shoreline activity,

they do not necessarily indicate a long-continued stability of the water plane.

Lake terraces.—Many of the so-called lake terraces in Cook County (Schwartz, 1925, pp. 80-82) are actually gravel-mantled dip slopes on Keweenaw lavas and intrusives. Bonafide terraces are seen above and below the Nipissing cliff east of Grand Marais, at the base of a prominent cliff on the Kodonce shoreline 110 feet above lake level near Tofte, and at Thomasville in the southwest corner of the county.

Lake deposits.—For the most part sub-aqueous deposits indicate only that the area has been submerged and are not particularly useful in locating shorelines. This is especially true of the red clays laid down by Lake Duluth and its successors along much of the Cook County coast. Materials of near-shore origin such as thin accumulations of sand and gravel; interlayered sand, silt and clay beds dipping lakeward; and abandoned deltas, especially at the mouths of Temperance, Cascade, and Brule rivers and several smaller streams indicate approximate minimum elevations for former water planes.

Miscellaneous features and relations.—Leverett (1929, pp. 61-64) appears to have used the upper limit of "wave-washed" slopes as an indicator of the highest shoreline in some areas. To his trained and discerning eye this may have been a reliable criterion, but in Cook County bare rock slopes are numerous far above the level of the Glacial Great Lakes and this criterion was not applicable.

A series of flattish treads backed by steep risers can be recognized in the profiles of many ridges and slopes bordering Lake Superior. Good examples of stairlike steps are seen along Caribou Lake road, McFarland Lake road, a road on the east edge of sec. 25, T. 60 N., R. 3 W., and along the trails leading to lookouts on Mt. Leveaux and Mt. Josephine. Lawson (1893, pp. 242, 252-253, 280) interprets many such features as the marks of ancient shorelines, and some of the risers do indeed have the aspects of wave-cut cliffs. If the associated treads are mantled by shore gravels and if the form has some lateral extent, a shoreline origin seems likely. However, many of the topographic breaks appear to be the product of subaerial erosion controlled by structures within the gently dipping Keweenaw volcanics. They are not considered reliable shore-

line markers unless discordant with bedrock structure and confirmed by some independent evidence.

Reliability and accuracy of shoreline features as indicators of water planes.—Cliffs are the most accurate indicator of water plane elevations in this area, but even they are not ideal. The wave-cut notch at the cliff base is usually buried by debris, and the exact level of the water line cannot be determined more closely than several feet. Furthermore, the base of a continuous cliff does not necessarily have a uniform elevation, for on

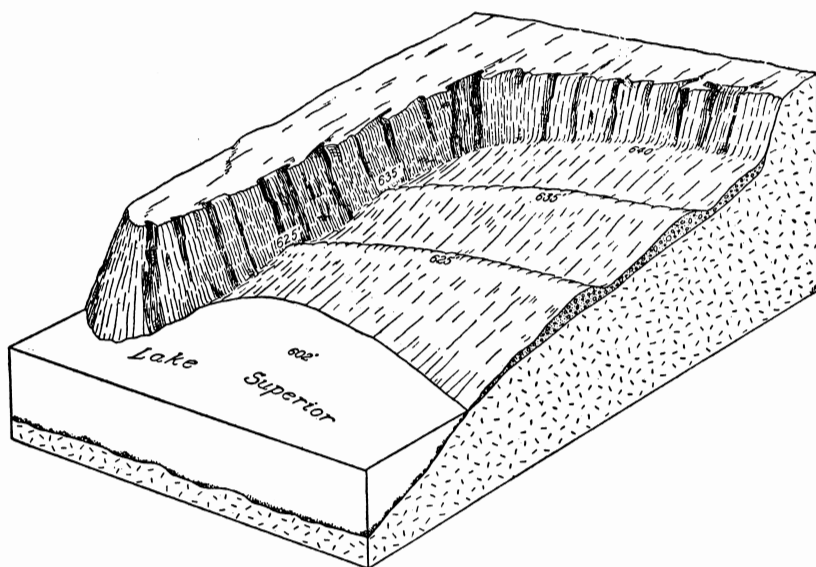


Fig. 2. Diagrammatic sketch showing different elevations at base of cliff.

exposed headlands it is usually lower than in re-entrants. Along the Nipissing shoreline near Kodonce Creek the cliff base on a projecting headland is 10 feet lower than in an adjacent bight. This may be due in part to lithologic relations, as the headland is composed of platy rhyolite and the bight is in red clay till. More likely, it is due to the fact that the base of a cliff can be progressively lowered by wave erosion as the water level falls, provided the offshore water is deep (Stanley, 1937, p. 1683). As the water level fell, in the example cited, the waves built beach ridges in the re-entrant while they continued to cut the headland cliff (fig. 2).

Beach ridges are usually built by storms to heights a few feet above mean water level. At Deronda Bay a storm ridge on the present beach rises 7 feet above water level, and at Horseshoe Bay the crest of a similar boulder ridge is 11 feet above water level. Lawson (1893, p. 231) reports modern beach ridges along the north shore of Lake Superior 9 to 14 feet above water level. These figures are probably extreme, but since some ridges are of subaqueous origin (Stanley, 1936, p. 1936), a 10-foot range in elevation is possible for beach ridges along a water plane. Deane (1950, p. 79) reaches a similar conclusion.

Thus, elevations based on the most reliable shoreline features in Cook County may be as much as 10 feet off the level of the water plane, although most departures are probably not this great. Nonetheless, it is obvious that separation of shore features and conclusions as to degree of shoreline tilting cannot be based on differences of only a few feet.

METHODS OF STUDY

Elevations were measured to the crests of beach ridges and to the bases of wave-cut cliffs. Near bench marks or close to the present shore, measurements were by hand leveling. Other elevations, including the majority, were determined by barometer and are considered accurate within 10 feet at the higher levels and within 2 or 3 feet at the lower shorelines. This modest accuracy was obtained by repeated measurements to the same feature, often on different days, by frequent reference to the level of Lake Superior, and by recourse to numerous bench marks established in 1935 by the Coast and Geodetic Survey, two of which are located exactly on ancient shorelines. Evaluation of the various shoreline features is attempted in the following tabulations (tables 1 to 10). More data are included in these tables than are shown in the maps (figs. 4-11).

LAKE DULUTH

The large body of water impounded in the Superior basin as the late Wisconsin Superior lobe receded east-northeast was first termed "Western Superior Glacial Lake" (Upham, 1894, p. 54) but subsequently became known as Lake Duluth. Its outlet was southward to the Mississippi by way of St. Croix River.

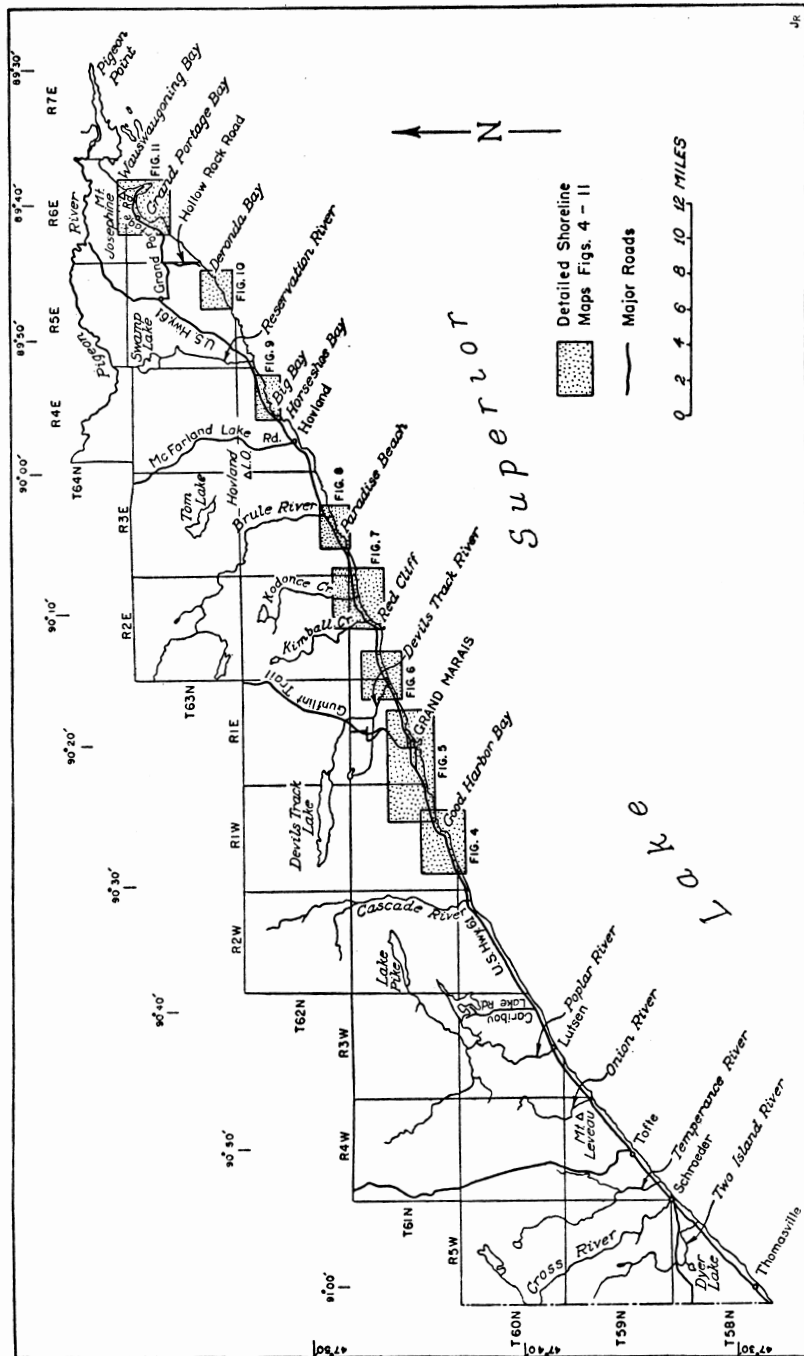


Fig. 3. Locations of detailed shoreline maps.

In its westernmost part, Lake Duluth is represented by 3 strong beaches, separated by intervals of 25 feet, and possibly by a fourth beach, 25 feet higher (Leverett, 1929, p. 59). The upper levels in this series supposedly do not extend into Cook County, because the outlet was lowered by erosion while the lake expanded eastward after the receding ice front. Leverett (1929, p. 59) records the following Lake Duluth levels in Cook County: in the southwestern corner at 1191, 1175, and 1126 feet above sea level;¹ on Poplar River at 1224 feet; north of Grand Marais at 1275, 1250, and 1206 to 1209 feet; and northwest of Howland at 1300 feet. During the present study the following shoreline features attributed to Lake Duluth were identified (table 1).

TABLE 1
Shoreline Features of Lake Duluth in Cook County

Location (from SW. to NE.; see fig. 3)	Feature	Elevation (in feet above sea level)	Rating
Mt. Leveaux	Narrow tread at base of steep rock slope, good lateral extent	1225	fair
Caribou Lake road	Bedrock riser	1250	poor
North of Good Harbor Bay (fig. 4)	Wave-cut cliff 30 feet high and gravel-mantled tread	1270	good
	Wave-cut cliff, 50 feet high, and tread	1250	good
Northwest of Grand Marais (fig. 5)	Strong cliff with gravel at base	1255-1260	good
	Strong double cliff with narrow intervening terrace	1258 and 1270	good
	Double cliff, weaker	1240 and 1280	fair
North of Grand Marais (fig. 5)	Weak cliff	1280-1290	poor
	Weak tread and riser	1270	fair
Red Cliff - Kodonce Creek area (fig. 7)	Topographic break with gravel, good lateral extent	1270	poor
Mt. Josephine	Gravel bar	1265	poor

¹ Elevation of the water level in Lake Superior is 602 feet.

Shoreline features of Lake Duluth are most prominent north of Good Harbor Bay and Grand Marais (figs. 4 and 5) where a wave-cut cliff up to 50 feet high can be traced with minor interruptions for 4.5 miles. In places, it is a double cliff with a narrow intervening tread (plate 1, fig. 2). Aside from a gravel bar at Mt. Josephine, the Lake Duluth shores in Cook County are marked solely by cliffs or risers fronted by narrow gravel-mantled treads.

The most reliable altitudes obtained for Lake Duluth water planes are near Grand Marais and Good Harbor Bay. These range from 1240 to 1270 feet above sea level, roughly 640 to

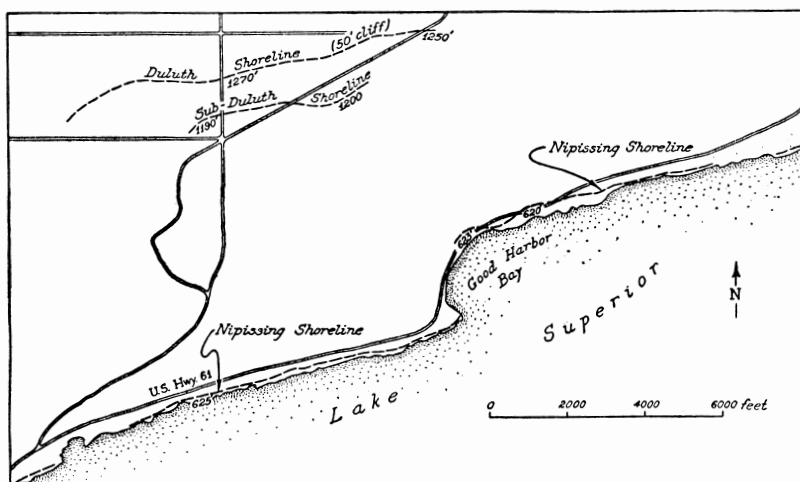


Fig. 4. Shoreline features in Good Harbor Bay area.

670 feet above Lake Superior, and the close agreement with some of the figures cited by Leverett for this locality is gratifying. However, no traces could be found of the Lake Duluth shorelines reported by Leverett in the southwest part of the county, at Poplar River, or northwest of Hovland.

SUB-DULUTH PHASE

With further eastward recession of the Superior lobe, a lower outlet was opened on the flanks of the Huron Mountains in Marquette County, Michigan. This permitted waters of the Superior basin to drain into Lake Chicago. At this time a large independent lake, Algonquin I, occupied the Huron basin, and

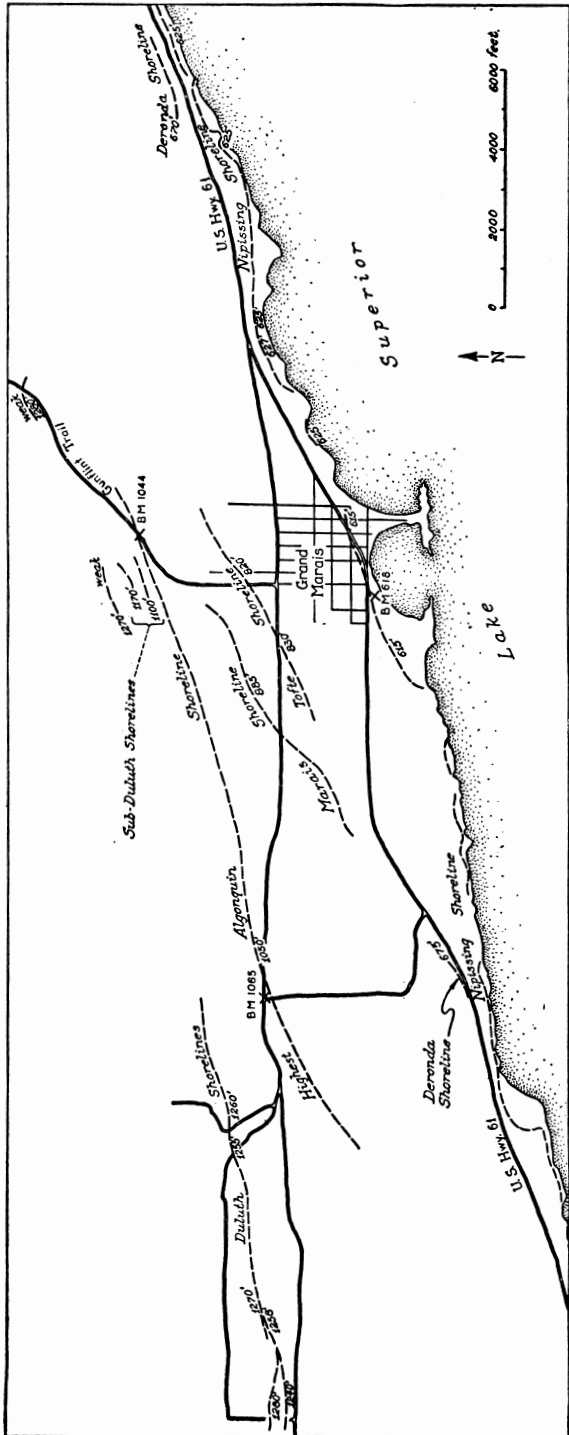


Fig. 5. Shoreline features in Grand Marais area.

subsequently waters in the Superior basin became part of Lake Algonquin II.²

Shoreline features in Cook County between the lowest level attributed to Lake Duluth and the highest Algonquin shore are herein designated sub-Duluth. Leverett (1929, p. 63) recognized that the drop from the Duluth to the Algonquin level occurred intermittently as successively lower outlets were developed between the Huron Mountains and the receding ice lobe. The nature and elevation of features assigned to the sub-Duluth phase are summarized in table 2. Among these features, the wave-cut cliff north of Good Harbor Bay, 1190 to 1200 feet above sea level or 590 to 600 feet above Lake Superior, is the strongest.

TABLE 2
Features of the Sub-Duluth Phase

Location (from SW. to NE.; see fig. 3)	Feature	Elevation (in feet above sea level)	Rating
Schroeder	Topographic break with gravel, good lateral extent	1160	fair
	Modest tread and step	1165	poor
Mt. Leveaux	Steep rock cliff with well- formed tread	1180	fair
	Sand deposit	1200	poor
Good Harbor Bay (fig. 4)	Wave-cut cliff, prominent, good lateral extent	1190-1200	good
	Rock cliff, 40-50 feet high with narrow bouldery tread	1170	fair
Grand Marais	Gravel deposit	1180	poor
	Rock cliff, 10-15 feet high with narrow bouldery tread	1100	fair
Devils Track River (fig. 6)	Cliff	1175	fair
	Riser	1210	poor
Hovland	Topographic break with gravel	1100	poor
	Gravel bar	1205	fair

² Much has been written about the history of the Glacial Great Lakes, but a brief up-to-date account with pertinent references to the literature is provided by Flint (1947, pp. 254-262).

LAKE ALGONQUIN

The Superior basin first became part of Lake Algonquin during the Algonquin II stage (Flint, 1947, p. 256) when the Superior, Michigan, and Huron basins were integrated into a single huge lake with an outlet via Trent Valley, Ontario (Leverett and Taylor, 1915, pp. 412-413). Subsequently, post-glacial uplift on the north raised the Trent outlet and diverted some of the overflow southward into the St. Clair River past Detroit and into the Des Plaines-Illinois channel at Chicago. During this transitional stage the "Algonquin beach"³ was cut. Continued uplift eventually diverted the entire overflow into the southern outlets. This initiated Algonquin III, during which so-called "upper" Algonquin shorelines in the Huron basin were formed. Further ice recession eventually opened a series of lower outlets across highlands east of Georgian Bay, and the water planes of the Algonquin IV stage were established. The data tabulated below (table 3) pertain to the highest Lake Algonquin shore features recognized in Cook County.

TABLE 3
Highest Shoreline Features of Lake Algonquin in Cook County

Location (from SW. to NE.; see fig. 3)	Feature	Elevation (in feet above sea level)	Rating
Grand Marais (fig. 5)	Rock cliff, 10 feet high, with gravel at base	1044-1050	good
Devils Track River (fig. 6)	Extensive break with gravel	1045-1055	good
	Extensive break with gravel	1020-1030	good
Red Cliff - Kodonce Creek area (fig. 7)	Extensive break	1030	fair
Mt. Josephine (fig. 11)	Extensive cliff and tread	1058	good

Highest Lake Algonquin features are best seen near Grand Marais and Devils Track River where low cliffs and risers with good lateral extent have been mapped (figs. 5 and 6), at elevations of 1020 to 1055 feet. The close agreement between the

³ The term "Algonquin beach" is used for the shore features developed during this transitional stage (letter, G. M. Stanley, March 5, 1949). For a corresponding recommendation see Deane (1950, p. 43).

1042 given by Leverett and the 1043.604 feet of a Coast and Geodetic Survey bench mark set on an Algonquin shoreline north of Grand Marais is noteworthy.

It is possible that the highest Algonquin shorelines in Cook County were cut during the Algonquin III stage, Algonquin II being too transitional or perhaps standing at a lower level. However, this cannot be demonstrated on the basis of local data. If radiocarbon dating of the Mankato climax is correct (Flint and Deevey, 1951, pp. 261-263), the entire history of the Glacial Great Lakes probably took place in the last 10,000 years. Lake Algonquin III existed about half way through this period, 4,930 \pm 260 years ago (Flint, 1951, p. 889).

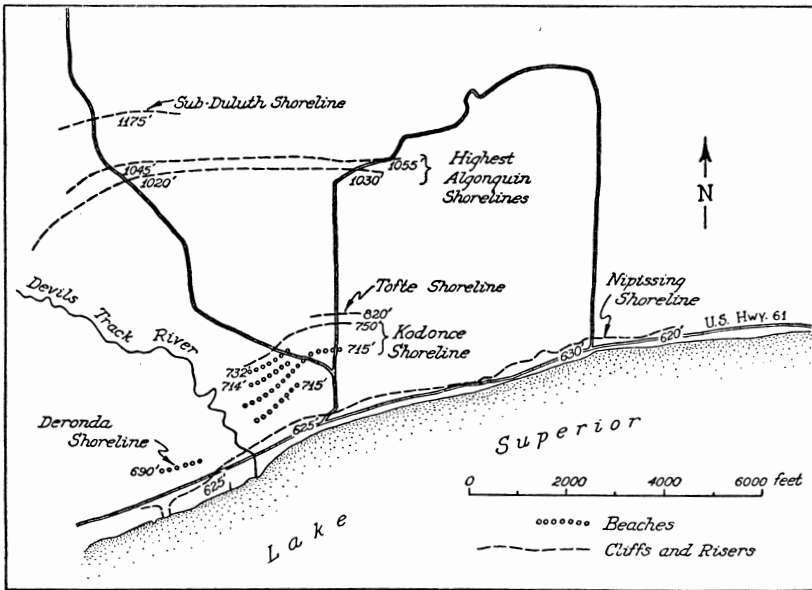


Fig. 6. Shoreline features in Devils Track River area.

LOWER ALGONQUIN SHORELINES

Shore features are scattered over the 400-foot interval between the highest Algonquin shores and the Nipissing level in Cook County. Some of these features were probably earlier attributed to the Battlefield and Fort Brady groups (Leverett and Taylor, 1915, pp. 433, 436), which, according to Leverett (1929, p. 68) are well represented along the north shore of Lake Superior, but he cites no localities and gives no elevations.

Detailed studies by Stanley (1936, 1937) in Georgian Bay of Lake Huron established four lower Algonquin shorelines between the "upper" Algonquin level and Lake Nipissing, and Deane (1950, p. 43) finds a corresponding situation in the Lake Simcoe District, Ontario. At Lake Huron these shorelines all display approximately the same tilt as the "upper" Algonquin water planes and were presumably formed, not by uplift, but by opening of successively lower outlets across the highlands between Georgian Bay and Lake Ontario. Since the Battlefield and Fort Brady beaches were supposedly abandoned because of uplift and should, therefore, not be parallel with the "upper" Algonquin shores, Stanley (1936, p. 1955) suggests that use of these names be discontinued for the present. He has given local names to the lower Algonquin shorelines in Georgian Bay.

In keeping with this procedure the shore features between the highest Algonquin levels and Lake Nipissing in Cook County, here arranged in five groups, are given the following local names from highest to lowest: Lutsen, Marais, Tofte, Kodonce, and Deronda. This is wholly provisional and is

TABLE 4
Features of the Lutsen Shoreline

Location (from SW. to NE.; see fig. 3)	Feature	Elevation (in feet above sea level)	Rating
Schroeder	Topographic break with gravel, good linear extent	950	fair
Tofte	Gravel deposit	975	poor
Mt. Leveaux	Topographic break with gravel	950	fair
Onion River to Lutsen	Beach ridge	1000	fair
	Beach ridge	970-975	fair to good
Caribou Lake road	Sand and gravel	980, 985	poor
Grand Portage	Gravel deposit	970	poor
Mt. Josephine	Tread and cliff	965	fair
	Tread and cliff	958	fair

adopted primarily as an aid in presentation of data. Exact correlations are not yet possible, but it seems likely that these shores are of the Algonquin IV stage.

Lutsen shoreline.—The highest of the lower Algonquin levels is named from the resort center of Lutsen. The relative paucity and weakness of the Lutsen shore features (fig. 12) suggest that the water plane was not long stabilized at this level. The most reliable mean elevation is between 975 and 985 feet, or about 375 and 385 feet above Lake Superior. Table 4 summarizes pertinent data.

Marais shoreline.—This shoreline is named from a low but extensive gravel-fronted cliff just north of Grand Marais (fig. 5). Other features of this water plane are to be seen along the Caribou Lake road and on Mt. Josephine as shown in table 5. Mean elevation is 885 feet, or 283 feet above Lake Superior.

TABLE 5
Features of the Marais Shoreline

Location (from SW. to NE.; see fig. 3)	Feature	Elevation (in feet above sea level)	Rating
Mt. Leveaux	Topographic breaks with gravel	910, 895, 845	poor
Caribou Lake road	Extensive topographic break with gravel	900-910	fair
	Topographic break with gravel	870-875	fair
Grand Marais (fig. 5)	Extensive low cliff with gravel, well developed	885	good
West of Brule River	Cliff, weak	920	poor
	Topographic break with gravel	840	poor
Grand Portage	Gravel accumulation	845	poor
Mt. Josephine	Cliff and tread	880	fair

Tofte shoreline.—This shoreline is named from two beach ridges at Gervais airport north of Tofte. Good features can also

be seen near Grand Marais (fig. 5) at 820 to 830 feet elevation, roughly 200 to 230 feet above Lake Superior. Pertinent data are presented in table 6.

TABLE 6
Features of the Tofte Shoreline

Location (from SW. to NE.; see fig. 3)	Feature	Elevation (in feet above sea level)	Rating
Temperance River	3 beaches	770-780	poor to fair
Tofte	2 beaches	792, 800	fair to good
	Break with sand	770	poor
Mt. Leveaux	Cliff with good tread, good linear extent	780	fair to good
Onion River to Lutsen	Gravel beach	795-800	fair
	Strong cliff	815	good
Caribou Lake road	Break with gravel	805	fair
	Break with sand	775	fair
Grand Marais (fig. 5)	Extensive riser with tread and gravel	820-830	good
Devils Track River (fig. 6)	Cliff	820-830	fair
Red Cliff - Kodonce Creek	Gravel deposit	835	poor
	Topographic break	820	poor
West of Brule River	Topographic break with gravel	800	poor to fair
Brule River mouth	Gravel deposit	815	poor
Mt. Josephine	Cliff and tread	800	fair

Kodonce shoreline.—An extensive riser at 745 feet elevation near Kodonce Creek (fig. 7) identifies this shoreline. It is also represented by a prominent cliff and wide terrace at the village of Tofte, and by features in many other parts of Cook County (fig. 12). The elevation of 712 to 715 feet at Tofte, 110 to 113 feet above Lake Superior, appears the most reliable. Data are summarized in table 7.

TABLE 7
Features of the Kodonce Shoreline

Location (from SW. to NE.; see fig. 3)	Feature	Elevation (in feet above sea level)	Rating
Thomasville to Two Island River	Weak cliff, upper limit of gravel	700-718	poor to fair
Schroeder	Topographic break with gravel	755	poor
Temperance River	Cliff	715	fair
Tofte	Strong cliff and terrace	712-715	good
Onion River to Lutsen	Local cliff	715	fair
Caribou Lake road	Riser	737	poor
Good Harbor Bay	Gravel deposits	715, 730	poor
Grand Marais	Gravel deposits	700, 735, 750	poor
Devils Track River (fig. 6)	Four beaches and one riser	715-750	fair to good
Red Cliff to Kodonce Creek (fig. 7)	Extensive cliff	745	good
West of Brule River	Gravel deposit	725	poor
Brule River Mouth	Gravel deposit	730	poor
Hollow Rock road	Two boulder beaches	703, 710	fair
Grand Portage area (fig. 11)	Beaches	725, 742, 750	fair
	Gravel deposit	750	poor

Deronda shoreline.—A large beach ridge at Deronda Bay (fig. 10) identifies this shoreline. The same level is marked by beaches, local cliffs, and gravel accumulations in many other parts of the county. Elevations between 670 and 690 feet, roughly 70 to 90 feet above Lake Superior, appear most representative as shown in table 8.

TABLE 8
Features of the Deronda Shoreline

Location (from SW. to NE.; see fig. 3)	Feature	Elevation (in feet above sea level)	Rating
Thomasville	Gravel on terrace	675-685	fair
	Broad beach ridge	657	fair
Dyer Lake area	Beach and cliff line	685	fair
	Gravels on terrace	665	poor
Two Island River	Cliff and beach ridge	640	fair
Schroeder area	Beaches and cliffs	650-685	fair to good

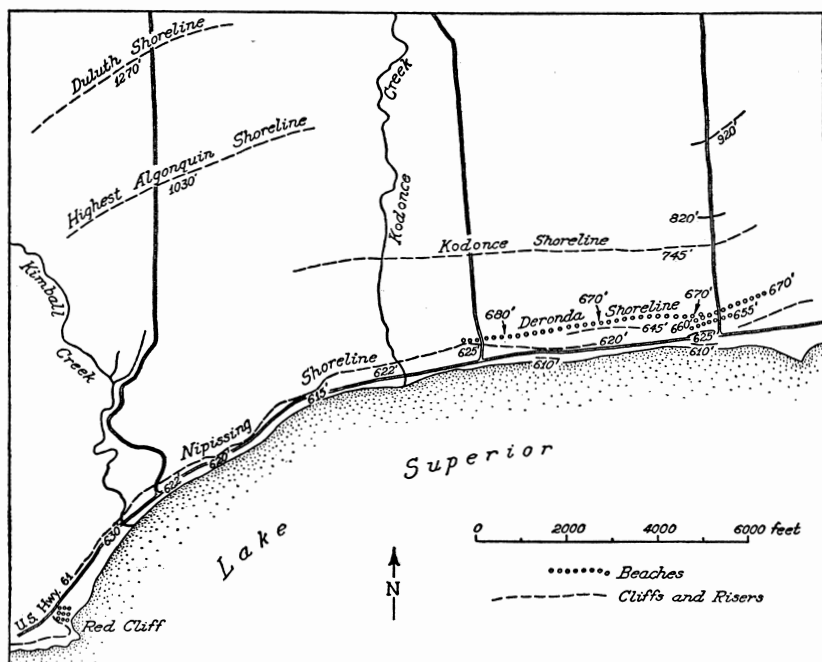


Fig. 7. Shoreline features in Red Cliff-Kodonce Creek area.

TABLE 8 (Cont.)
Features of the Deronda Shoreline

Location (from SW. to NE.; see fig. 3)	Feature	Elevation (in feet above sea level)	Rating
Temperance River mouth	Cliff	650-660	fair
Onion River	Cliff and gravel	675	poor
Lutsen to Caribou Lake road	Terrace	675	fair
	Gravel deposit	690	poor
Caribou Lake road	Topographic breaks	680, 685	poor
	Topographic break with gravel	658	fair
East of Caribou Lake road	Cliff	650	fair
Cascade River	Beach gravels and broad beach ridge	690	fair
Good Harbor Bay	Gravel deposit	685	poor
Grand Marais (fig. 5)	Cliff, with gravel tread	670-675	fair
East of Grand Marais (fig. 5)	Gravels and cliff	670-690	poor
Devils Track River (fig. 6)	Topographic break with gravel	670-685	poor
	Gravel beach	690	fair
	Break	690	poor
Red Cliff-Kodonce Creek (fig. 7)	Strong beach and break	670-680	good
	Two beaches	655, 660-670	fair
West of Brule River	Breaks with gravel	670-690	poor
Brule River mouth (fig. 8)	Cliff	665-670	fair
Hovland	Gravel deposit	690	poor
Horseshoe Bay	Gravel deposit	675	poor
Big Bay area (fig. 9)	Boulder beach ridge	675-680	good
Reservation River	Gravel Deposits	672, 697	poor
Deronda Bay (fig. 10)	Beach ridge, extensive	665	good
Grand Portage (fig. 11)	Beach ridges	680 672 652-670	good
Mt. Josephine	Cliff and tread	690	poor
Wauswaugoning Bay	Boulder beach ridge	679	good

A possible relation between the Deronda shoreline and Stanley's (1941) Minong beaches on Isle Royale warrants attention. Stanley has kindly furnished the following unpublished information. Elevation of the highest of a continuous series of Minong beaches at the southwest end of Isle Royale is 685 feet, and their angle of tilt is 2.6 feet per mile along a line bearing N. 22° E.

From these data, elevations of the highest Minong beach at Wauswaugoning Bay, Grand Portage, and Deronda Bay in Cook County are calculated as 677, 675, 660 feet respectively.

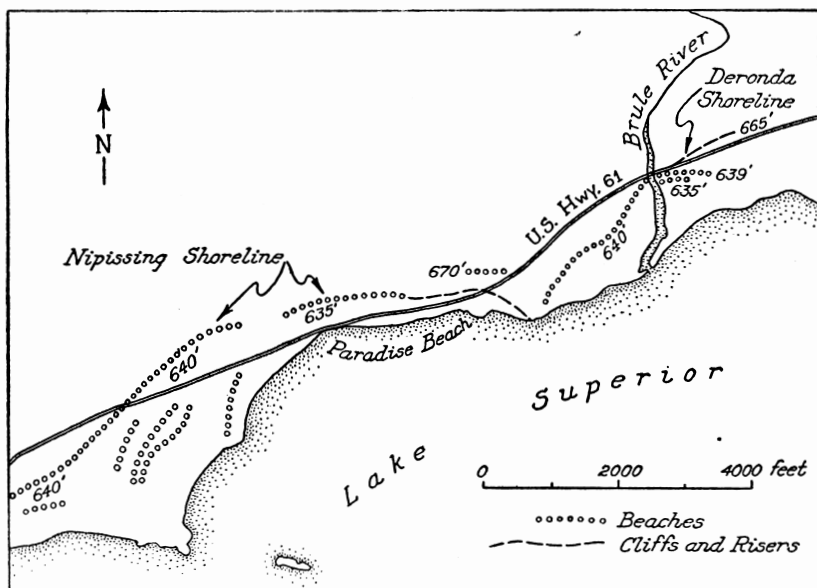


Fig. 8. Shoreline features in Brule River-Paradise Beach area.

Actual elevations of the highest Deronda shoreline at these spots are 679, 680, and 665. This close agreement, and the fact that the Deronda shore displays a series of lower levels at Grand Portage and at Deronda Bay resembling the lower Minong beaches on Isle Royale, leads Stanley to the conclusion⁴ that Minong beaches are represented among the data in Cook County as far west as Deronda Bay.

Although correlation of the Minong and Deronda shores in eastern Cook County seems a good possibility, some reserva-

⁴ Personal communication.

PLATE 1



Fig. 1. Lake Superior Coast at Grand Portage Bay, looking west-southwest from Mt. Josephine.



Fig. 2. Double cliff (A and B) and intervening terrace cut in red clay till along Lake Duluth shoreline northwest of Grand Marais (NW 1/4 sec. 23, T. 61 N., R. 1 W.). Cliff bases at 1270 and 1258 feet above sea level.

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PLATE 2



Fig. 1. Lake Nipissing cliff 30 feet high cut in red clay till east of Kodonce Creek (NW 1/4 sec. 1, T. 61 N., R. 2 E.). Base of cliff at 625 feet altitude, beach ridges in foreground.



Fig. 2. Bouldery Lake Nipissing beach ridge 40 feet above Lake Superior (642 feet altitude) at Horseshoe Bay.

tions are held because correlation west of Deronda Bay is less certain. For example, at Big Bay (fig. 9) the level identified as Deronda is marked by a prominent boulder beach at 680 feet. The highest Minong beach should have here an elevation of 647 feet if the angle of tilt established by Stanley remains constant. Even if elevation of the Deronda beach at Big Bay is adjusted for a maximum observational error of 10 feet, it is still far above the calculated height of the Minong water plane. Farther west, Deronda shore features are also consistently too high for correlation with Minong beaches. This difference might

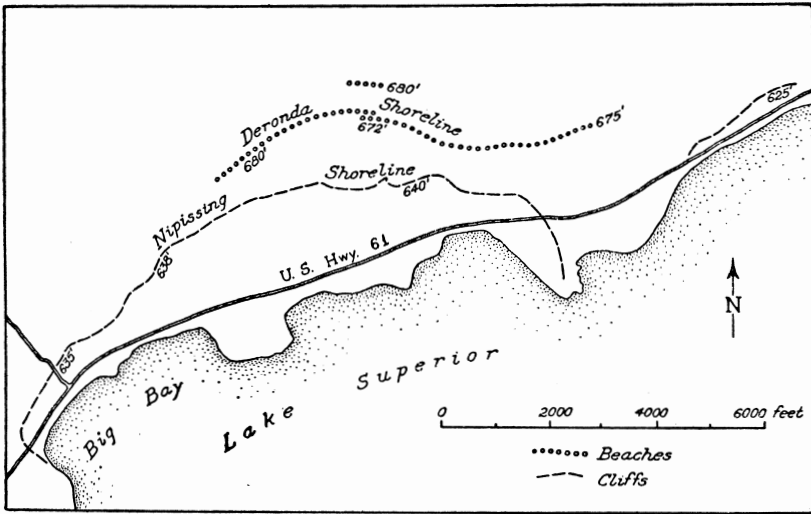


Fig. 9. Shoreline features in Big Bay area.

be resolved if the angle of tilt in Cook County were not as steep as on Isle Royale, and, as subsequently shown, the inclination of other shorelines in Cook County supports this possibility.

Summary statement on lower Algonquin shores.—In this work, a strong feature of considerable lateral extent was considered a necessary requisite for recognition of a specific water plane, and it is felt that someone else using the same field data on lower Algonquin shore features would arrive at reasonably similar interpretations. Of the shorelines identified, the Lutsen and Marais are the weakest (fig. 12), although each is marked by local features of considerable strength.

Identification of five lower Algonquin shorelines here as compared to four in Georgian Bay (Stanley, 1936, 1937) need not be especially significant. If a specific relation between the Deronda and Minong beaches can be firmly established, a means of correlating Cook County and Georgian Bay water planes

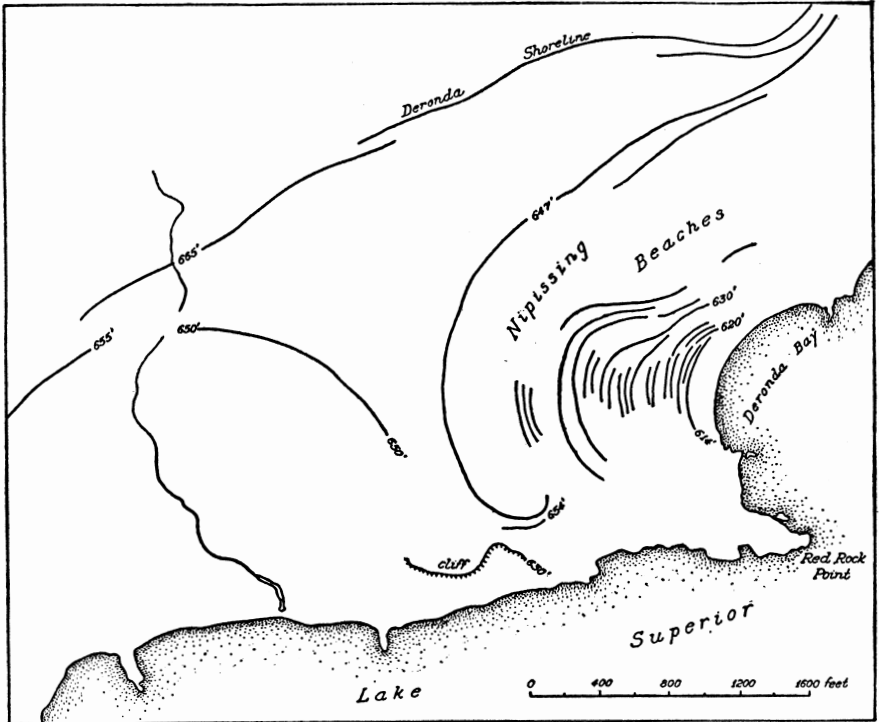


Fig. 10. Shoreline features at Deronda Bay.

may be provided, although Stanley (1936, p. 1956) is not yet certain of the relation between Minong beaches and the shorelines at Georgian Bay.

Identification of these Cook County shores as lower Algonquin, presumably Algonquin IV, is less certain than in Georgian Bay, for here it is not possible to demonstrate a conformity of tilt between upper and lower Algonquin shores or a discordance between them and the Nipissing water planes as in the Georgian Bay area (Stanley, 1937, p. 1678).

NIPISSING GREAT LAKES

In Cook County the Nipissing shore is marked principally by a wave-cut cliff, 15 to 30 feet high, with its base 15 to 35 feet above Lake Superior. This cliff is especially prominent from Grand Marais eastward to Brule River (plate 2, fig. 1). Beach ridges are also numerous along the Nipissing level at Deronda, Grand Portage, Wauswaugoning, and Horseshoe bays and at Paradise Beach. Table 9 summarizes pertinent data.

TABLE 9
Shoreline Features of Lake Nipissing

Location (from SW. to NE.; see fig. 3)	Feature	Elevation (in feet above sea level)	Rating
Thomasville	Cliff	615-620	good
Dyer Lake to Two Island River	Cliff	617-620	fair to good
Schroeder area	Cliff	630-635	fair
	Boulder beach	640	fair
Temperance River	Cliff	615, 630	fair to good
Tofte	Cliff	620	fair to poor
Onion River to Lutsen	Cliff and terrace	615-620	good
Lutsen to Caribou Lake road	Cliff and terrace	615-620	good
Caribou Lake road and east	Cliff and terrace	615-625	good
Cascade River and west	Cliff and terrace	620-630	fair to good
	Beach ridge	640	poor
Good Harbor Bay	Cliff	615-626	good to fair
Grand Marais (fig. 5)	Cliff and terrace	615	fair
East of Grand Marais (fig. 5)	Cliff and terrace	620-627	good
Devils Track River (fig. 6)	Cliff and terrace	620-630	good
Red Cliff-Kodonce Creek (fig. 7)	Cliff and terrace	615-630	good

TABLE 9 (Cont.)
Shoreline Features of Lake Nipissing

Location (from SW. to NE.; see fig. 3)	Feature -	Elevation (in feet above sea level)	Rating
West of Brule River	Beach ridges	630-640	good
	Cliff	640	fair
Brule River (fig. 8)	Beach ridges, cliff	635-639	good
East of Brule River	Beach ridges	625-636	good
	Beach ridges	615-630	fair
Hovland	Cliff	620-627	fair to poor
Horseshoe Bay	Beach ridge	640	good
Big Bay (fig. 9)	Cliff	635-640	good
	Cliff	625	fair
Reservation River	Cliff	630	fair
	Cliff	630	fair
Deronda Bay (fig. 10)	Beach ridges	614-630	good
	Beach ridges	647-650	good
Hollow Rock road	Cliff	625	fair
	Boulder beach ridge	650	fair
Grand Portage (fig. 11)	Cliff	630-640	good
	Beach ridge	638-640	good
Wauswaugoning Bay	Beach ridge	646	good

In Cook County the Nipissing shoreline, 615 to 640 feet above sea level, is by far the most clearly marked of the ancient water planes. This may be due partly to initial strength of the features, but it must also reflect their slight geological antiquity of $3,656 \pm 640$ years as determined by radiocarbon dating of early Nipissing peat from the west end of Lake Superior (Flint and Deevey, 1951, p. 284). This dating is not far from Antevs' (1939, pp. 718-720) earlier estimate of 4000 to 6000 years but much less than Merrill's (1936, p. 43) 16,000 years.

of a lower water plane, 10 to 12 feet above the level of Lake Superior. These features are designated sub-Nipissing.

At Deronda Bay (fig. 10) a succession of beach ridges extends from the Nipissing to the sub-Nipissing level suggesting a gradual transition between them. However, cliffs along the sub-Nipissing level indicate that the water plane paused here an appreciable time. In the eastern part of the Superior basin, Taylor (1895*a*, p. 166; 1895*b*, p. 312) recognized a shoreline approximately 50 feet below the Nipissing which he initially named the Sault and subsequently correlated with the Algoma of Lake Huron (Leverett and Taylor, 1915, p. 465). If the same separation between Nipissing and Sault levels is maintained into the western part of Lake Superior, the Sault would be below water level in Cook County. Hence, the sub-Nipissing level probably does not correspond to the Sault. Table 10 summarizes the sub-Nipissing shoreline data.

TABLE 10
Features of the Sub-Nipissing Shoreline

Location (from SW. to NE.; see fig. 3)	Feature	Elevation (in feet above sea level)	Rating
Red Cliff to Kodonce Creek (fig. 7)	Cliff	610	good
Horseshoe Bay	Boulder beach ridge	611	good (age question- able).
Deronda Bay (fig. 10)	Beach ridge	614	good
Grand Portage (fig. 11)	Cliff	610	fair
	Beach ridge	612	fair

TILTING OF SHORELINES

Earlier studies over wide areas by many workers have established that shorelines of the Glacial Great Lakes are tilted by relative uplift in the north and northeast. Cook County shorelines have been less steeply tilted by this uplift than heretofore supposed.

The Nipissing shore furnishes the most abundant and reliable data for calculation of tilt. The gradual rise of Nipissing fea-

tures in a northeasterly direction is too consistent to be due to errors in measurements. Altitudes at the base of the Nipissing cliff are for the most part 615 to 620 feet in southwestern and 630 to 640 feet in northeastern Cook County. This indicates a

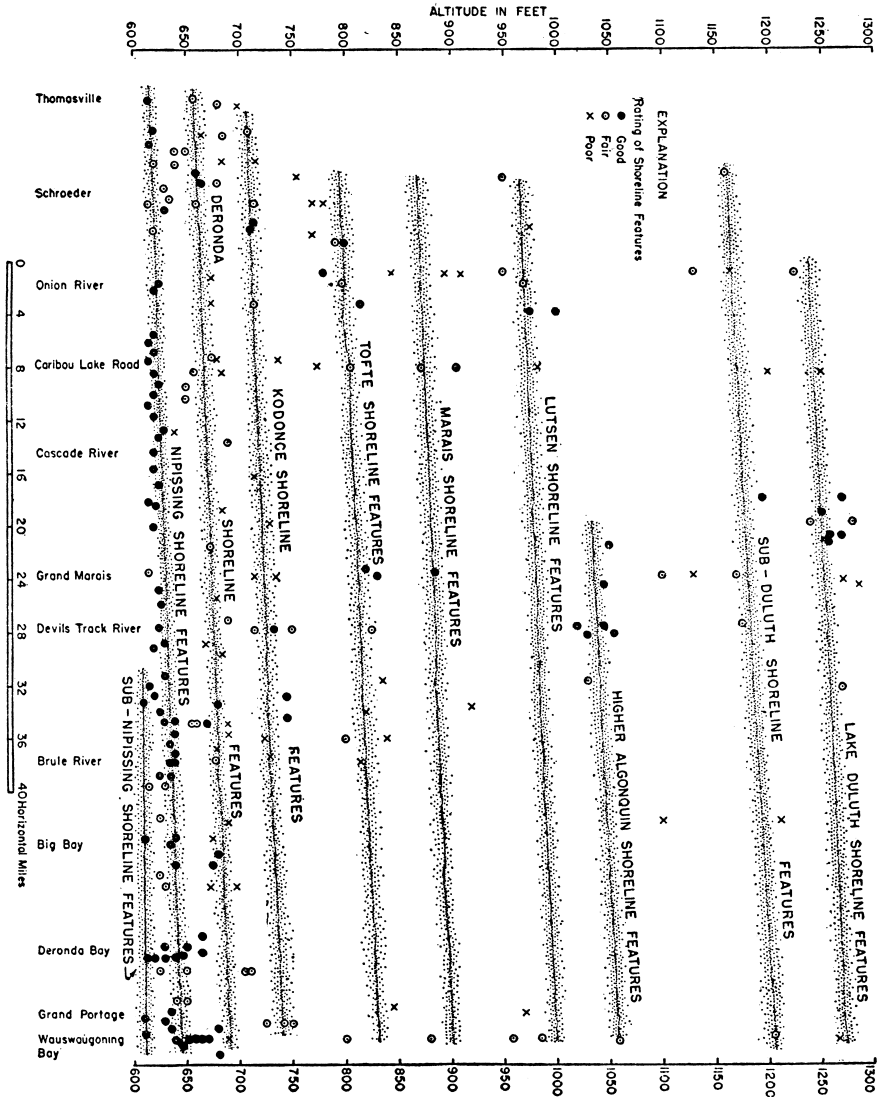


Fig. 12. Profile plots of shoreline features in Cook County. Inclinations of shorelines are approximate.

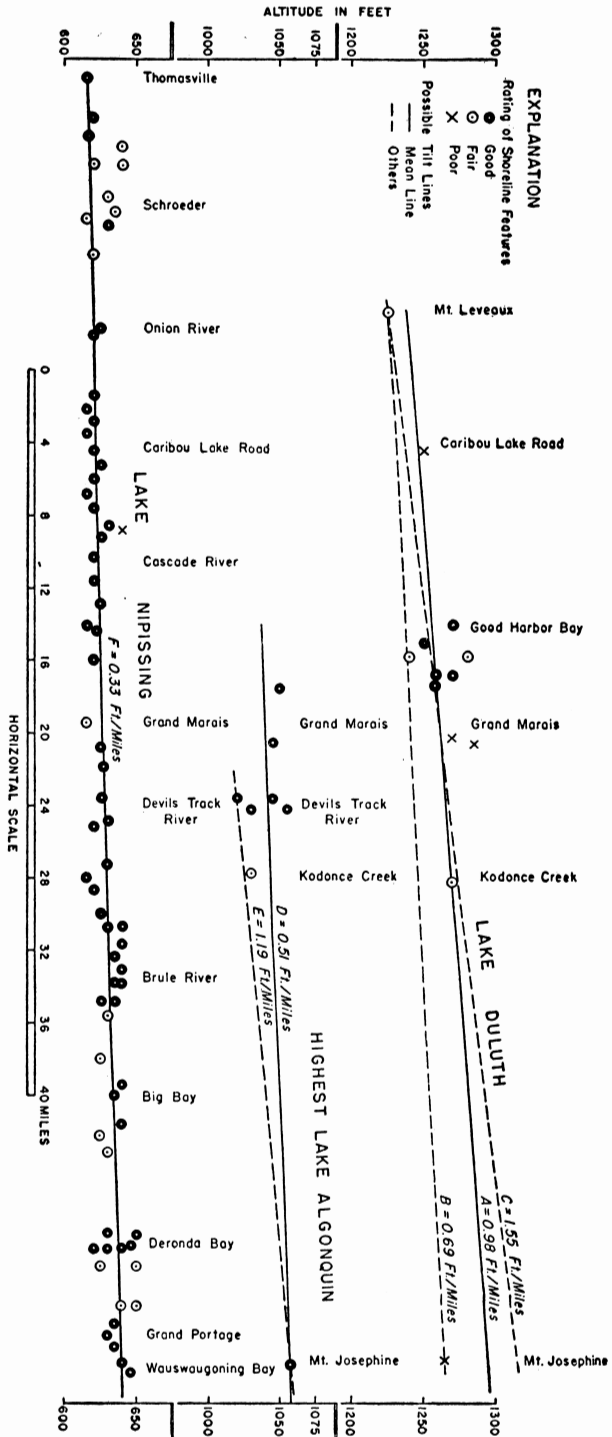


Fig. 13. Possible angles of tilt for Lake Duluth, highest Lake Algonquin, and Lake Nipissing shorelines.

tilt of about 0.25 feet per mile along a line bearing N. 62° E., roughly parallel to the present shore. A median line through a profile plot of all Nipissing shore features has a somewhat steeper inclination, about 0.33 feet per mile (line F, fig. 13). If these inclinations are resolved into the direction of supposed maximum tilt, N. 30° E. (Leverett, 1929, p. 61), they amount respectively to 0.29 and 0.39 feet per mile. This is distinctly less than the 0.58 feet per mile commonly cited for this area (Taylor, 1895*b*, p. 307; Martin, 1911, p. 449) and the 0.47 feet per mile calculated from Leverett's map (1929, p. 70, fig. 10). A tilt of 0.36 feet per mile on a map by Taylor (Leverett and Taylor, 1915, p. 461, fig. 9) is in closer agreement.

Data from the various lower Algonquin shorelines in Cook County confirm the general direction of tilt but permit such a wide variety of interpretations that no reliable measure of the inclination is possible. Features of the highest Algonquin water plane, although relatively few, are strong and the altitudes are reliable. In profile plot they suggest a mean tilt of about 0.51 feet per mile (line D, fig. 13) or an extreme of 1.19 feet per mile if the lowest features in the west are correlated with the highest in the east (line E, fig. 13). If resolved into the direction of maximum tilt, N. 30° E., these amount to 0.62 and 1.42 feet per mile respectively. Again both the median and the extreme figures are considerably less than the tilt of nearly 2 feet per mile reported by Leverett (1929, p. 68) for highest Algonquin features between the north and south shores of Lake Superior.

In the Good Harbor-Grand Marais area, the Lake Duluth shoreline features extend over a vertical interval of 40 to 50 feet. However, in all other parts of Cook County evidence of only one Lake Duluth level has been found, and its position within the 40 to 50 feet vertical interval cannot usually be determined. This makes calculations of tilt on Lake Duluth shorelines unsatisfactory. A median line through a profile plot of all Lake Duluth shoreline features has a tilt of 0.98 feet per mile along a line bearing N. 63° E. (line A, fig. 13), or 1.18 feet per mile in the N. 30° E. direction. This is far below the 3 feet per mile cited for the highest Lake Duluth level (Leverett, 1929, p. 62). Even if one were to assume that the shore feature at Mt. Leveaux belongs to the lowest and that at Mt. Josephine to the highest Lake Duluth shoreline (line C,

fig. 13), the tilt would be only 1.55 feet per mile, or 1.85 feet per mile in the N. 30° E. direction, still considerably below Leverett's maximum figure. Furthermore, a line drawn through the lowest Lake Duluth features at Mt. Leveaux, Grand Marais, and Mt. Josephine (line B, fig. 13) has a tilt of 0.69 feet per mile, or 0.83 feet per mile in the N. 30° E. direction, which is less than the 1.13 feet per mile given by Leverett (1929, pp. 61-62) for the lowest Lake Duluth shore in Cook County.

The fact that the highest and lowest Lake Duluth shore features show a vertical separation of about 50 feet both at the west end of Lake Superior (Leverett, 1929, p. 59; Schwartz, 1949, p. 72) and in Cook County, 100 miles farther east, throws suspicion on Leverett's postulate of a strong differential tilt between the uppermost and lowermost Lake Duluth shores.

The data gathered in this study consistently indicate lower degrees of tilt than heretofore reported in Cook County. Since the earlier data were sparse and scattered and could be confirmed only in a few instances, it seems likely that Leverett's conclusions were based in some degree on generalizations arising from his work in other areas. Likewise, many of Lawson's (1893, pp. 284-285) observations could not be confirmed, and the basis for his conclusions, that the intervals between shorelines are constant and that no differential tilt exists, appear unreliable.

The tilt of these shorelines is supposedly caused by recoil of a broad area depressed by the continental ice sheet. There is every reason to expect that the Earth's crust will respond to such an uplift by differential warping rather than by uniform tilting as a rigid plate. Detailed studies of shorelines along the extensive north coast on Lake Superior in United States and Canada might well provide a measure of the differences in response of the Earth's crust to this recoil.

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